

Package ‘mssm’

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Type Package

Title Multivariate State Space Models

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Description Provides methods to perform parameter estimation and make analysis of multivariate observed outcomes through time which depends on a latent state variable. All methods scale well in the dimension of the observed outcomes at each time point. The package contains an implementation of a Laplace approximation, particle filters like suggested by Lin, Zhang, Cheng, & Chen (2005) [<doi:10.1198/016214505000000349>](https://doi.org/10.1198/016214505000000349), and the gradient and observed information matrix approximation suggested by Poyiadjis, Doucet, & Singh (2011) [<doi:10.1093/biomet/asq062>](https://doi.org/10.1093/biomet/asq062).

BugReports <https://github.com/boennecd/mssm/issues>

URL <https://github.com/boennecd/mssm>

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mssm-package	<i>Multivariate State Space Models</i>
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Description

This package contains particle filter methods for multivariate observed outcomes and low dimensional state vectors. The methods are intended to scale well in the dimension of the observed outcomes. The main function in the package is the `mssm` function. The package also includes a method to estimate the parameters using a Laplace approximation.

The README contains an example of the features in the package. See <https://github.com/boennecd/mssm>.

The package is still under development and the API and results of the methods may change.

get_ess	<i>Effective Sample Sizes of a mssm Object</i>
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Description

Extracts the effective sample size at each time point from a mssm object.

Usage

```
get_ess(object)
```

Arguments

object an object of class mssm.

Value

An object of class mssmEss with the effective sample sizes.

Examples

```

if(require(Ecdat)){
  # load data and fit glm to get some parameters to use in an illustration
  data("Gasoline", package = "Ecdat")
  glm_fit <- glm(lgaspcar ~ factor(country) + lincomep + lrpmpg + lcarpcap,
                Gamma("log"), Gasoline)

  # get object to run particle filter
  library(mssm)
  ll_func <- mssm(
    fixed = formula(glm_fit), random = ~ 1, family = Gamma("log"),
    data = Gasoline, ti = year, control = mssm_control(
      N_part = 1000L, n_threads = 1L))

  # run particle filter
  pf <- ll_func$pf_filter(
    cfix = coef(glm_fit), disp = summary(glm_fit)$dispersion,
    F. = as.matrix(.0001), Q = as.matrix(.0001^2))

  # summary statistics for effective sample sizes
  print(ess <- get_ess(pf))
}

```

logLik.mssm

*Approximate Log-likelihood for a mssm Object***Description**

Function to extract the log-likelihood from a mssm or mssmLaplace object.

Usage

```

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

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

```

Arguments

object	an object of class mssm or mssmLaplace.
...	un-used.

Value

A logLik object. The log_lik_terms attribute contains the log-likelihood contributions from each time point.

The degrees of freedom assumes that all parameters are free. The number of observations may be invalid for some models (e.g., discrete survival analysis).

Examples

```

if(require(Ecdat)){
  # load data and fit glm to get starting values
  data("Gasoline", package = "Ecdat")
  glm_fit <- glm(lgaspcar ~ factor(country) + lincomep + lrpmpg + lcarpcap,
                Gamma("log"), Gasoline)

  # get object to perform estimation
  library(mssm)
  ll_func <- mssm(
    fixed = formula(glm_fit), random = ~ 1, family = Gamma("log"),
    data = Gasoline, ti = year, control = mssm_control(
      N_part = 1000L, n_threads = 1L))

  # fit model with time-varying intercept with Laplace approximation
  disp <- summary(glm_fit)$dispersion
  laplace <- ll_func$Laplace(
    cfix = coef(glm_fit), disp = disp, F. = diag(.5, 1), Q = diag(1))

  # run particle filter
  pf <- ll_func$pf_filter(
    cfix = laplace$cfix, disp = laplace$disp, F. = laplace$F., Q = laplace$Q)

  # compare approximate log-likelihoods
  print(logLik(pf))
  print(logLik(laplace))
}

```

mssm

Get Multivariate State Space Model Functions

Description

Returns an object with a function that can be used to run a particle filter, a function to perform parameter estimation using a Laplace approximation, and a function to perform smoothing of particle weights.

Usage

```

mssm(fixed, family, data, random, weights, offsets, ti,
     control = mssm_control())

```

Arguments

fixed	formula with outcome variable on the left hand side and covariates with fixed effects on the right hand side.
family	family for the observed outcome given the state variables and covariates.
data	data.frame or environment containing the variables in fixed and random.

random	formula for covariates with a random effect. Left hand side is ignored.
weights	optional prior weights.
offsets	optional a priori known component in the linear predictor.
ti	integer vector with time indices matching with each observation of fixed and random.
control	list with arguments passed to mssm_control .

Value

An object of class `mssmFunc` with the following elements

<code>pf_filter</code>	function to perform particle filtering. See mssm-pf .
<code>Laplace</code>	function to perform parameter estimation with a Laplace approximation. See mssm-Laplace .
<code>smoother</code>	function to compute smoothing weights for an <code>mssm</code> object returned by the <code>pf_filter</code> function. See mssm-smoother .
<code>terms_fixed</code>	terms.object for the covariates with fixed effects.
<code>terms_random</code>	terms.object for the covariates with random effects.
<code>y</code>	vector with outcomes.
<code>X</code>	covariates with fixed effects.
<code>Z</code>	covariates with random effects.
<code>ti</code>	time indices for each observation.
<code>weights</code>	prior weights for each observation.
<code>offsets</code>	a priori known component in the linear predictor for each observation.
<code>call</code>	the matched call.
<code>family</code>	character describing the conditional distribution of the outcomes.

See Also

The README of the package contains examples of how to use this function. See <https://github.com/boennecd/mssm>.

Examples

```
if(require(Ecdat)){
  # load data and fit glm to get starting values
  . <- print
  data("Gasoline", package = "Ecdat")
  glm_fit <- glm(lgaspcar ~ factor(country) + lincomep + lrpmpg + lcarpcap,
                Gamma("log"), Gasoline)

  # get object to perform estimation
  library(mssm)
  ll_func <- mssm(
    fixed = formula(glm_fit), random = ~ 1, family = Gamma("log"),
    data = Gasoline, ti = year, control = mssm_control(
```

```

      N_part = 1000L, n_threads = 1L))
    .(ll_func)

    # fit model with time-varying intercept with Laplace approximation
    disp <- summary(glm_fit)$dispersion
    laplace <- ll_func$Laplace(
      cfix = coef(glm_fit), disp = disp, F. = diag(.5, 1), Q = diag(1))
    .(laplace)

    # compare w/ glm
    .(logLik(laplace))
    .(logLik(glm_fit))
    .(rbind(laplace = laplace$cfix, glm = coef(glm_fit)))

    # run particle filter
    pf <- ll_func$pf_filter(
      cfix = laplace$cfix, disp = laplace$disp, F. = laplace$F., Q = laplace$Q)
    .(pf)

    # compare approximate log-likelihoods
    .(logLik(pf))
    .(logLik(laplace))

    # predicted values from filtering (does not appear random...)
    plot(pf)

    # plot predicted values from smoothing distribution
    pf <- ll_func$smoother(pf)
    plot(pf, which_weights = "smooth")
  }

```

mssm-Laplace

*Parameter Estimation with Laplace Approximation for Multivariate
State Space Model*

Description

Function returned from `mssm` which can be used to perform parameter estimation with a Laplace approximation.

Arguments

<code>cfix</code>	starting values for coefficient for the fixed effects.
<code>disp</code>	starting value for additional parameters for the family (e.g., a dispersion parameter).
<code>F.</code>	starting values for matrix in the transition density of the state vector.
<code>Q</code>	starting values for covariance matrix in the transition density of the state vector.

Q0	un-used.
mu0	un-used.
trace	integer controlling whether information should be printed during parameter estimation. Zero yields no information.

Value

An object of class `mssmLaplace` with the following elements

F.	estimate of F..
Q	estimate of Q.
cfix	estimate of cfix.
logLik	approximate log-likelihood at estimates.
n_it	number of Laplace approximations.
code	returned code from <code>nlopt</code> .
disp	estimated dispersion parameter.

Remaining elements are the same as returned by [mssm](#).

See Also

[mssm](#).

Examples

```
if(require(Ecdat)){
  # load data and fit glm to get starting values
  data("Gasoline", package = "Ecdat")
  glm_fit <- glm(lgaspcar ~ factor(country) + lincomep + lrpmg + lcarpcap,
                Gamma("log"), Gasoline)

  # get object to perform estimation
  library(mssm)
  ll_func <- mssm(
    fixed = formula(glm_fit), random = ~ 1, family = Gamma("log"),
    data = Gasoline, ti = year, control = mssm_control(
      N_part = 1000L, n_threads = 1L))

  # fit model with time-varying intercept with Laplace approximation
  disp <- summary(glm_fit)$dispersion
  laplace <- ll_func$Laplace(
    cfix = coef(glm_fit), disp = disp, F. = diag(.5, 1), Q = diag(1))
  print(laplace)
}
```

mssm-pf

*Particle Filter Function for Multivariate State Space Model***Description**

Function returned from `mssm` which can be used to perform particle filtering given values for the parameters in the model.

Arguments

<code>cfix</code>	values for for coefficient for the fixed effects.
<code>disp</code>	additional parameters for the family (e.g., a dispersion parameter).
<code>F</code>	matrix in the transition density of the state vector.
<code>Q</code>	covariance matrix in the transition density of the state vector.
<code>Q0</code>	optional covariance matrix at the first time point. Default is the covariance matrix in the time invariant distribution.
<code>mu0</code>	optional mean at the first time point. Default is the zero vector.
<code>trace</code>	integer controlling whether information should be printed during particle filtering. Zero yields no information.
<code>seed</code>	integer to pass to <code>set.seed</code> . The seed is not set if the argument is NULL.
<code>what, N_part</code>	same as in <code>mssm_control</code> .

Value

An object of class `mssm` with the following elements

<code>pf_output</code>	A list with an element for each time period. Each element is a list with <code>particles</code> : the sampled particles, <code>stats</code> : additional object that is requested to be computed with each particle, <code>ws</code> : unnormalized log particle weights for the filtering distribution, and <code>ws_normalized</code> : normalized log particle weights for the filtering distribution.
------------------------	---

Remaining elements are the same as returned by `mssm`.

If gradient approximation is requested then the first elements of `stats` are w.r.t. the fixed coefficients, the next elements are w.r.t. the matrix in the map from the previous state vector to the mean of the next, and the last element is w.r.t. the covariance matrix. Only the lower triangular matrix is kept for the covariance matrix. See the examples in the README at <https://github.com/boennecd/mssm>. There will be an additional element for the dispersion parameter if the family has a dispersion parameter.

If the Hessian is requested then the $\tilde{\beta}_n^{(i)}$ s in Poyiadjis et al. (2011) are returned after the gradient elements. These can be used to approximate the observed information matrix. That is, using that the approximation of the observed information matrix is

$$\tilde{S}_n \tilde{S}_n^\top = \sum_{i=1}^n \tilde{W}_n^{(i)} (\tilde{\alpha}_n^{(i)} \tilde{\alpha}_n^{(i)\top} + \tilde{\beta}_n^{(i)}), \quad \tilde{S}_n = \sum_{i=1}^n \tilde{W}_n^{(i)} \tilde{\alpha}_n^{(i)}$$

as in Poyiadjis et al. (2011). See the README for an example.

References

Poyiadjis, G., Doucet, A. and Singh, S. S. (2011) Particle Approximations of the Score and Observed Information Matrix in State Space Models with Application to Parameter Estimation. *Biometrika*, **98(1)**, 65–80.

See Also

[mssm](#).

Examples

```
if(require(Ecdat)){
  # load data and get object to perform particle filtering
  data("Gasoline", package = "Ecdat")

  library(mssm)
  ll_func <- mssm(
    fixed = lgaspcar ~ factor(country) + lincomep + lrpmpg + lcarpcap,
    random = ~ 1, family = Gamma("log"), data = Gasoline, ti = year,
    control = mssm_control(N_part = 1000L, n_threads = 1L))

  # run particle filter
  cfix <- c(0.612, -0.015, 0.214, 0.048, -0.013, -0.016, -0.022, 0.047,
           -0.046, 0.007, -0.001, 0.008, -0.117, 0.075, 0.048, -0.054, 0.017,
           0.228, 0.077, -0.056, -0.139)
  pf <- ll_func$pf_filter(
    cfix = cfix, Q = as.matrix(2.163e-05), F. = as.matrix(0.9792),
    disp = 0.000291)
  print(pf)
}
```

mssm-smoother

Computes Smoothed Particle Weights for Multivariate State Space Model

Description

Computes smoothed weights using the backward smoothing formula for a mssm object. The k-dual tree approximation is also used if it used for the mssm object.

Arguments

object an object of class mssm from [mssm-pf](#).

Value

Same as [mssm-pf](#) but where the pf_output's list elements has an additional element called ws_normalized_smooth. This contains the normalized log smoothing weights.

See Also[mssm](#).**Examples**

```

if(require(Ecdat)){
  # load data and get object to perform particle filtering
  data("Gasoline", package = "Ecdat")

  library(mssm)
  ll_func <- mssm(
    fixed = lgaspcar ~ factor(country) + lincomep + lrpmpg + lcarpcap,
    random = ~ 1, family = Gamma("log"), data = Gasoline, ti = year,
    control = mssm_control(N_part = 1000L, n_threads = 1L))

  # run particle filter
  cfix <- c(0.612, -0.015, 0.214, 0.048, -0.013, -0.016, -0.022, 0.047,
           -0.046, 0.007, -0.001, 0.008, -0.117, 0.075, 0.048, -0.054, 0.017,
           0.228, 0.077, -0.056, -0.139)
  pf <- ll_func$pf_filter(
    cfix = cfix, Q = as.matrix(2.163e-05), F. = as.matrix(0.9792),
    disp = 0.000291)

  print(is.null(pf$pf_output[[1L]]$ws_normalized_smooth))
  pf <- ll_func$smoother(pf)
  print(is.null(pf$pf_output[[1L]]$ws_normalized_smooth))
}

```

mssm_control

Auxiliary for Controlling Multivariate State Space Model Fitting

Description

Auxiliary function for [mssm](#).

Usage

```

mssm_control(N_part = 1000L, n_threads = 1L, covar_fac = 1.2,
  ftol_rel = 1e-06, nu = 8, what = "log_density",
  which_sampler = "mode_aprx", which_ll_cp = "no_aprx", seed = 1L,
  KD_N_max = 10L, aprx_eps = 0.001, ftol_abs = 1e-04,
  ftol_abs_inner = 1e-04, la_ftol_rel = -1, la_ftol_rel_inner = -1,
  maxeval = 10000L, maxeval_inner = 10000L, use_antithetic = FALSE)

```

Arguments

`N_part` integer greater than zero for the number of particles to use.
`n_threads` integer greater than zero for the number of threads to use.

covar_fac	positive numeric scalar used to scale the covariance matrix in the proposal distribution.
ftol_rel	positive numeric scalar with convergence threshold passed to <code>nloptr</code> if the mode approximation method is used for the proposal distribution.
nu	degrees of freedom to use for the multivariate t -distribution that is used as the proposal distribution. A multivariate normal distribution is used if $\text{nu} \leq 2$.
what	character indicating what to approximate. "log_density" implies only the log-likelihood. "gradient" also yields a gradient approximation. "Hessian" also yields an approximation of the observed information matrix.
which_sampler	character indicating what type of proposal distribution to use. "mode_aprx" yields a Taylor approximation at the mode. "bootstrap" yields a proposal distribution similar to the common bootstrap filter.
which_ll_cp	character indicating what type of computation should be performed in each iteration of the particle filter. "no_aprx" yields no approximation. "KD" yields an approximation using a dual k-d tree method.
seed	integer with seed to pass to <code>set.seed</code> .
KD_N_max	integer greater than zero with the maximum number of particles to include in each leaf of the two k-d trees if the dual k-d trees method is used.
aprx_eps	positive numeric scalar with the maximum error if the dual k-d tree method is used.
ftol_abs, ftol_abs_inner, la_ftol_rel, la_ftol_rel_inner, maxeval, maxeval_inner	scalars passed to <code>nlopt</code> when estimating parameters with a Laplace approximation. The <code>_inner</code> denotes the values passed in the inner mode estimation. The mode estimation is done with a custom Newton–Raphson method
use_antithetic	logical which is true if antithetic variables should be used.

See Also

`mssm`.

See the README of the package for details of the dual k-d tree method at <https://github.com/boennecd/mssm>.

Examples

```
library(mssm)
str(mssm_control())
str(mssm_control(N_part = 2000L))
```

plot.mssm

Plot Predicted State Variables for mssm Object.

Description

Plots the predicted mean and pointwise prediction interval of the state variables for the filtering distribution or smoothing distribution.

Usage

```
## S3 method for class 'mssm'
plot(x, y, qs = c(0.05, 0.95), do_plot = TRUE,
     which_weights = c("filter", "smooth"), ...)
```

Arguments

x	an object of class mssm.
y	un-used.
qs	two-dimensional numeric vector with bounds of the prediction interval.
do_plot	TRUE to create a plot with the mean and quantiles.
which_weights	character of which weights to use. Either "filter" for filter weights or "smooth" for smooth for smooth weights. The latter requires that smooth element has been used.
...	un-used.

Value

List with means and quantiles.

Examples

```
if(require(Ecdat)){
  # load data and get object to perform particle filtering
  data("Gasoline", package = "Ecdat")

  library(mssm)
  ll_func <- mssm(
    fixed = lgaspcar ~ factor(country) + lincomep + lrpmg + lcarpcap,
    random = ~ 1, family = Gamma("log"), data = Gasoline, ti = year,
    control = mssm_control(N_part = 1000L, n_threads = 1L))

  # run particle filter
  cfix <- c(0.612, -0.015, 0.214, 0.048, -0.013, -0.016, -0.022, 0.047,
           -0.046, 0.007, -0.001, 0.008, -0.117, 0.075, 0.048, -0.054, 0.017,
           0.228, 0.077, -0.056, -0.139)
  pf <- ll_func$pf_filter(
    cfix = cfix, Q = as.matrix(2.163e-05), F. = as.matrix(0.9792),
```

```

    disp = 0.000291)

# plot predicted values and prediction intervals
plot(pf)
plot(pf, qs = c(.01, .99))
pf <- ll_func$smoother(pf)
plot(pf, which_weights = "smooth")
}

```

plot.mssmEss

Plot Effective Sample Sizes

Description

Plots the effective sample sizes.

Usage

```

## S3 method for class 'mssmEss'
plot(x, y, ...)

```

Arguments

x	an object of class mssmEss.
y	un-used.
...	un-used.

Value

The plotted x-values, y-values, and maximum possible effective sample size.

Examples

```

if(require(Ecdat)){
# load data and fit glm to get some parameters to use in an illustration
data("Gasoline", package = "Ecdat")
glm_fit <- glm(lgaspcar ~ factor(country) + lincomep + lrpmpg + lcarpcap,
              Gamma("log"), Gasoline)

# get object to run particle filter
library(mssm)
ll_func <- mssm(
  fixed = formula(glm_fit), random = ~ 1, family = Gamma("log"),
  data = Gasoline, ti = year, control = mssm_control(
    N_part = 1000L, n_threads = 1L))

# run particle filter
pf <- ll_func$pf_filter(
  cfix = coef(glm_fit), disp = summary(glm_fit)$dispersion,

```

```
F. = as.matrix(.0001), Q = as.matrix(.0001^2))  
# plot effective samples sizes  
plot(get_ess(pf))  
}
```

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