

# Package ‘mcgf’

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**Title** Markov Chain Gaussian Fields Simulation and Parameter Estimation

**Version** 1.0.1

**Description** Simulating and estimating (regime-switching) Markov chain Gaussian fields with covariance functions of the Gneiting class. It supports parameter estimation by weighted least squares and maximum likelihood methods, and produces Kriging forecasts and intervals (Cressie 1993)  [<doi:10.1002/9781119115151>](https://doi.org/10.1002/9781119115151).

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<code>acfs</code>	<i>Generic function for calculating autocorrelation</i>
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---

### Description

Generic function for calculating autocorrelation

### Usage

```
acfs(x, ...)
```

### Arguments

<code>x</code>	An <b>R</b> object.
<code>...</code>	Additional parameters or attributes.

### Details

Refer to [acfs.mcgf\(\)](#) and [acfs.mcgf\\_rs\(\)](#) for more details.

### Value

A vector of mean auto-correlations for `mcgf` objects, or that plus a list of regime-switching mean auto-correlations for `mcgf_rs` objects.

---

<code>acfs.mcgf</code>	<i>Extract, calculate, or assign mean auto-correlations for an <code>mcgf</code> or <code>mcgf_rs</code> object</i>
------------------------	---

---

### Description

Extract, calculate, or assign mean auto-correlations for an `mcgf` or `mcgf_rs` object

**Usage**

```
## S3 method for class 'mcgf'
acfs(x, lag_max, replace = FALSE, ...)

## S3 method for class 'mcgf_rs'
acfs(x, lag_max, replace = FALSE, ...)

acfs(x) <- value

add_acfs(x, lag_max, ...)
```

**Arguments**

x	An mcgf or mcgf_rs object.
lag_max	Maximum lag at which to calculate the acf.
replace	Logical; if TRUE, acfs are recalculated.
...	Additional parameters or attributes.
value	A Vector of mean of auto-correlations for time lags starting from 0.

**Details**

For mcgf objects, `acfs()` computes mean auto-correlations for each time lag across locations. The output is a vector of acfs.

For mcgf\_rs objects, `acfs()` computes regime-switching mean auto-correlations for each time lag across locations. The output is a list of vectors of acfs, where each vector in the list corresponds to the acfs for a regime.

`acfs<-` assigns acfs to x.

`add_acfs()` adds acfs to x.

**Value**

`acfs()` returns (regime-switching) mean auto-correlations. `add_acfs()` returns the same object with additional attributes of (regime-switching) mean auto-correlations.

**Examples**

```
# Calculate acfs for 'sim1'
data(sim1)
sim1_mcgf <- mcgf(sim1$data, dists = sim1$dists)
acfs(sim1_mcgf, lag_max = 5)

# Add acfs to 'sim1_mcgf'
sim1_mcgf <- add_acfs(sim1_mcgf, lag_max = 5)
print(sim1_mcgf, "acfs")

# Calculate acfs for 'sim2'
data(sim2)
sim2_mcgf <- mcgf_rs(sim2$data, dists = sim2$dists, label = sim2$label)
```

```
acfs(sim2_mcgf, lag_max = 5)

# Add acfs to 'sim2_mcgf'
sim2_mcgf <- add_acfs(sim2_mcgf, lag_max = 5)
print(sim2_mcgf, "acfs")
```

---

acf\_rs

*Calculate regime-switching auto-correlation*

---

### Description

Calculate regime-switching auto-correlation

### Usage

```
acf_rs(x, label, lag_max, demean = TRUE)
```

### Arguments

x	A univariate numeric time series.
label	A factor of regime labels.
lag_max	Maximum lag at which to calculate the acf.
demean	Logical. Should the covariances be about the sample means?

### Value

Mean auto-correlations for each group in label.

### Examples

```
set.seed(123)
x <- rnorm(100)
label <- sample(1:2, 100, replace = TRUE)
acf_rs(x, label = factor(label), lag_max = 3)
```

---

add_base	<i>Generic function for adding a base model</i>
----------	---

---

### Description

Generic function for adding a base model

### Usage

```
add_base(x, ...)
```

### Arguments

x	An <b>R</b> object.
...	Additional parameters or attributes.

### Details

Refer to [add\\_base.mcgf\(\)](#) and [add\\_base.mcgf\\_rs\(\)](#) for more details.

### Value

x with the newly added base model.

---

add_base.mcgf	<i>Add base model outputted from <a href="#">fit_base()</a> to an mcgf object.</i>
---------------	--

---

### Description

Add base model outputted from [fit\\_base\(\)](#) to an mcgf object.

### Usage

```
## S3 method for class 'mcgf'  
add_base(x, fit_base, fit_s, fit_t, sep = FALSE, old = FALSE, ...)  
  
base(x) <- value
```

**Arguments**

x	An mcgf object.
fit_base	Output from the <code>fit_base()</code> function.
fit_s	Pure spatial model outputted from the <code>fit_base()</code> function. Used only when <code>sep = TRUE</code> .
fit_t	Pure temporal model outputted from the <code>fit_base()</code> function. Used only when <code>sep = TRUE</code> .
sep	Logical; TRUE if spatial and temporal models are fitted separately.
old	Logical; TRUE if the old base model needs to be kept.
...	Additional arguments. Not in use.
value	A list containing the base model as well as its parameters. It must contain the same output as <code>add_base.mcgf()</code> or <code>add_base.mcgf_rs()</code> .

**Details**

After fitting the base model by `fit_base()`, the results can be added to `x` by `add_base()`. To supply the base model directly, use `base<-` to add the base model; the value must contain model, `par_base`, `cor_base`, `lag`, and `horizon`.

**Value**

`x` with newly added attributes of the base model.

**See Also**

Other functions on fitting an mcgf: `add_lagr.mcgf()`, `fit_base.mcgf()`, `fit_lagr.mcgf()`, `krige.mcgf()`

**Examples**

```
data(sim1)
sim1_mcgf <- mcgf(sim1$data, dists = sim1$dists)
sim1_mcgf <- add_acfs(sim1_mcgf, lag_max = 5)
sim1_mcgf <- add_ccfs(sim1_mcgf, lag_max = 5)

# Fit a pure spatial model
fit_spatial <- fit_base(
  sim1_mcgf,
  model = "spatial",
  lag = 5,
  par_init = c(c = 0.001, gamma = 0.5),
  par_fixed = c(nugget = 0)
)
# Fit a pure temporal model
fit_temporal <- fit_base(
  sim1_mcgf,
  model = "temporal",
  lag = 5,
```

```

    par_init = c(a = 0.3, alpha = 0.5)
  )

# Store the fitted models to 'sim1_mcgf'
sim1_mcgf <-
  add_base(sim1_mcgf,
    fit_s = fit_spatial,
    fit_t = fit_temporal,
    sep = TRUE
  )

# Fit a separable model
fit_sep <- fit_base(
  sim1_mcgf,
  model = "sep",
  lag = 5,
  par_init = c(
    c = 0.001,
    gamma = 0.5,
    a = 0.3,
    alpha = 0.5
  ),
  par_fixed = c(nugget = 0)
)
# Store the newly fitted model, and keep the old fit
sim1_mcgf <- add_base(sim1_mcgf, fit_base = fit_sep, old = TRUE)
model(sim1_mcgf, model = "base", old = TRUE)

```

---

add\_base.mcgf\_rs

Add base model outputted from [fit\\_base\(\)](#) to an mcgf\_rs object.

---

## Description

Add base model outputted from [fit\\_base\(\)](#) to an mcgf\_rs object.

## Usage

```
## S3 method for class 'mcgf_rs'
add_base(x, fit_base_ls, fit_s_ls, fit_t_ls, sep = FALSE, old = FALSE, ...)
```

## Arguments

x	An mcgf_rs' object.
fit_base_ls	Output from the <a href="#">fit_base()</a> function.
fit_s_ls	Pure spatial model outputted from the <a href="#">fit_base()</a> function. Used only when sep = TRUE.
fit_t_ls	Pure temporal model outputted from the <a href="#">fit_base()</a> function. Used only when sep = TRUE.



sep	Logical; TRUE if spatial and temporal models are fitted separately.
old	Logical; TRUE if the old base model needs to be kept. The lag and horizon of the new model are assumed to be the same as that of the old model.
...	Additional arguments. Not in use.

### Details

After fitting the base model by `fit_base()`, the results can be added to `x` by `add_base()`. To supply the base model directly, use `base<-` to add the base model; the value must contain the same output as `add_base.mcgf()` or `add_base.mcgf_rs()`.

### Value

`x` with newly added attributes of the base model.

### See Also

Other functions on fitting an `mcgf_rs`: `add_lagr.mcgf_rs()`, `fit_base.mcgf_rs()`, `fit_lagr.mcgf_rs()`, `krige.mcgf_rs()`

### Examples

```
data(sim2)
sim2_mcgf <- mcgf_rs(sim2$data, dists = sim2$dists, label = sim2$label)
sim2_mcgf <- add_acfs(sim2_mcgf, lag_max = 5)
sim2_mcgf <- add_ccfs(sim2_mcgf, lag_max = 5)

# Fit a regime-switching pure spatial model
fit_spatial <-
  fit_base(
    sim2_mcgf,
    lag_ls = 5,
    model_ls = "spatial",
    par_init_ls = list(c(c = 0.000001, gamma = 0.5)),
    par_fixed_ls = list(c(nugget = 0))
  )

# Fit a regime-switching pure temporal model
fit_temporal <-
  fit_base(
    sim2_mcgf,
    lag_ls = 5,
    model_ls = "temporal",
    par_init_ls = list(
      list(a = 0.8, alpha = 0.8),
      list(a = 0.5, alpha = 0.5)
    )
  )

# Store the fitted models to 'sim2_mcgf'
sim2_mcgf <- add_base(sim2_mcgf,
```

```
    fit_s_ls = fit_spatial,
    fit_t_ls = fit_temporal,
    sep = TRUE
  )

  # Fit a regime-switching separable model
  fit_sep <- fit_base(
    sim2_mcgf,
    lag_ls = 5,
    model_ls = "sep",
    par_init_ls = list(list(
      c = 0.000001,
      gamma = 0.5,
      a = 0.5,
      alpha = 0.5
    )),
    par_fixed_ls = list(c(nugget = 0))
  )

  # Store the newly fitted model, and keep the old fit
  sim2_mcgf <- add_base(sim2_mcgf, fit_base_ls = fit_sep, old = TRUE)
  model(sim2_mcgf, model = "base", old = TRUE)
```

---

add\_lagr

*Generic function for adding a Lagrangian model*

---

## Description

Generic function for adding a Lagrangian model

## Usage

```
add_lagr(x, ...)
```

## Arguments

x	An <b>R</b> object.
...	Additional parameters or attributes.

## Details

Refer to [add\\_lagr.mcgf\(\)](#) and [add\\_lagr.mcgf\\_rs\(\)](#) for more details.

## Value

x with the newly added Lagrangian model.

---

add_lagr.mcgf	Add lagr model outputted from <code>fit_lagr()</code> to a mcgf object.
---------------	---

---

### Description

Add lagr model outputted from `fit_lagr()` to a mcgf object.

### Usage

```
## S3 method for class 'mcgf'  
add_lagr(x, fit_lagr, ...)  
  
lagr(x) <- value
```

### Arguments

x	An mcgf object.
fit_lagr	Output from the <code>fit_lagr()</code> function.
...	Additional arguments. Not in use.
value	A list containing the lagr model as well as its parameters. It must contains model, par_lagr, and cor_lagr.

### Value

x with newly added attributes of the Lagrangian model.

### See Also

Other functions on fitting an mcgf: `add_base.mcgf()`, `fit_base.mcgf()`, `fit_lagr.mcgf()`, `krige.mcgf()`

### Examples

```
data(sim1)  
sim1_mcgf <- mcgf(sim1$data, dists = sim1$dists)  
sim1_mcgf <- add_acfs(sim1_mcgf, lag_max = 5)  
sim1_mcgf <- add_ccfs(sim1_mcgf, lag_max = 5)  
  
# Fit a separable model and store it to 'sim1_mcgf'  
fit_sep <- fit_base(  
  sim1_mcgf,  
  model = "sep",  
  lag = 5,  
  par_init = c(  
    c = 0.001,  
    gamma = 0.5,  
    a = 0.3,  
    alpha = 0.5
```

```

    ),
    par_fixed = c(nugget = 0)
  )
sim1_mcgf <- add_base(sim1_mcgf, fit_base = fit_sep)

# Fit a Lagrangian model
fit_lagr <- fit_lagr(
  sim1_mcgf,
  model = "lagr_tri",
  par_init = c(v1 = 300, v2 = 300, lambda = 0.15),
  par_fixed = c(k = 2)
)

# Store the fitted Lagrangian model to 'sim1_mcgf'
sim1_mcgf <- add_lagr(sim1_mcgf, fit_lagr = fit_lagr)
model(sim1_mcgf, old = TRUE)

```

---

add\_lagr.mcgf\_rs      *Add lagr model outputted from `fit_lagr()` to a mcgf\_rs object.*

---

## Description

Add lagr model outputted from `fit_lagr()` to a mcgf\_rs object.

## Usage

```
## S3 method for class 'mcgf_rs'
add_lagr(x, fit_lagr_ls, ...)
```

## Arguments

x	An mcgf_rs object.
fit_lagr_ls	Output from the <code>fit_lagr()</code> function.
...	Additional arguments. Not in use.

## Details

After fitting the Lagrangian model by `fit_lagr()`, the results can be added to x by `add_base()`. To supply the Lagrangian model directly, use `lagr<-` to add the Lagrangian model; the value must contain the same output as `add_lagr.mcgf()` or `add_lagr.mcgf_rs()`.

## Value

x with newly added attributes of the Lagrangian model.

## See Also

Other functions on fitting an mcgf\_rs: `add_base.mcgf_rs()`, `fit_base.mcgf_rs()`, `fit_lagr.mcgf_rs()`, `krige.mcgf_rs()`

**Examples**

```

data(sim3)
sim3_mcgf <- mcgf_rs(sim3$data, dists = sim3$dists, label = sim3$label)
sim3_mcgf <- add_acfs(sim3_mcgf, lag_max = 5)
sim3_mcgf <- add_ccfs(sim3_mcgf, lag_max = 5)

# Fit a fully symmetric model with known variables
fit_fs <- fit_base(
  sim3_mcgf,
  lag_ls = 5,
  model_ls = "fs",
  rs = FALSE,
  par_init_ls = list(list(beta = 0)),
  par_fixed_ls = list(list(
    nugget = 0,
    c = 0.05,
    gamma = 0.5,
    a = 0.5,
    alpha = 0.2
  )))
)

# Set beta to 0 to fit a separable model with known variables
fit_fs[[1]]$fit$par <- 0

# Store the fitted separable model to 'sim3_mcgf'
sim3_mcgf <- add_base(sim3_mcgf, fit_base_ls = fit_fs)

# Fit a regime-switching Lagrangian model.
fit_lagr_rs <- fit_lagr(
  sim3_mcgf,
  model_ls = list("lagr_tri"),
  par_init_ls = list(
    list(v1 = -50, v2 = 50),
    list(v1 = 100, v2 = 100)
  ),
  par_fixed_ls = list(list(lambda = 0.2, k = 2))
)

# Store the fitted Lagrangian model to 'sim3_mcgf'
sim3_mcgf <- add_lagr(sim3_mcgf, fit_lagr_ls = fit_lagr_rs)
model(sim3_mcgf)

```

---

ccfs

*Generic function for calculating cross-correlation*


---

**Description**

Generic function for calculating cross-correlation

**Usage**

```
ccfs(x, ...)
```

**Arguments**

`x` An **R** object.  
`...` Additional parameters or attributes.

**Details**

Refer to `ccfs.mcgf()` and `ccfs.mcgf_rs()` for more details.

**Value**

An array of cross-correlations for `mcgf` objects, or that plus a list of regime-switching cross-correlations for `mcgf_rs` objects.

---

<code>ccfs.mcgf</code>	<i>Extract, calculate, or assign cross-correlations for an <code>mcgf</code> or <code>mcgf_rs</code> object</i>
------------------------	---

---

**Description**

Extract, calculate, or assign cross-correlations for an `mcgf` or `mcgf_rs` object

**Usage**

```
## S3 method for class 'mcgf'
ccfs(x, lag_max, ncores = 1, replace = FALSE, ...)

## S3 method for class 'mcgf_rs'
ccfs(x, lag_max, ncores = 1, replace = FALSE, ...)

ccfs(x) <- value

add_ccfs(x, lag_max, ncores = 1, ...)
```

**Arguments**

`x` An `mcgf` or `mcgf_rs` object.  
`lag_max` Maximum lag at which to calculate the `ccfs`.  
`ncores` Number of cpu cores used for computing. The `doParallel` package is required when `ncores > 1`.  
`replace` Logical; if `TRUE`, `ccfs` are recalculated.  
`...` Additional parameters or attributes. Not in use.  
`value` Cross-correlations.

## Details

For `mcgf` objects, `ccfs()` computes cross-correlations for each time lag. The output is an array of matrices where each matrix corresponds to the cross-correlation for a time lag.

For `mcgf_rs` objects, `ccfs()` computes regime-switching cross-correlations for each time lag. The output is a list of array of matrices where each array in the list corresponds to the cross-correlation for a regime.

`ccfs<-` assigns `ccfs` to `x`.

`add_ccfs()` adds `ccfs` and `sds` to `x`.

## Value

`ccfs()` returns (regime-switching) cross-correlations. `add_ccfs()` returns the same object with additional attributes of (regime-switching) cross-correlations and (regime-switching) empirical standard deviations.

## Examples

```
# Calculate ccfs for 'sim1'
data(sim1)
sim1_mcgf <- mcgf(sim1$data, dists = sim1$dists)
ccfs(sim1_mcgf, lag_max = 5)

# To use multiple cores, use the `ncores` argument
ccfs(sim1_mcgf, lag_max = 5, ncores = 2)

# Add ccfs and sds to 'sim1_mcgf'
sim1_mcgf <- add_ccfs(sim1_mcgf, lag_max = 5)
print(sim1_mcgf, "ccfs")
print(sim1_mcgf, "sds")

# Calculate ccfs for 'sim2'
data(sim2)
sim2_mcgf <- mcgf_rs(sim2$data, dists = sim2$dists, label = sim2$label)
ccfs(sim2_mcgf, lag_max = 5)

# Add ccfs and sds to 'sim2_mcgf'
sim2_mcgf <- add_ccfs(sim2_mcgf, lag_max = 5)
print(sim2_mcgf, "ccfs")
print(sim2_mcgf, "sds")
```

---

ccf\_rs

*Calculate regime-switching cross-correlation*

---

## Description

Calculate regime-switching cross-correlation

**Usage**

```
ccf_rs(x, y, label, lag_max)
```

**Arguments**

<code>x, y</code>	A univariate numeric time series.
<code>label</code>	A factor of regime labels.
<code>lag_max</code>	Maximum lag at which to calculate the ccf.

**Value**

Cross-correlations for each group in `label`.

**Examples**

```
set.seed(123)
x <- rnorm(100)
y <- rnorm(100)
label <- sample(1:2, 100, replace = TRUE)
ccf_rs(x, y, label = factor(label), lag_max = 3)
```

---

ccov

*Generic functions for calculating joint covariance/correlation matrix for mcgf objects*

---

**Description**

Generic functions for calculating joint covariance/correlation matrix for mcgf objects

**Usage**

```
ccov(x, ...)
```

**Arguments**

<code>x</code>	An <b>R</b> object.
<code>...</code>	Additional parameters or attributes.

**Details**

Refer to [ccov.mcgf\(\)](#) and [ccov.mcgf\\_rs\(\)](#) for more details.

**Value**

Joint correlation/covariance matrix.



---

`ccov.mcgf`*Covariance/correlation for joint distribution of an mcgf object*

---

**Description**

Covariance/correlation for joint distribution of an mcgf object

**Usage**

```
## S3 method for class 'mcgf'  
ccov(x, model = c("all", "base", "empirical"), cor = FALSE, ...)
```

**Arguments**

<code>x</code>	An mcgf object.
<code>model</code>	Which model to use. One of all, base, and empirical.
<code>cor</code>	Logical; if TRUE, correlation is outputted.
<code>...</code>	Additional arguments. Not in use.

**Value**

Joint covariance/correlation matrix.

**Examples**

```
data(sim1)  
sim1_mcgf <- mcgf(sim1$data, dists = sim1$dists)  
sim1_mcgf <- add_acfs(sim1_mcgf, lag_max = 5)  
sim1_mcgf <- add_ccfs(sim1_mcgf, lag_max = 5)  
  
# Fit a separable model and store it to 'sim1_mcgf'  
fit_sep <- fit_base(  
  sim1_mcgf,  
  model = "sep",  
  lag = 5,  
  par_init = c(  
    c = 0.001,  
    gamma = 0.5,  
    a = 0.3,  
    alpha = 0.5  
  ),  
  par_fixed = c(nugget = 0)  
)  
sim1_mcgf <- add_base(sim1_mcgf, fit_base = fit_sep)  
  
ccov(sim1_mcgf, model = "base")
```

---

 ccov.mcgf\_rs

*Covariance/correlation for joint distribution of an mcgf\_rsubject*


---

**Description**

Covariance/correlation for joint distribution of an mcgf\_rsubject

**Usage**

```
## S3 method for class 'mcgf_rs'
ccov(x, model = c("all", "base", "empirical"), cor = FALSE, ...)
```

**Arguments**

x	An mcgf object.
model	Which model to use. One of all, base, and empirical.
cor	Logical; if TRUE, correlation is returned
...	Additional arguments. Not in use.

**Value**

A list of joint covariance/correlation matrix.

**Examples**

```
data(sim2)
sim2_mcgf <- mcgf_rs(sim2$data, dists = sim2$dists, label = sim2$label)
sim2_mcgf <- add_acfs(sim2_mcgf, lag_max = 5)
sim2_mcgf <- add_ccfs(sim2_mcgf, lag_max = 5)

# Fit a regime-switching separable model
fit_sep <- fit_base(
  sim2_mcgf,
  lag_ls = 5,
  model_ls = "sep",
  par_init_ls = list(list(
    c = 0.000001,
    gamma = 0.5,
    a = 0.5,
    alpha = 0.5
  )),
  par_fixed_ls = list(c(nugget = 0))
)
sim2_mcgf <- add_base(sim2_mcgf, fit_base_ls = fit_sep)

ccov(sim2_mcgf, model = "base")
```

---

cor2cov	<i>Convert correlation to covariance</i>
---------	--

---

**Description**

Convert correlation to covariance

**Usage**

```
cor2cov(V, sd, empirical = FALSE)
cor2cov_ar(V, sd, empirical = FALSE)
```

**Arguments**

V	A correlation matrix, usually positive semi-definite.
sd	A vector of standard deviations.
empirical	Logical; TRUE if V is empirical correlation.

**Details**

cor2cov converts a matrix. cor2cov\_ar converts an 3-D array.

**Value**

A correlation matrix.

**Examples**

```
V <- matrix(c(1, 0.5, 0.5, 1), ncol = 2)
sd <- 1:2
cor2cov(V, sd)

V_ar <- array(c(1, 0.5, 0.5, 1), dim = c(2, 2, 2))
cor2cov_ar(V_ar, sd)
```

---

cor_cauchy	<i>Calculate Cauchy correlation</i>
------------	-------------------------------------

---

**Description**

Calculate Cauchy correlation

**Usage**

```
cor_cauchy(x, a, alpha, nu = 1, nugget = 0, is.dist = FALSE)
```

**Arguments**

x	A numeric vector, matrix, or array.
a	Smooth parameter, $a > 0$ .
alpha	Scale parameter, $\alpha \in (0, 1]$ .
nu	Power parameter, $\nu > 0$ . Default is 1.
nugget	The nugget effect $\in [0, 1]$ .
is.dist	Logical; if TRUE, x is a distance matrix or an array of distance matrices.

**Details**

The Cauchy correlation function with scale parameter  $a$  and smooth parameter  $\alpha$  has the form

$$C(x) = (1 - \text{nugget})(a|x|^{2\alpha} + 1)^{-\nu} + \text{nugget} \cdot \delta_{x=0},$$

where  $\delta_{x=0}$  is 1 when  $x = 0$  and 0 otherwise.

**Value**

Correlations of the same dimension as x.

**References**

Gneiting, T., and Schlather, M. (2004). Stochastic Models That Separate Fractal Dimension and the Hurst Effect. *SIAM Review*, 46(2), 269–282.

**See Also**

Other correlation functions: [cor\\_exp\(\)](#), [cor\\_fs\(\)](#), [cor\\_lagr\\_askey\(\)](#), [cor\\_lagr\\_tri\(\)](#), [cor\\_sep\(\)](#), [cor\\_stat\\_rs\(\)](#), [cor\\_stat\(\)](#)

**Examples**

```
x <- matrix(c(0, 5, 5, 0), nrow = 2)
cor_cauchy(x, a = 1, alpha = 0.5)

x <- matrix(c(0, 5, 5, 0), nrow = 2)
cor_cauchy(x, a = 1, alpha = 0.5, nugget = 0.3, is.dist = TRUE)
```

---

cor\_exp                      *Calculate exponential correlation*

---

### Description

Calculate exponential correlation

### Usage

```
cor_exp(x, c, gamma = 1/2, nugget = 0, is.dist = FALSE)
```

### Arguments

x	A numeric vector, matrix, or array.
c	Smooth parameter, $c > 0$ .
gamma	Scale parameter, $\gamma \in (0, 1/2]$ . Default is 1/2.
nugget	The nugget effect $\in [0, 1]$ .
is.dist	Logical; if TRUE, x is a distance matrix or an array of distance matrices.

### Details

The exponential correlation function with scale parameter  $c$  and smooth parameter  $\gamma$  has the form

$$C(x) = (1 - \text{nugget}) \exp(-c|x|^{2\gamma}) + \text{nugget} \cdot \delta_{x=0},$$

where  $\delta_{x=0}$  is 1 when  $x = 0$  and 0 otherwise.

### Value

Correlations of the same dimension as x.

### References

Diggle, P. J., Tawn, J. A., & Moyeed, R. A. (1998). Model-Based Geostatistics. *Journal of the Royal Statistical Society. Series C (Applied Statistics)*, 47(3), 299–350.

### See Also

Other correlation functions: [cor\\_cauchy\(\)](#), [cor\\_fs\(\)](#), [cor\\_lagr\\_askey\(\)](#), [cor\\_lagr\\_tri\(\)](#), [cor\\_sep\(\)](#), [cor\\_stat\\_rs\(\)](#), [cor\\_stat\(\)](#)

### Examples

```
x <- matrix(c(0, 5, 5, 0), nrow = 2)
cor_exp(x, c = 0.01, gamma = 0.5)

x <- matrix(c(0, 5, 5, 0), nrow = 2)
cor_exp(x, c = 0.01, gamma = 0.5, nugget = 0.3, is.dist = TRUE)
```

cor\_fs

*Calculate correlation for fully symmetric model***Description**

Calculate correlation for fully symmetric model

**Usage**

```
cor_fs(nugget = 0, c, gamma = 1/2, a, alpha, beta = 0, h, u)
```

**Arguments**

nugget	The nugget effect $\in [0, 1]$ .
c	Scale parameter of cor_exp, $c > 0$ .
gamma	Smooth parameter of cor_exp, $\gamma \in (0, 1/2]$ .
a	Scale parameter of cor_cauchy, $a > 0$ .
alpha	Smooth parameter of cor_cauchy, $\alpha \in (0, 1]$ .
beta	Interaction parameter, $\beta \in [0, 1]$ .
h	Euclidean distance matrix or array.
u	Time lag, same dimension as h.

**Details**

The fully symmetric correlation function with interaction parameter  $\beta$  has the form

$$C(\mathbf{h}, u) = \frac{1}{(a|u|^{2\alpha} + 1)} \left( (1 - \text{nugget}) \exp\left(\frac{-c\|\mathbf{h}\|^{2\gamma}}{(a|u|^{2\alpha} + 1)^{\beta\gamma}}\right) + \text{nugget} \cdot \delta_{\mathbf{h}=\mathbf{0}} \right),$$

where  $\|\cdot\|$  is the Euclidean distance, and  $\delta_{x=0}$  is 1 when  $x = 0$  and 0 otherwise. Here  $\mathbf{h} \in \mathbb{R}^2$  and  $u \in \mathbb{R}$ . By default beta = 0 and it reduces to the separable model.

**Value**

Correlations of the same dimension as h and u.

**References**

Gneiting, T. (2002). Nonseparable, Stationary Covariance Functions for Space–Time Data, *Journal of the American Statistical Association*, 97:458, 590-600.

**See Also**

Other correlation functions: [cor\\_cauchy\(\)](#), [cor\\_exp\(\)](#), [cor\\_lagr\\_askey\(\)](#), [cor\\_lagr\\_tri\(\)](#), [cor\\_sep\(\)](#), [cor\\_stat\\_rs\(\)](#), [cor\\_stat\(\)](#)

**Examples**

```

h <- matrix(c(0, 5, 5, 0), nrow = 2)
u <- matrix(0, nrow = 2, ncol = 2)
cor_fs(c = 0.01, gamma = 0.5, a = 1, alpha = 0.5, beta = 0.5, h = h, u = u)

h <- array(c(0, 5, 5, 0), dim = c(2, 2, 3))
u <- array(rep(0:2, each = 4), dim = c(2, 2, 3))
cor_fs(c = 0.01, gamma = 0.5, a = 1, alpha = 0.5, beta = 0.5, h = h, u = u)

```

cor\_lagr\_askey

*Calculate Lagrangian correlation of the Askey form***Description**

Calculate Lagrangian correlation of the Askey form

**Usage**

```
cor_lagr_askey(v1, v2, k = 2, h1, h2, u)
```

**Arguments**

v1	Prevailing wind, u-component.
v2	Prevailing wind, v-component.
k	Scale parameter of $\ \mathbf{v}\ $ , $k > 0$ . Default is 2.
h1	Horizontal distance matrix or array.
h2	Vertical distance matrix or array, same dimension as h1.
u	Time lag, same dimension as h1.

**Details**

The Lagrangian correlation function of the Askey form with parameters  $\mathbf{v} = (v_1, v_2)^\top \in \mathbb{R}^2$  has the form

$$C(\mathbf{h}, u) = \left( 1 - \frac{1}{k\|\mathbf{v}\|} \|\mathbf{h} - u\mathbf{v}\| \right)_+^{3/2},$$

where  $\|\cdot\|$  is the Euclidean distance,  $x_+ = \max(x, 0)$ ,  $\mathbf{h} = (h_1, h_2)^\top \in \mathbb{R}^2$ , and  $k > 0$  is the scale parameter controlling the magnitude of asymmetry in correlation.

**Value**

Correlations of the same dimension as h1.

**References**

Askey, R. (1973). Radial characteristic functions, Tech. Report No. 1262, Math. Research Center, University of Wisconsin-Madison.

**See Also**

Other correlation functions: [cor\\_cauchy\(\)](#), [cor\\_exp\(\)](#), [cor\\_fs\(\)](#), [cor\\_lagr\\_tri\(\)](#), [cor\\_sep\(\)](#), [cor\\_stat\\_rs\(\)](#), [cor\\_stat\(\)](#)

**Examples**

```
h1 <- matrix(c(0, -5, 5, 0), nrow = 2)
h2 <- matrix(c(0, -8, 8, 0), nrow = 2)
u <- matrix(0.1, nrow = 2, ncol = 2)
cor_lagr_askey(v1 = 5, v2 = 10, h1 = h1, h2 = h2, u = u)
```

```
h1 <- array(c(0, -10, 10, 0), dim = c(2, 2, 3))
h2 <- array(c(0, -10, 10, 0), dim = c(2, 2, 3))
u <- array(rep(-c(1, 2, 3), each = 4), dim = c(2, 2, 3))
cor_lagr_askey(v1 = 10, v2 = 10, h1 = h1, h2 = h2, u = u)
```

---

cor\_lagr\_tri

*Calculate Lagrangian correlation of the triangular form*


---

**Description**

Calculate Lagrangian correlation of the triangular form

**Usage**

```
cor_lagr_tri(v1, v2, k = 2, h1, h2, u)
```

**Arguments**

v1	Prevailing wind, u-component.
v2	Prevailing wind, v-component.
k	Scale parameter of $\ \mathbf{v}\ $ , $k > 0$ . Default is 2.
h1	Horizontal distance matrix or array.
h2	Vertical distance matrix or array, same dimension as h1.
u	Time lag, same dimension as h1.

**Details**

The Lagrangian correlation function of the triangular form with parameters  $\mathbf{v} = (v_1, v_2)^\top \in \mathbb{R}^2$  has the form

$$C(\mathbf{h}, u) = \left( 1 - \frac{1}{k \|\mathbf{v}\|} \left| \frac{\mathbf{h}^\top \mathbf{v}}{\|\mathbf{v}\|} - u \|\mathbf{v}\| \right| \right)_+,$$

where  $\|\cdot\|$  is the Euclidean distance,  $x_+ = \max(x, 0)$ ,  $\mathbf{h} = (h_1, h_2)^\top \in \mathbb{R}^2$ , and  $k > 0$  is the scale parameter controlling the magnitude of asymmetry in correlation.



**Value**

Correlations of the same dimension as h1.

**See Also**

Other correlation functions: [cor\\_cauchy\(\)](#), [cor\\_exp\(\)](#), [cor\\_fs\(\)](#), [cor\\_lagr\\_askey\(\)](#), [cor\\_sep\(\)](#), [cor\\_stat\\_rs\(\)](#), [cor\\_stat\(\)](#)

**Examples**

```
h1 <- matrix(c(0, -5, 5, 0), nrow = 2)
h2 <- matrix(c(0, -8, 8, 0), nrow = 2)
u <- matrix(0.1, nrow = 2, ncol = 2)
cor_lagr_tri(v1 = 5, v2 = 10, h1 = h1, h2 = h2, u = u)

h1 <- array(c(0, -10, 10, 0), dim = c(2, 2, 3))
h2 <- array(c(0, -10, 10, 0), dim = c(2, 2, 3))
u <- array(rep(-c(1, 2, 3), each = 4), dim = c(2, 2, 3))
cor_lagr_tri(v1 = 10, v2 = 10, h1 = h1, h2 = h2, u = u)
```

---

cor\_sep

*Calculate correlation for separable model*


---

**Description**

Calculate correlation for separable model

**Usage**

```
cor_sep(
  spatial = c("exp", "cauchy"),
  temporal = c("exp", "cauchy"),
  par_s,
  par_t,
  h,
  u
)
```

**Arguments**

spatial	Pure spatial model, exp or cauchy for now.
temporal	Pure temporal model, exp or cauchy for now.
par_s	Parameters for the pure spatial model. Nugget effect supported.
par_t	Parameters for the pure temporal model.
h	Euclidean distance matrix or array.
u	Time lag, same dimension as h.

## Details

The separable model is the product of a pure temporal model,  $C_T(u)$ , and a pure spatial model,  $C_S(\mathbf{h})$ . It is of the form

$$C(\mathbf{h}, u) = C_T(u) [(1 - \text{nugget})C_S(\mathbf{h}) + \text{nugget}\delta_{\mathbf{h}=0}],$$

where  $\delta_{x=0}$  is 1 when  $x = 0$  and 0 otherwise. Here  $\mathbf{h} \in \mathbb{R}^2$  and  $u \in \mathbb{R}$ . Now only exponential and Cauchy correlation models are available.

## Value

Correlations of the same dimension as  $\mathbf{h}$  and  $u$ .

## References

Gneiting, T. (2002). Nonseparable, Stationary Covariance Functions for Space–Time Data, *Journal of the American Statistical Association*, 97:458, 590-600.

## See Also

Other correlation functions: [cor\\_cauchy\(\)](#), [cor\\_exp\(\)](#), [cor\\_fs\(\)](#), [cor\\_lagr\\_askey\(\)](#), [cor\\_lagr\\_tri\(\)](#), [cor\\_stat\\_rs\(\)](#), [cor\\_stat\(\)](#)

## Examples

```
h <- matrix(c(0, 5, 5, 0), nrow = 2)
par_s <- list(nugget = 0.5, c = 0.01, gamma = 0.5)
u <- matrix(0, nrow = 2, ncol = 2)
par_t <- list(a = 1, alpha = 0.5)
cor_sep(
  spatial = "exp", temporal = "cauchy", par_s = par_s, par_t = par_t,
  h = h, u = u
)
```

```
h <- array(c(0, 5, 5, 0), dim = c(2, 2, 3))
par_s <- list(nugget = 0.5, c = 0.01, gamma = 0.5)
u <- array(rep(0:2, each = 4), dim = c(2, 2, 3))
par_t <- list(a = 1, alpha = 0.5)
cor_sep(
  spatial = "exp", temporal = "cauchy", par_s = par_s, par_t = par_t,
  h = h, u = u
)
```

---

cor_stat	<i>Calculate general stationary correlation.</i>
----------	--

---

### Description

Calculate general stationary correlation.

### Usage

```
cor_stat(
  base = c("sep", "fs"),
  lagrangian = c("none", "lagr_tri", "lagr_askey"),
  par_base,
  par_lagr,
  lambda,
  h,
  h1,
  h2,
  u,
  base_fixed = FALSE
)
```

### Arguments

base	Base model, sep or fs for now. Or correlation matrix/array.
lagrangian	Lagrangian model, none, lagr_tri, or lagr_askey.
par_base	Parameters for the base model (symmetric), used only when base_fixed = FALSE.
par_lagr	Parameters for the Lagrangian model. Used only when lagrangian is not none.
lambda	Weight of the Lagrangian term, $\lambda \in [0, 1]$ .
h	Euclidean distance matrix or array, used only when base_fixed = FALSE.
h1	Horizontal distance matrix or array, same dimension as h. Used only when lagrangian is not none.
h2	Vertical distance matrix or array, same dimension as h. Used only when lagrangian is not none.
u	Time lag, same dimension as h.
base_fixed	Logical; if TRUE, base is the correlation.

### Details

The general station model, a convex combination of a base model and a Lagrangian model, has the form

$$C(\mathbf{h}, u) = (1 - \lambda)C_{\text{Base}}(\mathbf{h}, u) + \lambda C_{\text{Lagr}}(\mathbf{h}, u),$$

where  $\lambda$  is the weight of the Lagrangian term.

If `base_fixed = TRUE`, the correlation is of the form

$$C(\mathbf{h}, u) = (1 - \lambda)C_{\text{Base}} + \lambda C_{\text{Lagr}}(\mathbf{h}, u),$$

where `base` is a correlation matrix/array and `par_base` and `h` are not used.

When `lagrangian = "none"`, `lambda` must be 0.

### Value

Correlations for the general stationary model. Same dimension of `base` if `base_fixed = FALSE`.

### See Also

Other correlation functions: [cor\\_cauchy\(\)](#), [cor\\_exp\(\)](#), [cor\\_fs\(\)](#), [cor\\_lagr\\_askey\(\)](#), [cor\\_lagr\\_tri\(\)](#), [cor\\_sep\(\)](#), [cor\\_stat\\_rs\(\)](#)

### Examples

```
par_s <- list(nugget = 0.5, c = 0.01, gamma = 0.5)
par_t <- list(a = 1, alpha = 0.5)
par_base <- list(par_s = par_s, par_t = par_t)
par_lagr <- list(v1 = 5, v2 = 10)
h1 <- matrix(c(0, 5, -5, 0), nrow = 2)
h2 <- matrix(c(0, 8, -8, 0), nrow = 2)
h <- sqrt(h1^2 + h2^2)
u <- matrix(0.1, nrow = 2, ncol = 2)
cor_stat(
  base = "sep", lagrangian = "lagr_tri", par_base = par_base,
  par_lagr = par_lagr, lambda = 0.8, h = h, h1 = h1, h2 = h2, u = u
)

h1 <- array(c(0, 5, -5, 0), dim = c(2, 2, 3))
h2 <- array(c(0, 8, -8, 0), dim = c(2, 2, 3))
h <- sqrt(h1^2 + h2^2)
u <- array(rep(c(0.1, 0.2, 0.3), each = 4), dim = c(2, 2, 3))
fit_base <- cor_fs(
  nugget = 0.5, c = 0.01, gamma = 0.5, a = 1, alpha = 0.5,
  beta = 0.0, h = h, u = u
)
par_lagr <- list(v1 = 5, v2 = 10)
cor_stat(
  base = fit_base, lagrangian = "lagr_askey", par_lagr = par_lagr,
  h1 = h1, h2 = h2, u = u, lambda = 0.8, base_fixed = TRUE
)
```

---

cor\_stat\_rs                      *Calculate general stationary correlation.*

---

### Description

Calculate general stationary correlation.

### Usage

```
cor_stat_rs(
  n_regime,
  base_ls,
  lagrangian_ls,
  par_base_ls,
  par_lagr_ls,
  lambda_ls,
  h_ls,
  h1_ls,
  h2_ls,
  u_ls,
  base_fixed = FALSE
)
```

### Arguments

n_regime	Integer, number of regimes.
base_ls	List of base model, sep or fs for now. Or list of correlation matrices/arrays.
lagrangian_ls	List of Lagrangian model, lagr_tri or lagr_askey for now.
par_base_ls	List of parameters for the base model, used only when base_fixed = FALSE.
par_lagr_ls	List of parameters for the Lagrangian model. Used only when lagrangian_ls is not none.
lambda_ls	List of weight of the Lagrangian term, $\lambda \in [0, 1]$ .
h_ls	List of Euclidean distance matrix or array, used only when base_fixed = FALSE.
h1_ls	List of horizontal distance matrix or array, same dimension as h_ls. Used only when lagrangian_ls is not none.
h2_ls	List of vertical distance matrix or array, same dimension as h_ls. Used only when lagrangian_ls is not none.
u_ls	List of time lag, same dimension as h_ls.
base_fixed	Logical; if TRUE, base_ls is the list of correlation.

### Details

It gives a list of general stationary correlation for n\_regime regimes. See [cor\\_stat](#) for the model details. Model parameters are lists of length 1 or n\_regime. When length is 1, same values are used for all regimes. If base\_fixed = TRUE, the base is a list of correlation and par\_base\_ls and h\_ls are not used.

**Value**

Correlations for the general stationary model. Same dimension of base\_ls if base\_fixed = TRUE.

**See Also**

Other correlation functions: [cor\\_cauchy\(\)](#), [cor\\_exp\(\)](#), [cor\\_fs\(\)](#), [cor\\_lagr\\_askey\(\)](#), [cor\\_lagr\\_tri\(\)](#), [cor\\_sep\(\)](#), [cor\\_stat\(\)](#)

**Examples**

```
# Fit general stationary model with sep base.
par_s <- list(nugget = 0.5, c = 0.01, gamma = 0.5)
par_t <- list(a = 1, alpha = 0.5)
par_base <- list(par_s = par_s, par_t = par_t)
h1 <- array(c(0, 5, -5, 0), dim = c(2, 2, 3))
h2 <- array(c(0, 8, -8, 0), dim = c(2, 2, 3))
h <- sqrt(h1^2 + h2^2)
u <- array(rep(c(1, 2, 3), each = 4), dim = c(2, 2, 3))
cor_stat_rs(
  n_regime = 2,
  base_ls = list("sep"),
  lagrangian_ls = list("none", "lagr_tri"),
  par_base_ls = list(par_base),
  par_lagr_ls = list(NULL, list(v1 = 10, v2 = 20)),
  lambda_ls = list(0, 0.2),
  h_ls = list(h),
  h1_ls = list(NULL, h1),
  h2_ls = list(NULL, h2),
  u_ls = list(u, u + 1)
)

# Fit general stationary model given fs as the base model.
h1 <- array(c(0, 5, -5, 0), dim = c(2, 2, 3))
h2 <- array(c(0, 8, -8, 0), dim = c(2, 2, 3))
h <- sqrt(h1^2 + h2^2)
u <- array(rep(c(0.1, 0.2, 0.3), each = 4), dim = c(2, 2, 3))
fit_base <- cor_fs(
  nugget = 0.5, c = 0.01, gamma = 0.5, a = 1, alpha = 0.5,
  beta = 0.0, h = h, u = u
)
par_lagr <- list(v1 = 5, v2 = 10)
cor_stat_rs(
  n_regime = 2,
  par_lagr_ls = list(par_lagr),
  h1_ls = list(h1),
  h2_ls = list(h2),
  u_ls = list(u, u + 1),
  lambda_ls = list(0, 0.8),
  base_ls = list(fit_base),
  lagrangian = list("lagr_tri", "lagr_askey"),
  base_fixed = TRUE
)
```

---

dists	<i>Generic function for calculating distance matrices</i>
-------	---

---

**Description**

Generic function for calculating distance matrices

**Usage**

```
dists(x, ...)
```

**Arguments**

x	An <b>R</b> object.
...	Additional parameters or attributes.

**Value**

A list of signed distance matrices: h (Euclidean), h1 (horizontal), and h2 (vertical) with the same dimensions.

---

dists.mcgf	<i>Calculating distance matrices for an mcgf object</i>
------------	---

---

**Description**

Calculating distance matrices for an mcgf object

**Usage**

```
## S3 method for class 'mcgf'  
dists(x, ...)  
  
dists(x) <- value
```

**Arguments**

x	An mcgf object.
...	Additional parameters or attributes.
value	List of signed distance matrices, outputted from <code>dists()</code> .

**Details**

If the `dists` attribute is available in `x`, it will be printed. Otherwise `dists` will be calculated based on the `locations` attribute.

**Value**

A list of signed distance matrices: `h` (Euclidean), `h1` (horizontal), and `h2` (vertical).

**Examples**

```
data <- cbind(S1 = 1:5, S2 = 4:8, S3 = 5:9)
lon <- c(110, 120, 130)
lat <- c(50, 55, 60)
locations <- cbind(lon, lat)
obj <- mcgf(data = data, locations = locations)
obj
dists(obj)
dists(obj) <- dists(obj)
obj
```

---

find\_dists

*Calculate (signed) distances between coordinates*

---

**Description**

Calculate (signed) distances between coordinates

**Usage**

```
find_dists(locations, longlat = TRUE)
```

**Arguments**

<code>locations</code>	A matrix or data.frame of 2D points, the first column is x/longitude, and the second column is y/latitude.
<code>longlat</code>	Logical, if TRUE Great Circle (WGS84 ellipsoid) distance; if FALSE, Euclidean distance.

**Details**

`locations` must be a matrix or data.frame containing 2 columns, first column x/longitude, and second column y/latitude. The row names of `locations` are used as the names of the locations.

**Value**

List of signed distances.



**Examples**

```
lon <- c(110, 120, 130)
lat <- c(50, 55, 60)
locations <- cbind(lon, lat)
rownames(locations) <- paste("Site", 1:3)
find_dists(locations)
```

---

fit_base	<i>Fit correlation base models</i>
----------	------------------------------------

---

**Description**

Fit correlation base models

**Usage**

```
fit_base(x, ...)
```

**Arguments**

x	An <b>R</b> object.
...	Additional parameters or attributes.

**Details**

Refer to [fit\\_base.mcgf\(\)](#) and [fit\\_base.mcgf\\_rs\(\)](#) for more details.

**Value**

A vector of estimated parameters.

---

fit_base.mcgf	<i>Parameter estimation for symmetric correlation functions for an mcgf object.</i>
---------------	---

---

**Description**

Parameter estimation for symmetric correlation functions for an mcgf object.

**Usage**

```
## S3 method for class 'mcgf'
fit_base(
  x,
  lag,
  horizon = 1,
  model = c("spatial", "temporal", "sep", "fs", "none"),
  method = c("wls", "mle"),
  optim_fn = c("nlminb", "optim", "other"),
  par_fixed = NULL,
  par_init,
  lower = NULL,
  upper = NULL,
  other_optim_fn = NULL,
  dists_base = NULL,
  scale_time = 1,
  ...
)
```

**Arguments**

<code>x</code>	An <code>mcgf</code> object containing attributes <code>dists</code> , <code>acfs</code> , <code>ccfs</code> , and <code>sds</code> .
<code>lag</code>	Integer time lag.
<code>horizon</code>	Integer forecast horizon.
<code>model</code>	Base model, one of <code>spatial</code> , <code>temporal</code> , <code>sep</code> , <code>fs</code> , <code>none</code> . Only <code>sep</code> and <code>fs</code> are supported when <code>method = mle</code> . If <code>none</code> , <code>NULLs</code> are returned.
<code>method</code>	Parameter estimation methods, weighted least square ( <code>wls</code> ) or maximum likelihood estimation ( <code>mle</code> ).
<code>optim_fn</code>	Optimization functions, one of <code>nlminb</code> , <code>optim</code> , <code>other</code> . When <code>optim_fn = other</code> , supply <code>other_optim_fn</code> .
<code>par_fixed</code>	Fixed parameters.
<code>par_init</code>	Initial values for parameters to be optimized.
<code>lower</code>	Optional; lower bounds of parameters.
<code>upper</code>	Optional: upper bounds of parameters.
<code>other_optim_fn</code>	Optional, other optimization functions. The first two arguments must be initial values for the parameters and a function to be minimized respectively (same as that of <code>optim</code> and <code>nlminb</code> ).
<code>dists_base</code>	List of distance matrices. If <code>NULL</code> , <code>dists(x)</code> is used. Must be a matrix or an array of distance matrices.
<code>scale_time</code>	Scale of time unit, default is 1. <code>lag</code> is divided by <code>scale_time</code> for parameter estimation.
<code>...</code>	Additional arguments passed to <code>optim_fn</code> .

## Details

This function fits the separable and fully symmetric models using weighted least squares and maximum likelihood estimation. Optimization functions such as `nls` and `optim` are supported. Other functions are also supported by setting `optim_fn = "other"` and supplying `other_optim_fn`. Lower and upper are lower and upper bounds of parameters in `par_init` and default bounds are used if they are not specified.

Note that both `wls` and `mle` are heuristic approaches when `x` contains observations from a subset of the discrete spatial domain, though estimation results are close to that using the full spatial domain for large sample sizes.

## Value

A list containing outputs from optimization functions of `optim_fn`.

## See Also

Other functions on fitting an mcgf: [add\\_base.mcgf\(\)](#), [add\\_lagr.mcgf\(\)](#), [fit\\_lagr.mcgf\(\)](#), [krige.mcgf\(\)](#)

## Examples

```
data(sim1)
sim1_mcgf <- mcgf(sim1$data, dists = sim1$dists)
sim1_mcgf <- add_acfs(sim1_mcgf, lag_max = 5)
sim1_mcgf <- add_ccfs(sim1_mcgf, lag_max = 5)

# Fit a pure spatial model
fit_spatial <- fit_base(
  sim1_mcgf,
  model = "spatial",
  lag = 5,
  par_init = c(c = 0.001, gamma = 0.5),
  par_fixed = c(nugget = 0)
)
fit_spatial$fit

# Fit a pure temporal model
fit_temporal <- fit_base(
  sim1_mcgf,
  model = "temporal",
  lag = 5,
  par_init = c(a = 0.3, alpha = 0.5)
)
fit_temporal$fit

# Fit a separable model
fit_sep <- fit_base(
  sim1_mcgf,
  model = "sep",
  lag = 5,
  par_init = c(
```

```

        c = 0.001,
        gamma = 0.5,
        a = 0.3,
        alpha = 0.5
    ),
    par_fixed = c(nugget = 0)
)
fit_sep$fit

```

---

fit_base.mcgf_rs	<i>Parameter estimation for symmetric correlation functions for an mcgf_rs object.</i>
------------------	--

---

### Description

Parameter estimation for symmetric correlation functions for an mcgf\_rs object.

### Usage

```

## S3 method for class 'mcgf_rs'
fit_base(
  x,
  lag_ls,
  horizon = 1,
  model_ls,
  method_ls = "wls",
  optim_fn_ls = "nlminb",
  par_fixed_ls = list(NULL),
  par_init_ls,
  lower_ls = list(NULL),
  upper_ls = list(NULL),
  other_optim_fn_ls = list(NULL),
  dists_base_ls = list(NULL),
  scale_time = 1,
  rs = TRUE,
  ...
)

```

### Arguments

x	An mcgf_rs object containing attributes dists, acfs, ccfs, and sds.
lag_ls	List of integer time lags.
horizon	Integer forecast horizon.
model_ls	List of base models, each element must be one of spatial, temporal, sep, fs. Only sep and fs are supported when mle is used in model_ls.
method_ls	List of parameter estimation methods, weighted least square (wls) or maximum likelihood estimation (mle).

optim_fn_ls	List of optimization functions, each element must be one of nlminb, optim, other. When use other, supply other_optim_fn_ls.
par_fixed_ls	List of fixed parameters.
par_init_ls	List of initial values for parameters to be optimized.
lower_ls	Optional; list of lower bounds of parameters.
upper_ls	Optional: list of upper bounds of parameters.
other_optim_fn_ls	Optional, list of other optimization functions. The first two arguments must be initial values for the parameters and a function to be minimized respectively (same as that of optim and nlminb).
dists_base_ls	List of lists of distance matrices. If NULL, dists(x) is used. Each element must be a matrix or an array of distance matrices.
scale_time	Scale of time unit, default is 1. lag is divided by scale_time for parameter estimation.
rs	Logical; if TRUE x is treated as a regime-switching, FALSE if the parameters need to be estimated in a non-regime-switching setting.
...	Additional arguments passed to all optim_fn_ls.

### Details

This functions is the regime-switching variant of `fit_base.mcgf()`. Arguments are in lists. The length of arguments that end in `_ls` must be 1 or the same as the number of regimes in `x`. If the length of an argument is 1, then it is set the same for all regimes. Refer to `fit_base.mcgf()` for more details of the arguments.

Note that both `wls` and `mle` are heuristic approaches when `x` contains observations from a subset of the discrete spatial domain, though estimation results are close to that using the full spatial domain for large sample sizes.

### Value

A list containing outputs from optimization functions of `optim_fn` for each regime.

### See Also

Other functions on fitting an `mcgf_rs`: `add_base.mcgf_rs()`, `add_lagr.mcgf_rs()`, `fit_lagr.mcgf_rs()`, `krige.mcgf_rs()`

### Examples

```
data(sim2)
sim2_mcgf <- mcgf_rs(sim2$data, dists = sim2$dists, label = sim2$label)
sim2_mcgf <- add_acfs(sim2_mcgf, lag_max = 5)
sim2_mcgf <- add_ccfs(sim2_mcgf, lag_max = 5)

# Fit a regime-switching pure spatial model
fit_spatial <-
  fit_base(
```

```

        sim2_mcgf,
        lag_ls = 5,
        model_ls = "spatial",
        par_init_ls = list(c(c = 0.000001, gamma = 0.5)),
        par_fixed_ls = list(c(nugget = 0))
    )
lapply(fit_spatial[1:2], function(x) x$fit)

# Fit a regime-switching pure temporal model
fit_temporal <-
  fit_base(
    sim2_mcgf,
    lag_ls = 5,
    model_ls = "temporal",
    par_init_ls = list(
      list(a = 0.8, alpha = 0.8),
      list(a = 0.5, alpha = 0.5)
    )
  )
lapply(fit_temporal[1:2], function(x) x$fit)

# Fit a regime-switching separable model
fit_sep <- fit_base(
  sim2_mcgf,
  lag_ls = 5,
  model_ls = "sep",
  par_init_ls = list(list(
    c = 0.000001,
    gamma = 0.5,
    a = 0.5,
    alpha = 0.5
  )),
  par_fixed_ls = list(c(nugget = 0))
)
lapply(fit_sep[1:2], function(x) x$fit)

```

---

fit\_lagr

*Fit correlation Lagrangian models*


---

### Description

Fit correlation Lagrangian models

### Usage

```
fit_lagr(x, ...)
```

### Arguments

**x**                    An **R** object.  
**...**                Additional parameters or attributes.

**Details**

Refer to `fit_lagr.mcgf()` and `fit_lagr.mcgf_rs()` for more details.

**Value**

A vector of estimated parameters.

---

<code>fit_lagr.mcgf</code>	<i>Parameter estimation for Lagrangian correlation functions for an mcgf object.</i>
----------------------------	--

---

**Description**

Parameter estimation for Lagrangian correlation functions for an mcgf object.

**Usage**

```
## S3 method for class 'mcgf'
fit_lagr(
  x,
  model = c("lagr_tri", "lagr_askey", "none"),
  method = c("wls", "mle"),
  optim_fn = c("nlminb", "optim", "other"),
  par_fixed = NULL,
  par_init,
  lower = NULL,
  upper = NULL,
  other_optim_fn = NULL,
  dists_base = FALSE,
  dists_lagr = NULL,
  ...
)
```

**Arguments**

<code>x</code>	An mcgf object containing attributes <code>dists</code> , <code>acfs</code> , <code>ccfs</code> , and <code>sds</code> . <code>x</code> must have been passed to <code>add_base()</code> or <code>base&lt;-</code>
<code>model</code>	Base model, one of <code>lagr_tri</code> , <code>lagr_askey</code> , or <code>none</code> . If <code>none</code> , <code>NULLs</code> are returned.
<code>method</code>	Parameter estimation methods, weighted least square ( <code>wls</code> ) or maximum likelihood estimation ( <code>mle</code> ).
<code>optim_fn</code>	Optimization functions, one of <code>nlminb</code> , <code>optim</code> , <code>other</code> . When <code>optim_fn = other</code> , supply <code>other_optim_fn</code> .
<code>par_fixed</code>	Fixed parameters.
<code>par_init</code>	Initial values for parameters to be optimized.

lower	Optional; lower bounds of parameters lambda, v1, v2, and k.
upper	Optional: upper bounds of parameters lambda, v1, v2, and k.
other_optim_fn	Optional, other optimization functions. The first two arguments must be initial values for the parameters and a function to be minimized respectively (same as that of optim and nlm).
dists_base	Logical; if TRUE dists_base from the base model is used as the distance.
dists_lagr	List of distance matrices/arrays. Used when dists_base is FALSE. If NULL, dists(x) is used.
...	Additional arguments passed to optim_fn.

### Details

This function fits the Lagrangian models using weighted least squares and maximum likelihood estimation. The base model must be fitted first using `add_base()` or `base<-`. Optimization functions such as `nlminb` and `optim` are supported. Other functions are also supported by setting `optim_fn = "other"` and supplying `other_optim_fn`. `lower` and `upper` are lower and upper bounds of parameters in `par_init` and default bounds are used if they are not specified.

Note that both `wls` and `mle` are heuristic approaches when `x` contains observations from a subset of the discrete spatial domain, though estimation results are close to that using the full spatial domain for large sample sizes.

Since parameters for the base model and the Lagrangian model are estimated sequentially, more accurate estimation may be obtained if the full model is fitted all at once.

### Value

A list containing outputs from optimization functions of `optim_fn`.

### See Also

Other functions on fitting an mcgf: [add\\_base.mcgf\(\)](#), [add\\_lagr.mcgf\(\)](#), [fit\\_base.mcgf\(\)](#), [krige.mcgf\(\)](#)

### Examples

```
data(sim1)
sim1_mcgf <- mcgf(sim1$data, dists = sim1$dists)
sim1_mcgf <- add_acfs(sim1_mcgf, lag_max = 5)
sim1_mcgf <- add_ccfs(sim1_mcgf, lag_max = 5)

# Fit a separable model and store it to 'sim1_mcgf'
fit_sep <- fit_base(
  sim1_mcgf,
  model = "sep",
  lag = 5,
  par_init = c(
    c = 0.001,
    gamma = 0.5,
    a = 0.3,
```



```

        alpha = 0.5
      ),
      par_fixed = c(nugget = 0)
    )
  sim1_mcgf <- add_base(sim1_mcgf, fit_base = fit_sep)

  # Fit a Lagrangian model
  fit_lagr <- fit_lagr(
    sim1_mcgf,
    model = "lagr_tri",
    par_init = c(v1 = 300, v2 = 300, lambda = 0.15),
    par_fixed = c(k = 2)
  )
  fit_lagr$fit

```

---

fit_lagr.mcgf_rs	<i>Parameter estimation for Lagrangian correlation functions for an mcgf_rs object.</i>
------------------	---

---

## Description

Parameter estimation for Lagrangian correlation functions for an mcgf\_rs object.

## Usage

```

## S3 method for class 'mcgf_rs'
fit_lagr(
  x,
  model_ls,
  method_ls = "wls",
  optim_fn_ls = "nlminb",
  par_fixed_ls = list(NULL),
  par_init_ls,
  lower_ls = list(NULL),
  upper_ls = list(NULL),
  other_optim_fn_ls = list(NULL),
  dists_base_ls,
  dists_lagr_ls = list(NULL),
  rs = TRUE,
  ...
)

```

## Arguments

x	An mcgf_rs object containing attributes dists, acfs, ccfs, and sds. x must have been passed to add_base() or base<-
model_ls	List of base models, each element must be one of lagr_tri, lagr_askey, or none. If none, NULLs are returned.

method_ls	List of parameter estimation methods, weighted least square (wls) or maximum likelihood estimation (mle).
optim_fn_ls	List of optimization functions, each element must be one of nlmminb, optim, other. When use other, supply other_optim_fn_ls
par_fixed_ls	List of fixed parameters.
par_init_ls	List of initial values for parameters to be optimized.
lower_ls	Optional; list of lower bounds of parameters.
upper_ls	Optional: list of upper bounds of parameters.
other_optim_fn_ls	Optional, list of other optimization functions. The first two arguments must be initial values for the parameters and a function to be minimized respectively (same as that of optim and nlmminb).
dists_base_ls	List of lists of distance matrices. If NULL, dists(x) is used. Each element must be a matrix or an array of distance matrices.
dists_lagr_ls	List of distance matrices/arrays. Used when dists_base is FALSE. If NULL, dists(x) is used.
rs	Logical; if TRUE x is treated as a regime-switching, FALSE if the parameters need to be estimated in a non-regime-switching setting.
...	Additional arguments passed to optim_fn.

### Details

This functions is the regime-switching variant of `fit_lagr.mcgf()`. Arguments are in lists. The length of arguments that end in `_ls` must be 1 or the same as the number of regimes in `x`. If the length of an argument is 1, then it is set the same for all regimes. Refer to `fit_lagr.mcgf()` for more details of the arguments.

Note that both `wls` and `mle` are heuristic approaches when `x` contains observations from a subset of the discrete spatial domain, though estimation results are close to that using the full spatial domain for large sample sizes.

Since parameters for the base model and the Lagrangian model are estimated sequentially, more accurate estimation may be obtained if the full model is fitted all at once.

### Value

A list containing outputs from optimization functions of `optim_fn`.

### See Also

Other functions on fitting an `mcgf_rs`: `add_base.mcgf_rs()`, `add_lagr.mcgf_rs()`, `fit_base.mcgf_rs()`, `krige.mcgf_rs()`

### Examples

```
data(sim3)
sim3_mcgf <- mcgf_rs(sim3$data, dists = sim3$dists, label = sim3$label)
sim3_mcgf <- add_acfs(sim3_mcgf, lag_max = 5)
```

```

sim3_mcgf <- add_ccfs(sim3_mcgf, lag_max = 5)

# Fit a fully symmetric model with known variables
fit_fs <- fit_base(
  sim3_mcgf,
  lag_ls = 5,
  model_ls = "fs",
  rs = FALSE,
  par_init_ls = list(list(beta = 0)),
  par_fixed_ls = list(list(
    nugget = 0,
    c = 0.05,
    gamma = 0.5,
    a = 0.5,
    alpha = 0.2
  )))
)

# Set beta to 0 to fit a separable model with known variables
fit_fs[[1]]$fit$par <- 0

# Store the fitted separable model to 'sim3_mcgf'
sim3_mcgf <- add_base(sim3_mcgf, fit_base_ls = fit_fs)

# Fit a regime-switching Lagrangian model.
fit_lagr_rs <- fit_lagr(
  sim3_mcgf,
  model_ls = list("lagr_tri"),
  par_init_ls = list(
    list(v1 = -50, v2 = 50),
    list(v1 = 100, v2 = 100)
  ),
  par_fixed_ls = list(list(lambda = 0.2, k = 2))
)
apply(fit_lagr_rs[1:2], function(x) x$fit)

```

---

is.mcgf

*Check if an object is an mcgf object.*


---

### Description

Check if an object is an mcgf object.

### Usage

```
is.mcgf(x)
```

### Arguments

x                    An Object.

**Value**

Logical; TRUE if x is of the mcgf class

**Examples**

```
data(sim1)
is.mcgf(sim1)

sim1_mcgf <- mcgf(sim1$data, dists = sim1$dists)
is.mcgf(sim1_mcgf)
```

---

is.mcgf_rs	<i>Check if an object is an mcgf_rs object..</i>
------------	--

---

**Description**

Check if an object is an mcgf\_rs object..

**Usage**

```
is.mcgf_rs(x)

as.mcgf_rs(x, label, ncores = 1)
```

**Arguments**

x	An Object.
label	A vector of regime labels. Its length must be the same as the number rows in data.
ncores	Number of cpu cores used for computing in [ccfs()].

**Value**

is.mcgf\_rs returns a logical value; TRUE if x is of the mcgf\_rs class. as.mcgf\_rs coerces an mcgf object to an mcgf\_rs object by adding regime labels. Fitted base or Lagrangian models in x are kept.

**Examples**

```
data(sim2)
is.mcgf_rs(sim2)

sim2_mcgf <- mcgf(sim2$data, dists = sim2$dists)
is.mcgf_rs(sim2_mcgf)

sim2_mcgf <- mcgf_rs(sim2$data, dists = sim2$dists, label = sim2$label)
is.mcgf_rs(sim2_mcgf)
data(sim2)
```

```
sim2_mcgf <- mcgf(sim2$data, dists = sim2$dists)
sim2_mcgf <- as.mcgf_rs(sim2_mcgf, label = sim2$label)
```

---

krige	<i>Generic function for computing kriging forecasts</i>
-------	---

---

### Description

Generic function for computing kriging forecasts

### Usage

```
krige(x, ...)
```

### Arguments

x	An <b>R</b> object.
...	Additional parameters or attributes.

### Details

Refer to [krige.mcgf\(\)](#) and [krige.mcgf\\_rs\(\)](#) for more details.

### Value

Kriging results of x.

---

krige.mcgf	<i>Obtain kriging forecasts for an mcgf object.</i>
------------	---

---

### Description

Obtain kriging forecasts for an mcgf object.

### Usage

```
## S3 method for class 'mcgf'
krige(
  x,
  newdata,
  model = c("all", "base", "empirical"),
  interval = FALSE,
  level = 0.95,
  ...
)
```

**Arguments**

<code>x</code>	An <code>mcgf</code> object.
<code>newdata</code>	A <code>data.frame</code> with the same column names as <code>x</code> . If <code>newdata</code> is missing the forecasts at the original data points are returned.
<code>model</code>	Which model to use. One of <code>all</code> , <code>base</code> , and <code>empirical</code> .
<code>interval</code>	Logical; if <code>TRUE</code> , prediction intervals are computed.
<code>level</code>	A numeric scalar between 0 and 1 giving the confidence level for the intervals (if any) to be calculated. Used when <code>interval = TRUE</code>
<code>...</code>	Additional arguments. Give <code>lag</code> and <code>horizon</code> if they are not defined in <code>x</code> for the empirical model.

**Details**

It produces simple kriging forecasts for a zero-mean `mcgf`. It supports kriging for the empirical model, the base model, and the `all` model which is the general stationary model with the base and Lagrangian model from `x`.

When `interval = TRUE`, confidence interval for each forecasts and each horizon is given. Note that it does not compute confidence regions.

**Value**

A list of kriging forecasts (and prediction intervals).

**See Also**

Other functions on fitting an `mcgf`: [add\\_base.mcgf\(\)](#), [add\\_lagr.mcgf\(\)](#), [fit\\_base.mcgf\(\)](#), [fit\\_lagr.mcgf\(\)](#)

**Examples**

```
data(sim1)
sim1_mcgf <- mcgf(sim1$data, dists = sim1$dists)
sim1_mcgf <- add_acfs(sim1_mcgf, lag_max = 5)
sim1_mcgf <- add_ccfs(sim1_mcgf, lag_max = 5)

# Fit a separable model and store it to 'sim1_mcgf'
fit_sep <- fit_base(
  sim1_mcgf,
  model = "sep",
  lag = 5,
  par_init = c(
    c = 0.001,
    gamma = 0.5,
    a = 0.3,
    alpha = 0.5
  ),
  par_fixed = c(nugget = 0)
)
sim1_mcgf <- add_base(sim1_mcgf, fit_base = fit_sep)
```

```

# Fit a Lagrangian model
fit_lagr <- fit_lagr(
  sim1_mcgf,
  model = "lagr_tri",
  par_init = c(v1 = 300, v2 = 300, lambda = 0.15),
  par_fixed = c(k = 2)
)

# Store the fitted Lagrangian model to 'sim1_mcgf'
sim1_mcgf <- add_lagr(sim1_mcgf, fit_lagr = fit_lagr)

# Calculate the simple kriging predictions and intervals
sim1_krige <- krige(sim1_mcgf, interval = TRUE)

# Calculate RMSE for each location
rmse <- sqrt(colMeans((sim1_mcgf - sim1_krige$fit)^2, na.rm = TRUE))
rmse

# Calculate MAE for each location
mae <- colMeans(abs(sim1_mcgf - sim1_krige$fit), na.rm = TRUE)
mae

# Calculate POPI for each location
popi <- colMeans(
  sim1_mcgf < sim1_krige$lower | sim1_mcgf > sim1_krige$upper,
  na.rm = TRUE
)
popi

```

---

krige.mcgf\_rs

*Obtain kriging forecasts for an mcgf\_rs object.*


---

## Description

Obtain kriging forecasts for an mcgf\_rs object.

## Usage

```

## S3 method for class 'mcgf_rs'
krige(
  x,
  newdata,
  newlabel,
  soft = FALSE,
  prob,
  model = c("all", "base", "empirical"),
  interval = FALSE,
  level = 0.95,
  ...
)

```

**Arguments**

<code>x</code>	An <code>mcgf_rs</code> object.
<code>newdata</code>	A <code>data.frame</code> with the same column names as <code>x</code> . If <code>newdata</code> is missing the forecasts at the original data points are returned.
<code>newlabel</code>	A vector of new regime labels.
<code>soft</code>	Logical; if true, soft forecasts (and bounds) are produced.
<code>prob</code>	Matrix with simplex rows. Number of columns must be the same as unique labels in <code>x</code> .
<code>model</code>	Which model to use. One of <code>all</code> , <code>base</code> , and <code>empirical</code> .
<code>interval</code>	Logical; if TRUE, prediction intervals are computed.
<code>level</code>	A numeric scalar between 0 and 1 giving the confidence level for the intervals (if any) to be calculated. Used when <code>interval = TRUE</code>
<code>...</code>	Additional arguments. Give <code>lag</code> and <code>horizon</code> if they are not defined in <code>x</code> for the empirical model.

**Details**

It produces simple kriging forecasts for a zero-mean `mcgf`. It supports kriging for the empirical model, the base model, and the `all` model which is the general stationary model with the base and Lagrangian model from `x`.

When `soft = TRUE`, `prob` will be used to compute the soft forecasts (weighted forecasts). The number of columns must match the number of unique levels in `x`. The column order must be the same as the order of regimes as in `levels(attr(x, "label", exact = TRUE))`. If not all regimes are seen in `newlabel`, then only relevant columns in `prob` are used.

When `interval = TRUE`, confidence interval for each forecasts and each horizon is given. Note that it does not compute confidence regions.

**Value**

A list of kriging forecasts (and prediction intervals).

**See Also**

Other functions on fitting an `mcgf_rs`: [add\\_base.mcgf\\_rs\(\)](#), [add\\_lagr.mcgf\\_rs\(\)](#), [fit\\_base.mcgf\\_rs\(\)](#), [fit\\_lagr.mcgf\\_rs\(\)](#)

**Examples**

```
data(sim2)
sim2_mcgf <- mcgf_rs(sim2$data, dists = sim2$dists, label = sim2$label)
sim2_mcgf <- add_acfs(sim2_mcgf, lag_max = 5)
sim2_mcgf <- add_ccfs(sim2_mcgf, lag_max = 5)

# Fit a regime-switching separable model
fit_sep <- fit_base(
  sim2_mcgf,
```



```

    lag_ls = 5,
    model_ls = "sep",
    par_init_ls = list(list(
      c = 0.000001,
      gamma = 0.5,
      a = 0.5,
      alpha = 0.5
    )),
    par_fixed_ls = list(c(nugget = 0))
  )

# Store the fitted separable models to 'sim2_mcgf'
sim2_mcgf <- add_base(sim2_mcgf, fit_base_ls = fit_sep)

# Calculate the simple kriging predictions and intervals
sim2_krige <- krige(sim2_mcgf, model = "base", interval = TRUE)

# Calculate RMSE for each location
rmse <- sqrt(colMeans((sim2_mcgf - sim2_krige$fit)^2, na.rm = TRUE))
rmse

# Calculate MAE for each location
mae <- colMeans(abs(sim2_mcgf - sim2_krige$fit), na.rm = TRUE)
mae

# Calculate POPI for each location
popi <- colMeans(
  sim2_mcgf < sim2_krige$lower | sim2_mcgf > sim2_krige$upper,
  na.rm = TRUE
)
popi

```

---

mcgf

*Create mcgf object*


---

## Description

Create mcgf object

## Usage

```
mcgf(data, locations, dists, time)
```

## Arguments

data	Time series data set in space-wide format.
locations	A matrix of data.frame of 2D points, first column longitude, second column latitude, both in decimal degrees. Required when dists is not supplied.
dists	List of signed distance matrices. Required when locations is not supplied.
time	Optional, a vector of equally spaced time stamps.

**Details**

An mcgf object extends the S3 class `data.frame`.

For inputs, data must be in space-wide format where rows correspond to different time stamps and columns refer to spatial locations. Supply either `locations` or `dists`. `locations` is a matrix or `data.frame` of 2D points with first column longitude and second column latitude. Both columns must be in decimal degrees. Number of rows in `locations` must be the same as the number of columns of data. `dists` must be a list of signed distance matrices with names `h1`, `h2`, and `h`. If `h` is not given, it will be calculated as the Euclidean distance of `h1` and `h2`. `time` is a vector of equally spaced time stamps. If it is not supplied then data is assumed to be temporally equally spaced.

An mcgf object extends the S3 class `data.frame`, all methods remain valid to the data part of the object.

**Value**

An S3 object of class `mcgf`. As it inherits and extends the `data.frame` class, all methods remain valid to the data part of the object. Additional attributes may be assigned and extracted.

**Examples**

```
data <- cbind(S1 = 1:5, S2 = 4:8, S3 = 5:9)
lon <- c(110, 120, 130)
lat <- c(50, 55, 60)
locations <- cbind(lon, lat)
obj <- mcgf(data, locations = locations)
print(obj, "locations")
```

---

mcgf\_rs

*Create mcgf\_rs object*

---

**Description**

Create `mcgf_rs` object

**Usage**

```
mcgf_rs(data, locations, dists, label, time)
```

**Arguments**

<code>data</code>	Time series data set in space-wide format.
<code>locations</code>	A matrix of <code>data.frame</code> of 2D points, first column longitude, second column latitude, both in decimal degrees. Required when <code>dists</code> is not supplied.
<code>dists</code>	List of signed distance matrices. Required when <code>locations</code> is not supplied.
<code>label</code>	A vector of regime labels. Its length must be the same as the number rows in data.
<code>time</code>	Optional, a vector of equally spaced time stamps.

**Details**

An `mcgf_rs` object extends the S3 classes `mcgf` and `data.frame`.

For inputs, data must be in space-wide format where rows correspond to different time stamps and columns refer to spatial locations. Supply either `locations` or `dists`. `locations` is a matrix or `data.frame` of 2D points with first column longitude and second column latitude. Both columns must be in decimal degrees. Number of rows in `locations` must be the same as the number of columns of data. `dists` must be a list of signed distance matrices with names `h1`, `h2`, and `h`. If `h` is not given, it will be calculated as the Euclidean distance of `h1` and `h2`. `time` is a vector of equally spaced time stamps. If it is not supplied then data is assumed to be temporally equally spaced. `label` must be a vector containing regime labels, and its length must be the same as the number of rows in `x`.

An `mcgf_rs` object extends the S3 classes `mcgf` and `data.frame`, all methods remain valid to the data part of the object.

**Value**

An S3 object of class `mcgf_rs`. As it inherits and extends the `mcgf` and then the `data.frame` class, all methods remain valid to the data part of the object. Additional attributes may be assigned and extracted.

**Examples**

```
data <- cbind(S1 = 1:5, S2 = 4:8, S3 = 5:9)
lon <- c(110, 120, 130)
lat <- c(50, 55, 60)
locations <- cbind(lon, lat)
label <- c(1, 1, 2, 2, 2)
obj <- mcgf_rs(data, locations = locations, label = label)
print(obj, "locations")
print(obj, "label")
```

---

 mcgf\_rs\_sim

---

*Simulate regime-switching Markov chain Gaussian field*


---

**Description**

Simulate regime-switching Markov chain Gaussian field

**Usage**

```
mcgf_rs_sim(
  N,
  label,
  base_ls,
  lagrangian_ls,
  par_base_ls,
  par_lagr_ls,
```

```

    lambda_ls,
    dists_ls,
    sd_ls,
    lag_ls,
    scale_time = 1,
    init = 0,
    mu_c_ls = list(),
    mu_p_ls = list(),
    return_all = FALSE
)

```

### Arguments

N	Sample size.
label	Vector of regime labels of the same length as N.
base_ls	List of base model, sep or fs for now.
lagrangian_ls	List of Lagrangian model, "none" or lagr_tri for now.
par_base_ls	List of parameters for the base model.
par_lagr_ls	List of parameters for the Lagrangian model.
lambda_ls	List of weight of the Lagrangian term, $\lambda \in [0, 1]$ .
dists_ls	List of distance matrices or arrays.
sd_ls	List of standard deviation for each location.
lag_ls	List of time lags.
scale_time	Scale of time unit, default is 1. Elements in lag_ls are divided by scale_time.
init	Initial samples, default is 0.
mu_c_ls, mu_p_ls	List of means of current and past.
return_all	Logical; if TRUE the joint covariance matrix, arrays of distances and time lag are returned.

### Value

Simulated regime-switching Markov chain Gaussian field with user-specified covariance structures. The simulation is done by kriging. The output data is in space-wide format. Each element in dists\_ls must contain h for symmetric models, and h1 and h2 for general stationary models. init can be a scalar or a vector of appropriate size. List elements in sd\_ls, mu\_c\_ls, and mu\_p\_ls must be vectors of appropriate sizes.

### See Also

Other simulations of Markov chain Gaussian fields: [mcgf\\_sim\(\)](#)

**Examples**

```

par_s <- list(nugget = 0.5, c = 0.01, gamma = 0.5)
par_t <- list(a = 1, alpha = 0.5)
par_base <- list(par_s = par_s, par_t = par_t)
par_lagr <- list(v1 = 5, v2 = 10)
h1 <- matrix(c(0, 5, -5, 0), nrow = 2)
h2 <- matrix(c(0, 8, -8, 0), nrow = 2)
h <- sqrt(h1^2 + h2^2)
dists <- list(h = h, h1 = h1, h2 = h2)

set.seed(123)
label <- sample(1:2, 1000, replace = TRUE)
X <- mcgf_rs_sim(
  N = 1000,
  label = label,
  base_ls = list("sep"),
  lagrangian_ls = list("none", "lagr_tri"),
  lambda_ls = list(0, 0.5),
  par_base_ls = list(par_base),
  par_lagr_ls = list(NULL, par_lagr),
  dists_ls = list(dists, dists)
)
# plot.ts(X[, -1])

```

---

mcgf\_sim

*Simulate Markov chain Gaussian field*


---

**Description**

Simulate Markov chain Gaussian field

**Usage**

```

mcgf_sim(
  N,
  base = c("sep", "fs"),
  lagrangian = c("none", "lagr_tri", "lagr_askey"),
  par_base,
  par_lagr,
  lambda,
  dists,
  sd = 1,
  lag = 1,
  scale_time = 1,
  horizon = 1,
  init = 0,
  mu_c = 0,

```

```

    mu_p = 0,
    return_all = FALSE
  )

```

### Arguments

N	Sample size.
base	Base model, sep or fs for now.
lagrangian	Lagrangian model, "none" or lagr_tri for now.
par_base	Parameters for the base model (symmetric).
par_lagr	Parameters for the Lagrangian model.
lambda	Weight of the Lagrangian term, $\lambda \in [0, 1]$ .
dists	Distance matrices or arrays.
sd	Standard deviation for each location.
lag	Time lag.
scale_time	Scale of time unit, default is 1. lag is divided by scale_time.
horizon	Forecast horizon, default is 1.
init	Initial samples, default is 0.
mu_c, mu_p	Means of current and past.
return_all	Logical; if TRUE the joint covariance matrix, arrays of distances and time lag are returned.

### Value

Simulated Markov chain Gaussian field with user-specified covariance structure. The simulation is done by kriging. The output data is in space-wide format. `dists` must contain `h` for symmetric models, and `h1` and `h2` for general stationary models. `horizon` controls forecasting horizon. `sd`, `mu_c`, `mu_p`, and `init` must be vectors of appropriate sizes.

### See Also

Other simulations of Markov chain Gaussian fields: [mcgf\\_rs\\_sim\(\)](#)

### Examples

```

par_s <- list(nugget = 0.5, c = 0.01, gamma = 0.5)
par_t <- list(a = 1, alpha = 0.5)
par_base <- list(par_s = par_s, par_t = par_t)
par_lagr <- list(v1 = 5, v2 = 10)
h1 <- matrix(c(0, 5, -5, 0), nrow = 2)
h2 <- matrix(c(0, 8, -8, 0), nrow = 2)
h <- sqrt(h1^2 + h2^2)
dists <- list(h = h, h1 = h1, h2 = h2)

set.seed(123)
X <- mcgf_sim(

```

```
      N = 1000, base = "sep", lagrangian = "lagr_tri", lambda = 0.5,  
      par_base = par_base, par_lagr = par_lagr, dists = dists  
    )  
  plot.ts(X)
```

---

model

*Generic function for displaying fitted models for mcgf objects*

---

### Description

Generic function for displaying fitted models for mcgf objects

### Usage

```
model(x, ...)
```

### Arguments

x                    An **R** object.  
...                   Additional parameters or attributes.

### Details

Refer to [model.mcgf\(\)](#) and [model.mcgf\\_rs\(\)](#) for more details.

### Value

Details of the fitted models.

---

model.mcgf

*Display fitted models for an mcgf or mcgf\_rs object*

---

### Description

Display fitted models for an mcgf or mcgf\_rs object

**Usage**

```
## S3 method for class 'mcgf'
model(
  x,
  model = c("all", "base", "lagrangian"),
  old = FALSE,
  print_model = TRUE,
  ...
)

## S3 method for class 'mcgf_rs'
model(
  x,
  model = c("all", "base", "lagrangian"),
  old = FALSE,
  print_model = TRUE,
  ...
)
```

**Arguments**

x	An mcgf object.
model	Which model to display.
old	Logical; TRUE if the old model needs to be printed.
print_model	Logical; TRUE if time lag and forecast horizon need to be printed.
...	Additional arguments. Not in use.

**Details**

For mcgf and mcgf\_rs objects, `model()` displays the fitted models and their parameters. When `old = TRUE`, the old model is printed as well. Note that the old model is not used for parameter estimation or for kriging.

**Value**

None (invisible NULL).

---

print.mcgf

*Print an mcgf object.*

---

**Description**

Print an mcgf object.



**Usage**

```
## S3 method for class 'mcgf'  
print(x, attr = ".Data", ...)
```

**Arguments**

x	An mcgf object.
attr	Attribute to be printed.
...	Optional arguments to print methods.

**Value**

No return value, called for side effects.

**Examples**

```
data(sim1)  
sim1_mcgf <- mcgf(sim1$data, dists = sim1$dists)  
print(sim1_mcgf, "dists")
```

---

rdists	<i>Generate random distance matrices</i>
--------	--

---

**Description**

Generate random distance matrices

**Usage**

```
rdists(N, names, scale = 100)
```

**Arguments**

N	Number of locations.
names	Names of locations.
scale	Scale of the distance matrices. Default is 100.

**Details**

This function generates random distance matrices using `rnorm`. `scale` controls the scale of the distance matrices.

**Value**

List of signed distances.

**Examples**

```
set.seed(123)
rdists(3)
rdists(3, scale = 1)
rdists(3, names = LETTERS[1:3])
```

---

sds

*Generic function for standard deviations for each column*


---

**Description**

Generic function for standard deviations for each column

**Usage**

```
sds(x, ...)
```

**Arguments**

`x` An **R** object.  
`...` Additional parameters or attributes.

**Details**

Refer to [sds.mcgf\(\)](#) and [sds.mcgf\\_rs\(\)](#) for more details.

**Value**

A vector of standard deviations for mcgf objects, or that plus a list of regime-switching standard deviations for mcgf\_rs objects.

---

sds.mcgf

*Extract, calculate, or assign standard deviations for an mcgf or mcgf\_rs object.*


---

**Description**

Extract, calculate, or assign standard deviations for an mcgf or mcgf\_rs object.

**Usage**

```
## S3 method for class 'mcgf'
sds(x, ...)

## S3 method for class 'mcgf_rs'
sds(x, replace = FALSE, ...)

sds(x) <- value
```

**Arguments**

x	An mcgf or mcgf_rs object.
...	Additional parameters or attributes. Not in use.
replace	Logical; if TRUE, sds are recalculated.
value	A vector (or list of vectors) of standard deviations for all stations (under each regime and combined).

**Details**

For mcgf objects, `sds()` extracts or computes the empirical standard deviations. The output is a vector of sds.

For mcgf\_rs objects, `sds()` extracts or computes the regime-switching empirical standard deviations. The output is a list of vectors of sds. Each element in the list corresponds to the sds for a regime.

`sds<-` assigns sds to x. Use `add_ccfs()` to add both ccf's and sds to x.

**Value**

`sds()` returns empirical (regime-switching) standard deviations.

**Examples**

```
data(sim1)
sim1_mcgf <- mcgf(sim1$data, dists = sim1$dists)
sds(sim1_mcgf)

data(sim2)
sim2_mcgf <- mcgf_rs(sim2$data, dists = sim2$dists, label = sim2$label)
sds(sim2_mcgf)
data(sim1)
sim1_mcgf <- mcgf(sim1$data, dists = sim1$dists)
sim1_sds <- sds(sim1_mcgf)
sds(sim1_mcgf) <- sim1_sds

data(sim2)
sim2_mcgf <- mcgf_rs(sim2$data, dists = sim2$dists, label = sim2$label)
sim2_sds <- sds(sim2_mcgf)
sds(sim2_mcgf) <- sim2_sds
```

---

sd\_rs

---

*Calculate standard deviation for each location under each regime.*


---

**Description**

Calculate standard deviation for each location under each regime.

**Usage**

```
sd_rs(x, label)
```

**Arguments**

`x` A data.frame or matrix.  
`label` A vector of regime labels. Its length must be the same as the number rows in `x`.

**Value**

A list of standard deviations for each regime.

**Examples**

```
set.seed(123)
x <- matrix(rnorm(200), nrow = 100)
label <- sample(1:2, 100, replace = TRUE)
sd_rs(x, label = factor(label))
```

---

sim1

*Simulated Markov chain Gaussian field*

---

**Description**

Simulated MCGF for 10 locations.

**Usage**

```
sim1
```

**Format**

`sim1`: a list containing a data.frame with 1000 rows and 10 columns and a list of distances

**Details**

`sim1` contains a simulated MCGF for 10 locations. It is simulated with a separable base model and a triangular Lagrangian model. The true parameters for the base model are:  $\text{nugget} = 0, c = 0.001, \gamma = 0.5, a = 0.5, \alpha = 0.8$ , and those for the Lagrangian model are:  $v1 = 200, v2 = 200, k = 2, \lambda = 0.2$

**See Also**

Other (simulated) datasets: [sim2](#), [sim3](#), [wind](#)

**Examples**

```

# Code used to generate `sim1`

library(mcgf)
set.seed(123)
h <- rdists(10)

N <- 1000
lag <- 5

par_base <- list(
  par_s = list(nugget = 0, c = 0.001, gamma = 0.5),
  par_t = list(a = 0.5, alpha = 0.8)
)
par_lagr <- list(v1 = 200, v2 = 200, k = 2)

sim1 <- mcgf_sim(
  N = N,
  base = "sep",
  lagrangian = "lagr_tri",
  par_base = par_base,
  par_lagr = par_lagr,
  lambda = 0.2,
  dists = h,
  lag = lag
)
sim1 <- sim1[-c(1:(lag + 1)), ]
rownames(sim1) <- 1:nrow(sim1)

sim1 <- list(data = sim1, dists = h)

```

---

sim2

---

*Simulated regime-switching Markov chain Gaussian field*


---

**Description**

Simulated RS-MCGF for 10 locations.

**Usage**

```
sim2
```

**Format**

sim2: a list containing a data.frame with 1000 rows and 10 columns, a list of distances, and a vector of regime labels.

## Details

sim2 contains a simulated RS-MCGF for 10 locations. It is simulated with a regime-switching separable base model. The true parameters for the base model are:

Regime 1 : nugget = 0,  $c = 0.01$ ,  $\gamma = 0.5$ ,  $a = 0.5$ ,  $\alpha = 0.2$ ,

Regime 2 : nugget = 0,  $c = 0.04$ ,  $\gamma = 0.5$ ,  $a = 0.3$ ,  $\alpha = 0.9$ .

## See Also

Other (simulated) datasets: [sim1](#), [sim3](#), [wind](#)

## Examples

```
# Code used to generate `sim2`

library(mcgf)
set.seed(123)
h <- rdists(10)

# simulate regimes
K <- 2
N <- 1000
lag <- 5

tran_mat <-
  matrix(rnorm(K^2, mean = 0.06 / (K - 1), sd = 0.01), nrow = K)
diag(tran_mat) <- rnorm(K, mean = 0.94, sd = 0.1)
tran_mat <- sweep(abs(tran_mat), 1, rowSums(tran_mat), `/\`)
tran_mat

regime <- rep(NA, N)
regime[1] <- 1

for (n in 2:(N)) {
  regime[n] <- sample(1:K, 1, prob = tran_mat[regime[n - 1], ])
}
table(regime)

# simulate RS MCGF
par_base1 <- list(
  par_s = list(nugget = 0, c = 0.01, gamma = 0.5),
  par_t = list(a = 0.5, alpha = 0.2)
)

par_base2 <- list(
  par_s = list(nugget = 0, c = 0.04, gamma = 0.5),
  par_t = list(a = 0.3, alpha = 0.9)
)

sim2 <- mcgf_rs_sim(
  N = N,
```

```

    label = regime,
    base_ls = list("sep"),
    lagrangian_ls = list("none"),
    par_base_ls = list(par_base1, par_base2),
    lambda_ls = list(0.1, 0.3),
    lag_ls = list(lag, lag),
    dists_ls = list(h, h)
  )
  sim2 <- sim2[-c(1:(lag + 1)), ]
  rownames(sim2) <- 1:nrow(sim2)

  sim2 <- list(
    data = sim2[, -1],
    dists = h,
    label = sim2[, 1]
  )

```

---

sim3

*Simulated regime-switching Markov chain Gaussian field*


---

### Description

Simulated RS-MCGF for 20 locations.

### Usage

```
sim3
```

### Format

sim3: a list containing a data.frame with 5000 rows and 20 columns and a list of locations.

### Details

sim3 contains a simulated RS-MCGF for 20 locations. It is simulated with the same base model and a regime-switching Lagrangian model. The true parameters for the base model are: nugget = 0,  $c = 0.05$ ,  $\gamma = 0.5$ ,  $a = 0.5$ ,  $\alpha = 0.2$ , and the true parameters for the Lagrangian model are

$$\text{Regime 1 : } \lambda = 0.2, v_1 = -100, v_2 = 100, k = 2,$$

$$\text{Regime 1 : } \lambda = 0.2, v_1 = 200, v_2 = 200, k = 2.$$

For parameter estimation, the base model is assumed known and is used to estimate the regime-switching prevailing winds.

### See Also

Other (simulated) datasets: [sim1](#), [sim2](#), [wind](#)

**Examples**

```

# Code used to generate `sim3`

library(mcgf)
set.seed(123)
h <- rdists(10)

# simulate regimes
K <- 2
N <- 1000
lag <- 5

tran_mat <-
  matrix(rnorm(K^2, mean = 0.06 / (K - 1), sd = 0.01), nrow = K)
diag(tran_mat) <- rnorm(K, mean = 0.94, sd = 0.1)
tran_mat <- sweep(abs(tran_mat), 1, rowSums(tran_mat), `/`)
tran_mat

regime <- rep(NA, N)
regime[1] <- 1

for (n in 2:(N)) {
  regime[n] <- sample(1:K, 1, prob = tran_mat[regime[n - 1], ])
}
table(regime)

# simulate RS MCGF
par_base <- list(
  par_s = list(nugget = 0, c = 0.05, gamma = 0.5),
  par_t = list(a = 0.5, alpha = 0.2)
)

par_lagr1 <- list(v1 = -100, v2 = 100, k = 2)
par_lagr2 <- list(v1 = 200, v2 = 200, k = 2)

sim3 <- mcgf_rs_sim(
  N = N,
  label = regime,
  base_ls = list("sep"),
  lagrangian_ls = list("lagr_tri"),
  par_base_ls = list(par_base),
  par_lagr_ls = list(par_lagr1, par_lagr2),
  lambda_ls = list(0.2, 0.2),
  lag_ls = list(lag, lag),
  dists_ls = list(h, h)
)
sim3 <- sim3[-c(1:(lag + 1)), ]
rownames(sim3) <- 1:nrow(sim3)

sim3 <- list(
  data = sim3[, -1],
  dists = h,

```



```
    label = sim3[, 1]  
  )
```

---

wind

*Ireland wind data, 1961-1978*

---

### Description

Daily average wind speeds for 1961-1978 at 11 synoptic meteorological stations in the Republic of Ireland (Haslett and Raftery 1989). Wind speeds are in m/s. De-trended data sets are also provided.

### Usage

wind

### Format

wind: a list containing a data.frame with 6574 rows and 12 columns, and a list of locations.

### Details

The data were obtained from the **gstat** package, and were modified so that the first column is the time stamps. Locations of the 11 stations are given in `wind_loc`. `wind_train` and `wind_test` contain de-trended and square-root transformed train (1961-1970) and test (1971-1978) data sets. See Gneiting et al. (2006) for de-trending details. `wind_trend` contains the estimated annual trend and station-wise mean from the training dataset.

### References

Haslett, J. and Raftery, A. E. (1989). Space-time Modelling with Long-memory Dependence: Assessing Ireland's Wind Power Resource (with Discussion). *Applied Statistics* 38, 1-50.

Gneiting, T., Genton, M., & Guttorp, P. (2006). Geostatistical Space-Time Models, Stationarity, Separability, and Full Symmetry. In *C&H/CRC Monographs on Statistics & Applied Probability* (pp. 151–175). Chapman and Hall/CRC.

### See Also

Other (simulated) datasets: [sim1](#), [sim2](#), [sim3](#)

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