

Package ‘walker’

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Type Package

Title Bayesian Generalized Linear Models with Time-Varying Coefficients

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Description Bayesian generalized linear models with time-varying coefficients as in Helske (2020, <arXiv:2009.07063>). Gaussian, Poisson, and binomial observations are supported. The Markov chain Monte Carlo (MCMC) computations are done using Hamiltonian Monte Carlo provided by Stan, using a state space representation of the model in order to marginalise over the coefficients for efficient sampling. For non-Gaussian models, the package uses the importance sampling type estimators based on approximate marginal MCMC as in Vihola, Helske, Franks (2020, <doi:10.1111/sjos.12492>).

License GPL (>= 3)

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R topics documented:

as.data.frame.walker_fit	2
coef.walker_fit	3
fitted.walker_fit	3
lfo	4
plot_coefs	5
plot_fit	6
plot_predict	6
pp_check.walker_fit	7
predict.walker_fit	8
predict_counterfactual	9
print.walker_fit	10
rw1	11
rw2	12
summary.walker_fit	12
walker	13
walker_glm	15
walker_rw1	18
Index	21

as.data.frame.walker_fit

Coerce Posterior Samples of walker Fit to a Data Frame

Description

Creates a data.frame object from the output of walker fit.

Usage

```
## S3 method for class 'walker_fit'
as.data.frame(x, row.names = NULL, optional = FALSE, type, ...)
```

Arguments

x	An output from walker or walker_glm .
row.names	NULL (default) or a character vector giving the row names for the data frame.
optional	Ignored (part of generic as.data.frame signature).
type	Either tiv (time-invariant parameters) or tv (time-varying coefficients).
...	Ignored.

Examples

```
## Not run:
as.data.frame(fit, "tiv") %>%
  group_by(variable) %>%
  summarise(mean = mean(value),
            lwr = quantile(value, 0.05),
            upr = quantile(value, 0.95))

## End(Not run)
```

coef.walker_fit	<i>Extract Coefficients of Walker Fit</i>
-----------------	---

Description

Returns the time-varying regression coefficients from output of walker or walker_glm.

Usage

```
## S3 method for class 'walker_fit'
coef(object, summary = TRUE, transform = identity, ...)
```

Arguments

object	Output of walker or walker_glm.
summary	If TRUE (default), return summary statistics. Otherwise returns samples.
transform	Optional vectorized function for transforming the coefficients (for example exp).
...	Ignored.

Value

Time series containing coefficient values.

fitted.walker_fit	<i>Extract Fitted Values of Walker Fit</i>
-------------------	--

Description

Returns fitted values (posterior means) from output of walker or walker_glm.

Usage

```
## S3 method for class 'walker_fit'
fitted(object, summary = TRUE, ...)
```

Arguments

object	Output of walker or walker_glm.
summary	If TRUE (default), return summary statistics. Otherwise returns samples.
...	Ignored.

Value

If summary=TRUE, matrix containing summary statistics of fitted values. Otherwise a matrix of samples.

lfo

Leave-Future-Out Cross-Validation

Description

Estimates the leave-future-out (LFO) information criterion for walker and walker_glm models.

Usage

```
lfo(object, L, exact = FALSE, verbose = TRUE, k_thres = 0.7)
```

Arguments

object	Output of walker or walker_glm.
L	Positive integer defining how many observations should be used for the initial fit.
exact	If TRUE, computes exact 1-step predictions by re-estimating the model repeatedly. If FALSE (default), uses approximate method based on Bürkner, Gabry and Vehtari (2020).
verbose	If TRUE (default), print the progress of the LFO computations to the console.
k_thres	Threshold for the pareto k estimate triggering refit. Default is 0.7.

Details

The LFO for non-Gaussian models is (currently) based on the corresponding Gaussian approximation and not the importance sampling corrected true posterior.

Value

List with components ELPD (Expected log predictive density), ELPDs (observation-specific ELPDs), ks (Pareto k values in case of approximation was used), and refits (time points where model was re-estimated)

References

Paul-Christian Bürkner, Jonah Gabry & Aki Vehtari (2020). Approximate leave-future-out cross-validation for Bayesian time series models, *Journal of Statistical Computation and Simulation*, 90:14, 2499-2523, DOI: 10.1080/00949655.2020.1783262.

Examples

```
## Not run:
fit <- walker(Nile ~ -1 +
  rw1(~ 1,
    beta = c(1000, 100),
    sigma = c(2, 0.001)),
  sigma_y_prior = c(2, 0.005),
  iter = 2000, chains = 1)

fit_lfo <- lfo(fit, L = 20, exact = FALSE)
fit_lfo$ELPD

## End(Not run)
```

plot_coefs

Posterior predictive check for walker object

Description

Plots sample quantiles from posterior predictive sample. See [ppc_ribbon](#) for details.

Usage

```
plot_coefs(
  object,
  level = 0.05,
  alpha = 0.33,
  transform = identity,
  scales = "fixed",
  add_zero = TRUE
)
```

Arguments

object	An output from walker .
level	Level for intervals. Default is 0.05, leading to 90% intervals.
alpha	Transparency level for geom_ribbon .
transform	Optional vectorized function for transforming the coefficients (for example <code>exp</code>).
scales	Should y-axis of the panels be "fixed" (default) or "free"?
add_zero	Logical, should a dashed line indicating a zero be included?

plot_fit	<i>Plot the fitted values and sample quantiles for a walker object</i>
----------	--

Description

Plot the fitted values and sample quantiles for a walker object

Usage

```
plot_fit(object, level = 0.05, alpha = 0.33, ...)
```

Arguments

object	An output from walker or walker_glm .
level	Level for intervals. Default is 0.05, leading to 90% intervals.
alpha	Transparency level for geom_ribbon .
...	Further arguments to ppc_ribbon .

plot_predict	<i>Prediction intervals for walker object</i>
--------------	---

Description

Plots sample quantiles and posterior means of the predictions of the `predict.walker_fit` output.

Usage

```
plot_predict(object, draw_obs = NULL, level = 0.05, alpha = 0.33)
```

Arguments

object	An output from predict.walker_fit .
draw_obs	Either "response", "mean", or "none", where "mean" is response variable divided by number of trials or exposures in case of binomial/poisson models.
level	Level for intervals. Default is 0.05, leading to 90% intervals.
alpha	Transparency level for geom_ribbon .

Examples

```

set.seed(1)
n <- 60
slope <- 0.0001 + cumsum(rnorm(n, 0, sd = 0.01))
beta <- numeric(n)
beta[1] <- 1
for(i in 2:n) beta[i] <- beta[i-1] + slope[i-1]
ts.plot(beta)
x <- rnorm(n, 1, 0.5)
alpha <- 2
ts.plot(beta * x)

signal <- alpha + beta * x
y <- rnorm(n, signal, 0.25)
ts.plot(cbind(signal, y), col = 1:2)
data_old <- data.frame(y = y[1:(n-10)], x = x[1:(n-10)])

# note very small number of iterations for the CRAN checks!
rw2_fit <- walker(y ~ 1 +
  rw2(~ -1 + x,
    beta = c(0, 10),
    nu = c(0, 10)),
  beta = c(0, 10),
  iter = 300, chains = 1, data = data_old)

pred <- predict(rw2_fit, newdata = data.frame(x=x[(n-9):n]))
data_new <- data.frame(t = (n-9):n, y = y[(n-9):n])
plot_predict(pred) +
  geom_line(data=data_new, aes(t, y), linetype = "dashed",
    colour = "red", inherit.aes = FALSE)

```

pp_check.walker_fit *Posterior predictive check for walker object*

Description

Plots sample quantiles from posterior predictive sample.

Usage

```

## S3 method for class 'walker_fit'
pp_check(object, ...)

```

Arguments

object An output from [walker](#).

... Further parameters to [ppc_ribbon](#).

Details

For other types of posterior predictive checks for example with bayesplot, you can extract the variable yrep from the output, see examples.#'

Examples

```
## Not run:
# Extracting the yrep variable for general use:
# extract yrep
y_rep <- extract(object$stanfit, pars = "y_rep", permuted = TRUE)$y_rep

# For non-gaussian model:
weights <- extract(object$stanfit, pars = "weights", permuted = TRUE)$weights
y_rep <- y_rep[sample(1:nrow(y_rep),
  size = nrow(y_rep), replace = TRUE, prob = weights), , drop = FALSE]

## End(Not run)
```

predict.walker_fit *Predictions for walker object*

Description

Given the new covariate data and output from walker, obtain samples from posterior predictive distribution for future time points.

Usage

```
## S3 method for class 'walker_fit'
predict(
  object,
  newdata,
  u,
  type = ifelse(object$distribution == "gaussian", "response", "mean"),
  ...
)
```

Arguments

object	An output from <code>walker</code> or <code>walker_glm</code> .
newdata	A data.frame containing covariates used for prediction.
u	For Poisson model, a vector of future exposures i.e. $E(y) = u \cdot \exp(x \cdot \beta)$. For binomial, a vector containing the number of trials for future time points. Defaults 1.

type	If "response" (default for Gaussian model), predictions are on the response level (e.g., number of successes for Binomial case, and for Gaussian case the observational level noise is added to the mean predictions). If "mean" (default for non-Gaussian case), predict means (e.g., success probabilities in Binomial case). If "link", predictions for non-Gaussian models are returned before applying the inverse of the link-function.
...	Ignored.

Value

A list containing samples from posterior predictive distribution.

See Also

[plot_predict](#) for example.

predict_counterfactual

Predictions for walker object

Description

Given the new covariate data and output from walker, obtain samples from posterior predictive distribution for counterfactual case, i.e. for past time points with different covariate values.

Usage

```
predict_counterfactual(
  object,
  newdata,
  u,
  summary = TRUE,
  type = ifelse(object$distribution == "gaussian", "response", "mean")
)
```

Arguments

object	An output from walker or walker_glm .
newdata	A data.frame containing covariates used for prediction. Should have equal number of rows as the original data
u	For Poisson model, a vector of exposures i.e. $E(y) = u \cdot \exp(x \cdot \beta)$. For binomial, a vector containing the number of trials. Defaults 1.
summary	If TRUE (default), return summary statistics. Otherwise returns samples.

type If "response" (default for Gaussian model), predictions are on the response level (e.g., number of successes for Binomial case, and for Gaussian case the observational level noise is added to the mean predictions). If "mean" (default for non-Gaussian case), predict means (e.g., success probabilities in Binomial case). If "link", predictions for non-Gaussian models are returned before applying the inverse of the link-function.

Value

If summary=TRUE, time series containing summary statistics of predicted values. Otherwise a matrix of samples from predictive distribution.

Examples

```
## Not run:
set.seed(1)
n <- 50
x1 <- rnorm(n, 0, 1)
x2 <- rnorm(n, 1, 0.5)
x3 <- rnorm(n)
beta1 <- cumsum(c(1, rnorm(n - 1, sd = 0.1)))
beta2 <- cumsum(c(0, rnorm(n - 1, sd = 0.1)))
beta3 <- -1
u <- sample(1:10, size = n, replace = TRUE)
y <- rbinom(n, u, plogis(beta3 * x3 + beta1 * x1 + beta2 * x2))

d <- data.frame(y, x1, x2, x3)
out <- walker_glm(y ~ x3 + rw1(~ -1 + x1 + x2, beta = c(0, 2),
  sigma = c(2, 10)), distribution = "binomial", beta = c(0, 2),
  u = u, data = d,
  iter = 2000, chains = 1, refresh = 0)

# what if our covariates were constant?
newdata <- data.frame(x1 = rep(0.4, n), x2 = 1, x3 = -0.1)

fitted <- fitted(out)
pred <- predict_counterfactual(out, newdata, type = "mean")

ts.plot(cbind(fitted[, c(1, 3, 5)], pred[, c(1, 3, 5)]),
  col = rep(1:2, each = 3), lty = c(1, 2, 2))

## End(Not run)
```

print.walker_fit

Print Summary of walker_fit Object

Description

Prints the summary information of time-invariant model parameters. In case of non-Gaussian models, results based on approximate model are returned with a warning.

Usage

```
## S3 method for class 'walker_fit'
print(x, ...)
```

Arguments

x An output from `walker` or `walker_glm`.

... Additional arguments to `print.stanfit`.

 rw1

Construct a first-order random walk component

Description

Auxiliary function used inside of the formula of `walker`.

Usage

```
rw1(formula, data, beta, sigma = c(2, 1e-04), gamma = NULL)
```

Arguments

formula Formula for RW1 part of the model. Only right-hand-side is used.

data Optional `data.frame`.

beta A length vector of length two which defines the prior mean and standard deviation of the Gaussian prior for coefficients at time 1.

sigma A vector of length two, defining the Gamma prior for the coefficient level standard deviation. First element corresponds to the shape parameter and second to the rate parameter. Default is `Gamma(2, 0.0001)`.

gamma An optional vector defining a damping of the random walk noises. More specifically, the variance of the conditional distribution of `state_t+1` given state is of form `gamma_t * sigma`.

rw2	<i>Construct a second-order random walk component</i>
-----	---

Description

Auxiliary function used inside of the formula of walker.

Usage

```
rw2(formula, data, beta, sigma = c(2, 1e-04), nu, gamma = NULL)
```

Arguments

formula	Formula for RW2 part of the model. Only right-hand-side is used.
data	Optional data.frame.
beta	A vector of length two which defines the prior mean and standard deviation of the Gaussian prior for coefficients at time 1.
sigma	A vector of length two, defining the Gamma prior for the slope level standard deviation. First element corresponds to the shape parameter and second to the rate parameter. Default is Gamma(2, 0.0001).
nu	A vector of length two which defines the prior mean and standard deviation of the Gaussian prior for the slopes nu at time 1.
gamma	An optional vector defining a damping of the slope level noises. More specifically, the variance of the conditional distribution of state _{t+1} given state is of form gamma _t * sigma.

summary.walker_fit	<i>Summary of walker_fit Object</i>
--------------------	-------------------------------------

Description

Return summary information of time-invariant model parameters.

Usage

```
## S3 method for class 'walker_fit'
summary(object, type = "tiv", ...)
```

Arguments

object	An output from walker or walker_glm .
type	Either tiv (time-invariant parameters, the default) or tv (time-varying coefficients).
...	Ignored.

walker *Bayesian regression with random walk coefficients*

Description

Function `walker` performs Bayesian inference of a linear regression model with time-varying, random walk regression coefficients, i.e. ordinary regression model where instead of constant coefficients the coefficients follow first or second order random walks. All Markov chain Monte Carlo computations are done using Hamiltonian Monte Carlo provided by Stan, using a state space representation of the model in order to marginalise over the coefficients for efficient sampling.

Usage

```
walker(
  formula,
  data,
  sigma_y_prior = c(2, 0.01),
  beta,
  init,
  chains,
  return_x_reg = FALSE,
  gamma_y = NULL,
  return_data = TRUE,
  ...
)
```

Arguments

<code>formula</code>	An object of class <code>{formula}</code> with additional terms <code>rw1</code> and/or <code>rw2</code> e.g. <code>y ~ x1 + rw1(~ -1 + x2)</code> . See details.
<code>data</code>	An optional <code>data.frame</code> or object coercible to such, as in <code>{lm}</code> .
<code>sigma_y_prior</code>	A vector of length two, defining the a Gamma prior for the observation level standard deviation with first element corresponding to the shape parameter and second to rate parameter. Default is <code>Gamma(2, 0.0001)</code> . Not used in <code>walker_glm</code> .
<code>beta</code>	A length vector of length two which defines the prior mean and standard deviation of the Gaussian prior for time-invariant coefficients
<code>init</code>	Initial value specification, see sampling . Note that compared to default in <code>rstan</code> , here the default is a to sample from the priors.
<code>chains</code>	Number of Markov chains. Default is 4.
<code>return_x_reg</code>	If <code>TRUE</code> , does not perform sampling, but instead returns the matrix of predictors after processing the formula.
<code>gamma_y</code>	An optional vector defining a damping of the observational level noise. More specifically, $\sigma_t = \text{gamma}_t * \sigma_y$.
<code>return_data</code>	if <code>TRUE</code> , returns data input to sampling. This is needed for <code>lfo</code> .
<code>...</code>	Further arguments to sampling .

Details

The `rw1` and `rw2` functions used in the formula define new formulas for the first and second order random walks. In addition, these functions need to be supplied with priors for initial coefficients and the standard deviations. For second order random walk model, these sigma priors correspond to the standard deviation of slope disturbances. For `rw2`, also a prior for the initial slope ν needs to be defined. See examples.

Value

A list containing the `stanfit` object, observations `y`, and covariates `xreg` and `xreg_new`.

Note

Beware of overfitting and identifiability issues. In particular, be careful in not defining multiple intercept terms (only one should be present).

See Also

[walker_glm](#) for non-Gaussian models.

Examples

```
## Not run:

rw1_fit <- walker(Nile ~ -1 +
  rw1(~ 1,
    beta = c(1000, 100),
    sigma = c(2, 0.001)),
  sigma_y_prior = c(2, 0.005),
  iter = 2000, chains = 1)

rw2_fit <- walker(Nile ~ -1 +
  rw2(~ 1,
    beta = c(1000, 100),
    sigma = c(2, 0.001),
    nu = c(0, 100)),
  sigma_y_prior = c(2, 0.005),
  iter = 2000, chains = 1)

g_y <- geom_point(data = data.frame(y = Nile, x = time(Nile)),
  aes(x, y, alpha = 0.5), inherit.aes = FALSE)
g_rw1 <- plot_coefs(rw1_fit) + g_y
g_rw2 <- plot_coefs(rw2_fit) + g_y
if(require("gridExtra")) {
  grid.arrange(g_rw1, g_rw2, ncol=2, top = "RW1 (left) versus RW2 (right)")
} else {
  g_rw1
  g_rw2
}
```

```

y <- window(log10(UKgas), end = time(UKgas)[100])
n <- 100
cos_t <- cos(2 * pi * 1:n / 4)
sin_t <- sin(2 * pi * 1:n / 4)
dat <- data.frame(y, cos_t, sin_t)
fit <- walker(y ~ -1 +
  rw1(~ cos_t + sin_t, beta = c(0, 10), sigma = c(2, 1)),
  sigma_y_prior = c(2, 10), data = dat, chains = 1, iter = 2000)
print(fit$stanfit, pars = c("sigma_y", "sigma_rw1"))

plot_coefs(fit)
# posterior predictive check:
pp_check(fit)

newdata <- data.frame(
  cos_t = cos(2 * pi * 101:108 / 4),
  sin_t = sin(2 * pi * 101:108 / 4))
pred <- predict(fit, newdata)
plot_predict(pred)

# example on scalability
set.seed(1)
n <- 2^12
beta1 <- cumsum(c(0.5, rnorm(n - 1, 0, sd = 0.05)))
beta2 <- cumsum(c(-1, rnorm(n - 1, 0, sd = 0.15)))
x1 <- rnorm(n, mean = 2)
x2 <- cos(1:n)
rw <- cumsum(rnorm(n, 0, 0.5))
signal <- rw + beta1 * x1 + beta2 * x2
y <- rnorm(n, signal, 0.5)

d <- data.frame(y, x1, x2)

n <- 2^(6:12)
times <- numeric(length(n))
for(i in seq_along(n)) {
  times[i] <- sum(get_elapsed_time(
    walker(y ~ 0 + rw1(~ x1 + x2,
      beta = c(0, 10)),
      data = d[1:n[i],],
      chains = 1, seed = 1, refresh = 0)$stanfit))
}
plot(log2(n), log2(times))

## End(Not run)

```

Description

Function `walker_glm` is a generalization of `walker` for non-Gaussian models. Compared to `walker`, the returned samples are based on Gaussian approximation, which can then be used for exact-approximate analysis by weighting the sample properly. These weights are also returned as a part of the `stanfit` (they are generated in the `generated quantities` block of Stan model). Note that plotting functions `pp_check`, `plot_coefs`, and `plot_predict` resample the posterior based on weights before plotting, leading to "exact" analysis.

Usage

```
walker_glm(
  formula,
  data,
  beta,
  init,
  chains,
  return_x_reg = FALSE,
  distribution,
  initial_mode = "kfas",
  u,
  mc_sim = 50,
  return_data = TRUE,
  ...
)
```

Arguments

<code>formula</code>	An object of class <code>{formula}</code> with additional terms <code>rw1</code> and/or <code>rw2</code> e.g. <code>y ~ x1 + rw1(~ -1 + x2)</code> . See details.
<code>data</code>	An optional <code>data.frame</code> or object coercible to such, as in <code>{lm}</code> .
<code>beta</code>	A length vector of length two which defines the prior mean and standard deviation of the Gaussian prior for time-invariant coefficients
<code>init</code>	Initial value specification, see sampling . Note that compared to default in <code>rstan</code> , here the default is a to sample from the priors.
<code>chains</code>	Number of Markov chains. Default is 4.
<code>return_x_reg</code>	If <code>TRUE</code> , does not perform sampling, but instead returns the matrix of predictors after processing the formula.
<code>distribution</code>	Either "poisson" or "binomial".
<code>initial_mode</code>	The initial guess of the fitted values on log-scale. Defines the Gaussian approximation used in the MCMC. Either "obs" (corresponds to $\log(y+0.1)$ in Poisson case), "glm" (mode is obtained from time-invariant GLM), "mle" (default; mode is obtained from maximum likelihood estimate of the model), or numeric vector (custom guess).
<code>u</code>	For Poisson model, a vector of exposures i.e. $E(y) = u * \exp(x * beta)$. For binomial, a vector containing the number of trials. Defaults 1.
<code>mc_sim</code>	Number of samples used in importance sampling. Default is 50.


```
return_data    if TRUE, returns data input to sampling. This is needed for lfo.
...           Further arguments to sampling.
```

Details

The underlying idea of `walker_glm` is based on paper "Importance sampling type estimators based on approximate marginal MCMC" by Vihola M, Helske J and Franks J which is available at ArXiv. `walker_glm` uses the global approximation (i.e. start of the MCMC) instead of more accurate but slower local approximation (where model is approximated at each iteration). However for these restricted models global approximation should be sufficient, assuming the the initial estimate of the conditional mode of $p(\text{xbeta} \mid y, \text{sigma})$ not too far away from the true posterior. Therefore by default `walker_glm` first finds the maximum likelihood estimates of the standard deviation parameters (using [KFAS](#)) package, and constructs the approximation at that point, before running the Bayesian analysis.

Value

A list containing the `stanfit` object, observations `y`, covariates `xreg_fixed`, and `xreg_rw`.

See Also

Package `diagis` in CRAN, which provides functions for computing weighted summary statistics.

Examples

```
set.seed(1)
n <- 25
x <- rnorm(n, 1, 1)
beta <- cumsum(c(1, rnorm(n - 1, sd = 0.1)))

level <- -1
u <- sample(1:10, size = n, replace = TRUE)
y <- rpois(n, u * exp(level + beta * x))
ts.plot(y)

# note very small number of iterations for the CRAN checks!
out <- walker_glm(y ~ -1 + rw1(~ x, beta = c(0, 10),
  sigma = c(2, 10)), distribution = "poisson",
  iter = 200, chains = 1, refresh = 0)
print(out$stanfit, pars = "sigma_rw1") ## approximate results
if (require("diagis")) {
  weighted_mean(extract(out$stanfit, pars = "sigma_rw1")$sigma_rw1,
    extract(out$stanfit, pars = "weights")$weights)
}
plot_coefs(out)
pp_check(out)

## Not run:
data("discoveries", package = "datasets")
out <- walker_glm(discoveries ~ -1 +
```

```

rw2(~ 1, beta = c(0, 10), sigma = c(2, 10), nu = c(0, 2)),
distribution = "poisson", iter = 2000, chains = 1, refresh = 0)

plot_fit(out)

# Dummy covariate example

fit <- walker_glm(VanKilled ~ -1 +
  rw1(~ law, beta = c(0, 1), sigma = c(2, 10)), dist = "poisson",
  data = as.data.frame(Seatbelts), chains = 1, refresh = 0)

# compute effect * law
d <- coef(fit, transform = function(x) {
  x[, 2, 1:170] <- 0
  x
})

require("ggplot2")
d %>% ggplot(aes(time, mean)) +
  geom_ribbon(aes(ymin = `2.5%`, ymax = `97.5%`), fill = "grey90") +
  geom_line() + facet_wrap(~ beta, scales = "free") + theme_bw()

## End(Not run)

```

walker_rw1

Comparison of naive and state space implementation of RW1 regression model

Description

This function is the first iteration of the function `walker`, which supports only time-varying model where all coefficients \sim `rw1`. This is kept as part of the package in order to compare "naive" and state space versions of the model in the vignette, but there is little reason to use it for other purposes.

Usage

```

walker_rw1(
  formula,
  data,
  beta,
  sigma,
  init,
  chains,
  naive = FALSE,
  return_x_reg = FALSE,
  ...
)

```

Arguments

formula	An object of class <code>formula</code> . See <code>lm</code> for details.
data	An optional <code>data.frame</code> or object coercible to such, as in <code>lm</code> .
beta	A matrix with k rows and 2 columns, where first column defines the prior means of the Gaussian priors of the corresponding k regression coefficients, and the second column defines the standard deviations of those prior distributions.
sigma	A matrix with $k + 1$ rows and two columns with similar structure as <code>beta</code> , with first row corresponding to the prior of the standard deviation of the observation level noise, and rest of the rows define the priors for the standard deviations of random walk noise terms. The prior distributions for all sigmas are Gaussians truncated to positive real axis. For non-Gaussian models, this should contain only k rows. For second order random walk model, these priors correspond to the slope level standard deviations.
init	Initial value specification, see <code>sampling</code> .
chains	Number of Markov chains. Default is 4.
naive	Only used for <code>walker</code> function. If TRUE, use "standard" approach which samples the joint posterior $p(\beta, \sigma y)$. If FALSE (the default), use marginalisation approach where we sample the marginal posterior $p(\sigma y)$ and generate the samples of $p(\beta \sigma, y)$ using state space modelling techniques (namely simulation smoother by Durbin and Koopman (2002)). Both methods give asymptotically identical results, but the latter approach is computationally much more efficient.
return_x_reg	If TRUE, does not perform sampling, but instead returns the matrix of predictors after processing the formula.
...	Additional arguments to <code>sampling</code> .

Examples

```
## Not run:
## Comparing the approaches, note that with such a small data
## the differences aren't huge, but try same with n = 500 and/or more terms...
set.seed(123)
n <- 100
beta1 <- cumsum(c(0.5, rnorm(n - 1, 0, sd = 0.05)))
beta2 <- cumsum(c(-1, rnorm(n - 1, 0, sd = 0.15)))
x1 <- rnorm(n, 1)
x2 <- 0.25 * cos(1:n)
ts.plot(cbind(beta1 * x1, beta2 * x2), col = 1:2)
u <- cumsum(rnorm(n))
y <- rnorm(n, u + beta1 * x1 + beta2 * x2)
ts.plot(y)
lines(u + beta1 * x1 + beta2 * x2, col = 2)
kalman_walker <- walker_rw1(y ~ -1 +
  rw1(~ x1 + x2, beta = c(0, 2), sigma = c(0, 2)),
  sigma_y = c(0, 2), iter = 2000, chains = 1)
print(kalman_walker$stanfit, pars = c("sigma_y", "sigma_rw1"))
betas <- extract(kalman_walker$stanfit, "beta")[[1]]
```

```

ts.plot(cbind(u, beta1, beta2, apply(betas, 2, colMeans)),
  col = 1:3, lty = rep(2:1, each = 3))
sum(get_elapsed_time(kalman_walker$stanfit))
naive_walker <- walker_rw1(y ~ x1 + x2, iter = 2000, chains = 1,
  beta = cbind(0, rep(2, 3)), sigma = cbind(0, rep(2, 4)),
  naive = TRUE)
print(naive_walker$stanfit, pars = c("sigma_y", "sigma_b"))
sum(get_elapsed_time(naive_walker$stanfit))

## Larger problem, this takes some time with naive approach

set.seed(123)
n <- 500
beta1 <- cumsum(c(1.5, rnorm(n - 1, 0, sd = 0.05)))
beta2 <- cumsum(c(-1, rnorm(n - 1, 0, sd = 0.5)))
beta3 <- cumsum(c(-1.5, rnorm(n - 1, 0, sd = 0.15)))
beta4 <- 2
x1 <- rnorm(n, 1)
x2 <- 0.25 * cos(1:n)
x3 <- runif(n, 1, 3)
ts.plot(cbind(beta1 * x1, beta2 * x2, beta3 * x3), col = 1:3)
a <- cumsum(rnorm(n))
signal <- a + beta1 * x1 + beta2 * x2 + beta3 * x3
y <- rnorm(n, signal)
ts.plot(y)
lines(signal, col = 2)
kalman_walker <- walker_rw1(y ~ x1 + x2 + x3, iter = 2000, chains = 1,
  beta = cbind(0, rep(2, 4)), sigma = cbind(0, rep(2, 5)))
print(kalman_walker$stanfit, pars = c("sigma_y", "sigma_b"))
betas <- extract(kalman_walker$stanfit, "beta")[[1]]
ts.plot(cbind(u, beta1, beta2, beta3, apply(betas, 2, colMeans)),
  col = 1:4, lty = rep(2:1, each = 4))
sum(get_elapsed_time(kalman_walker$stanfit))
# need to increase adapt_delta in order to get rid of divergences
# and max_treedepth to get rid of related warnings
# and still we end up with low BFMI warning after hours of computation
naive_walker <- walker_rw1(y ~ x1 + x2 + x3, iter = 2000, chains = 1,
  beta = cbind(0, rep(2, 4)), sigma = cbind(0, rep(2, 5)),
  naive = TRUE, control = list(adapt_delta = 0.9, max_treedepth = 15))
print(naive_walker$stanfit, pars = c("sigma_y", "sigma_b"))
sum(get_elapsed_time(naive_walker$stanfit))

## End(Not run)

```

Index

`as.data.frame.walker_fit`, 2
`coef.walker_fit`, 3
`fitted.walker_fit`, 3
`formula`, 19
`geom_ribbon`, 6
KFAS, 17
`lfo`, 4
`lm`, 19
`plot_coefs`, 5
`plot_fit`, 6
`plot_predict`, 6, 9
`pp_check.walker_fit`, 7
`ppc_ribbon`, 5–7
`predict.walker_fit`, 6, 8
`predict_counterfactual`, 9
`print.stanfit`, 11
`print.walker_fit`, 10
`rw1`, 11
`rw2`, 12
`sampling`, 13, 16, 17, 19
`summary.walker_fit`, 12
`walker`, 2, 5–9, 11, 12, 13
`walker_glm`, 2, 6, 8, 9, 11, 12, 14, 15
`walker_rw1`, 18