

# Package ‘viking’

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**Title** State-Space Models Inference by Kalman or Viking

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**Description** Inference methods for state-space models, relying on the Kalman Filter or on Viking (Variational Bayesian Variance tracking). See J. de Vilmarrest (2022) <<https://theses.hal.science/tel-03716104/>>.

**License** LGPL-3

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 expectation\_maximization

*Expectation-Maximization*


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### Description

expectation\_maximization is a method to choose hyper-parameters of the linear Gaussian State-Space Model with time-invariant variances relying on the Expectation-Maximization algorithm.

### Usage

```
expectation_maximization(
  X,
  y,
  n_iter,
  Q_init,
  sig_init = 1,
  verbose = 1000,
  lambda = 10^-9,
  mode_diag = FALSE,
  p1 = 0
)
```

### Arguments

X	explanatory variables
y	time series
n_iter	number of iterations of the EM algorithm
Q_init	initial covariance matrix on the state noise
sig_init	(optional, default 1) initial value of the standard deviation of the observation noise
verbose	(optional, default 1000) frequency for prints
lambda	(optional, default 10 <sup>-9</sup> ) regularization parameter to avoid singularity
mode_diag	(optional, default FALSE) if TRUE then we restrict the search to diagonal matrices for Q
p1	(optional, default 0) deterministic value of P1 = p1 I

### Details

E-step is realized through recursive Kalman formulae (filtering then smoothing).

M-step is the maximization of the expected complete likelihood with respect to the hyper-parameters.

We only have the guarantee of convergence to a LOCAL optimum. We fix P1 = p1 I (by default p1 = 0). We optimize theta1, sig, Q.

**Value**

a list containing values for P, theta, sig, Q, and two vectors DIFF, LOGLIK assessing the convergence of the algorithm.

**Examples**

```

set.seed(1)
### Simulate data
n <- 100
d <- 5
Q <- diag(c(0,0,0.25,0.25,0.25))
sig <- 1

X <- cbind(matrix(rnorm((d-1)*n,sd=1),n,d-1),1)
theta <- matrix(rnorm(d), d, 1)
theta_arr <- matrix(0, n, d)
for (t in 1:n) {
  theta_arr[t,] <- theta
  theta <- theta + matrix(mvtnorm::rmvnorm(1,matrix(0,d,1),Q),d,1)
}
y <- rowSums(X * theta_arr) + rnorm(n, sd=sig)

l <- viking::expectation_maximization(X, y, 50, diag(d), verbose=10)
print(l$Q)
print(l$sig)

```

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iterative\_grid\_search *Iterative Grid Search*

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**Description**

iterative\_grid\_search is an iterative method to choose hyper-parameters of the linear Gaussian State-Space Model with time-invariant variances.

**Usage**

```

iterative_grid_search(
  X,
  y,
  q_list,
  Q_init = NULL,
  max_iter = 0,
  delay = 1,
  use = NULL,
  restrict = NULL,
  mode = "gaussian",
  p1 = 0,
  ncores = 1,

```

```

    train_theta1 = NULL,
    train_Q = NULL,
    verbose = TRUE
  )

```

### Arguments

<code>x</code>	the explanatory variables
<code>y</code>	the observations
<code>q_list</code>	the possible values of $\text{diag}(Q) / \text{sig}^2$
<code>Q_init</code>	(default NULL) initial value of $Q / \text{sig}^2$ , if NULL it is set to 0
<code>max_iter</code>	(optional 0) maximal number of iterations. If 0 then optimization is done as long as we can improve the log-likelihood
<code>delay</code>	(optional, default 1) to predict $y[t]$ we have access to $y[t-\text{delay}]$
<code>use</code>	(optional, default NULL) the availability variable
<code>restrict</code>	(optional, default NULL) if not NULL it allows to specify the indices of the diagonal coefficient to optimize
<code>mode</code>	(optional, default gaussian)
<code>p1</code>	(optional, default 0) coefficient for $P1/\text{sig}^2 = p1 I$
<code>ncores</code>	(optional, default 1) number of available cores for computation
<code>train_theta1</code>	(optional, default NULL) training set for estimation of <code>theta1</code>
<code>train_Q</code>	(optional, default NULL) time steps on which the log-likelihood is computed
<code>verbose</code>	(optional, default TRUE) whether to print intermediate progress

### Details

We restrict ourselves to a diagonal matrix  $Q$  and we optimize  $Q / \text{sig}^2$  on a grid. Each diagonal coefficient is assumed to belong to a pre-defined `q_list`.

We maximize the log-likelihood on that region of search in an iterative fashion. At each step, we change the diagonal coefficient improving the most the log-likelihood. We stop when there is no possible improvement. This doesn't guarantee an optimal point on the grid, but the computational time is much lower.

### Value

a list containing values for  $P$ ,  $\theta$ ,  $\text{sig}$ ,  $Q$ , as well as `LOGLIK`, the evolution of the log-likelihood during the search.

### Examples

```

set.seed(1)
### Simulate data
n <- 100
d <- 5
Q <- diag(c(0,0,0.25,0.25,0.25))
sig <- 1

```

```
X <- cbind(matrix(rnorm((d-1)*n,sd=1),n,d-1),1)
theta <- matrix(rnorm(d), d, 1)
theta_arr <- matrix(0, n, d)
for (t in 1:n) {
  theta_arr[t,] <- theta
  theta <- theta + matrix(mvtnorm::rmvnorm(1,matrix(0,d,1),Q),d,1)
}
y <- rowSums(X * theta_arr) + rnorm(n, sd=sig)

l <- viking::iterative_grid_search(X, y, seq(0,1,0.25))
print(l$Q)
print(l$sig)
```

---

kalman\_filtering      *Kalman Filtering*

---

### Description

Compute the filtered estimation of the parameters theta and P.

### Usage

```
kalman_filtering(X, y, theta1, P1, Q = 0, sig = 1)
```

### Arguments

X	the explanatory variables
y	the time series
theta1	initial theta
P1	initial P
Q	(optional, default 0) covariance matrix of the state noise
sig	(optional, default 1) variance of the spate noise

### Value

a list containing theta\_arr and P\_arr, the filtered estimation of the parameters theta and P.

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kalman_smoothing	<i>Kalman Smoothing</i>
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**Description**

Compute the smoothed estimation of the parameters theta and P.

**Usage**

```
kalman_smoothing(X, y, theta1, P1, Q = 0, sig = 1)
```

**Arguments**

X	the explanatory variables
y	the time series
theta1	initial theta
P1	initial P
Q	(optional, default 0) covariance matrix of the state noise
sig	(optional, default 1) variance of the spate noise

**Value**

a list containing theta\_arr and P\_arr, the smoothed estimation of the parameters theta and P.

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loglik	<i>Log-likelihood</i>
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**Description**

loglik computes the log-likelihood of a state-space model of specified  $Q/\text{sig}^2$ ,  $P1/\text{sig}^2$ , theta1.

**Usage**

```
loglik(X, y, Qstar, use, p1, train_theta1, train_Q, mode = "gaussian")
```

**Arguments**

X	explanatory variables
y	time series
Qstar	the ratio $Q/\text{sig}^2$
use	the availability variable
p1	coefficient for $P1/\text{sig}^2 = p1 I$
train_theta1	training set for estimation of theta1
train_Q	time steps on which the log-likelihood is computed
mode	(optional, default gaussian)

**Value**

a numeric value for the log-likelihood.

---

plot.statespace	<i>Plot a statespace object</i>
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**Description**

plot.statespace displays different graphs expressing the behavior of the state-space model:

1. Evolution of the Bias: rolling version of the error of the model.
2. Evolution of the RMSE: root-mean-square-error computed on a rolling window.
3. State Evolution: time-varying state coefficients, subtracted of the initial state vector.
4. Normal Q-Q Plot: we check if the observation follows the Gaussian distribution of estimated mean and variance. To that end, we display a Q-Q plot of the residual divided by the estimated standard deviation, against the standard normal distribution.

**Usage**

```
## S3 method for class 'statespace'
plot(x, pause = FALSE, window_size = 7, date = NULL, sel = NULL, ...)
```

**Arguments**

x	the statespace object.
pause	(default FALSE) if set to FALSE then the plots are displayed on a single page, otherwise a new page is created for each plot.
window_size	(default 7) the window size of the rolling mean computed on the error to display the bias, and on the mean squared error to display a rolling RMSE.
date	(default NULL) defines the values for the x-axis.
sel	(default NULL) defines a subset of the data on which we zoom. For instance one can display the evolution of the SSM on a test set and not the whole data set.
...	additional parameters

**Value**

No return value, called to display plots.

---

predict.statespace      *Predict using a statespace object*

---

### Description

predict.statespace makes a prediction for a statespace object, in the offline or online setting.

### Usage

```
## S3 method for class 'statespace'
predict(
  object,
  newX,
  newy = NULL,
  online = TRUE,
  compute_smooth = FALSE,
  type = c("mean", "proba", "model"),
  ...
)
```

### Arguments

object	the statespace object
newX	the design matrix in the prediction set
newy	(default NULL) the variable of interest in the prediction set. If specified it allows to use the state-space model in the online setting. Otherwise the prediction is offline.
online	(default TRUE) specifies if the prediction is made online, that is if the observation at time t-1 is used to update the model before predicting at time t.
compute_smooth	(default FALSE) specifies if Kalman Smoothing is also computed.
type	type of prediction. Can be either <b>mean</b> return the mean forecast. <b>proba</b> return a probabilistic forecast (list containing estimation of the mean and standard deviation). <b>model</b> return the updated statespace object (containing also the forecasts).
...	additional parameters

### Value

Depending on the type specified, the result is  
- a vector of mean forecast if type='mean' - a list of two vectors, mean forecast and standard deviations if type='proba' - a statespace object if type='model'



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 select\_Kalman\_variances

*Select time-invariant variances of a State-Space Model*


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### Description

select\_Kalman\_variances is a function to choose hyper-parameters of the linear Gaussian State-Space Model with time-invariant variances. It relies on the functions iterative\_grid\_search and expectation\_maximization.

### Usage

```
select_Kalman_variances(ssm, X, y, method = "igd", ...)
```

### Arguments

ssm	the statespace object
X	explanatory variables
y	time series
method	(optional, default 'igd') it can be either 'igd' iterative_grid_search is called 'em' expectation_maximization is called
...	additional parameters

### Value

a new statespace object with new values in kalman\_params

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 statespace

*Design a State-Space Model*


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### Description

The function statespace builds a state-space model, with known or unknown variances. By default, this function builds a state-space model in the static setting, with a constant state (zero state noise covariance matrix) and constant observation noise variance.

### Usage

```
statespace(X, y, kalman_params = NULL, viking_params = NULL, ...)
```

**Arguments**

<code>X</code>	design matrix.
<code>y</code>	variable of interest.
<code>kalman_params</code>	(default NULL) list containing initial values for $\theta$ , $P$ as well as the variances ( $Q$ , $\text{sig}$ ). If it is not specified, the state-space model is constructed in the static setting ( $\theta=0$ , $P=I$ , $Q=0$ , $\text{sig}=1$ ).
<code>viking_params</code>	(default NULL) list of parameters for the Viking algorithm.
<code>...</code>	additional parameters

**Value**

a statespace object.

**Examples**

```

set.seed(1)
### Simulate data
n <- 1000
d <- 5
Q <- diag(c(0,0,0.25,0.25,0.25))
sig <- 1

X <- cbind(matrix(rnorm((d-1)*n,sd=1),n,d-1),1)
theta <- matrix(rnorm(d), d, 1)
theta_arr <- matrix(0, n, d)
for (t in 1:n) {
  theta_arr[t,] <- theta
  theta <- theta + matrix(mvtnorm::rmvnorm(1,matrix(0,d,1),Q),d,1)
}
y <- rowSums(X * theta_arr) + rnorm(n, sd=sig)

#####
### Kalman Filter
# Default Static Setting
ssm <- viking::statespace(X, y)
plot(ssm)

# Known variances
ssm <- viking::statespace(X, y, kalman_params = list(Q=Q, sig=sig))
plot(ssm)

```

---

viking

*Viking: Variational bayesian variance tracKING*


---

**Description**

viking is the state-space estimation realized by Viking, generalizing the Kalman Filter to variance uncertainty.

**Usage**

```

viking(
  X,
  y,
  theta0,
  P0,
  hata0,
  s0,
  hatb0,
  Sigma0,
  n_iter = 2,
  mc = 10,
  rho_a = 0,
  rho_b = 0,
  learn_sigma = TRUE,
  learn_Q = TRUE,
  K = NULL,
  mode = "diagonal",
  thresh = TRUE,
  phi = logt,
  phi1 = logt1,
  phi2 = logt2
)

```

**Arguments**

X	the explanatory variables
y	the time series
theta0	initial theta
P0	initial P
hata0	initial hata
s0	initial s
hatb0	initial hatb
Sigma0	initial Sigma
n_iter	(optional, default 2) number of alternate steps
mc	(optional, default 10) number of Monte-Carlo samples
rho_a	(optional, default 0) learning rate of a
rho_b	(optional, default 0) learning rate of b
learn_sigma	(optional, default TRUE) asserts the estimation of a
learn_Q	(optional, default TRUE) asserts the estimation of b
K	(optional, default NULL) if not NULL then it is a multiplicative factor of the state in the state update
mode	(optional, default 'diagonal')

thresh	(optional, default TRUE)
phi	(optional, default logt)
phi1	(optional, default logt1)
phi2	(optional, default logt2)

**Value**

a list composed of the evolving value of all the parameters: theta\_arr, P\_arr, q\_arr, hata\_arr, s\_arr, hatb\_arr, Sigma\_arr

**References**

J. de Villemarest, O. Wintenberger (2021), Viking: Variational Bayesian Variance Tracking. <arXiv:2104.10777>

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