

# Package ‘pomp’

December 5, 2014

**Type** Package

**Title** Statistical Inference for Partially Observed Markov Processes

**Version** 0.55-1

**Date** 2014-12-03

**URL** <http://pomp.r-forge.r-project.org>

**Description** Inference methods for partially observed Markov processes (AKA stochastic dynamical systems, state-space models)

**Depends** R(>= 3.0.0), methods, subplex, nloptr

**Imports** stats, graphics, mvtnorm, deSolve, coda

**License** GPL(>= 2)

**LazyData** true

**MailingList**

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**Collate** aaa.R authors.R generics.R eulermultinom.R  
csnippet.R pomp-fun.R plugins.R  
parmat.R logmeanexp.R slice-design.R  
profile-design.R sobol.R bsplines.R sannbox.R  
pomp-class.R pomp.R pomp-methods.R  
rmeasure-pomp.R rprocess-pomp.R init-state-pomp.R  
dmeasure-pomp.R dprocess-pomp.R skeleton-pomp.R  
dprior-pomp.R rprior-pomp.R  
simulate-pomp.R trajectory-pomp.R plot-pomp.R  
pfilter.R pfilter-methods.R minim.R traj-match.R  
bsmc.R bsmc2.R  
mif.R mif-methods.R  
pmcmc.R pmcmc-methods.R  
nlf-funcs.R nlf-guts.R nlf-objfun.R nlf.R  
probe.R probe-match.R basic-probes.R spect.R spect-match.R  
abc.R abc-methods.R  
builder.R example.R

**R topics documented:**

pomp-package . . . . .	3
abc . . . . .	4
abc-methods . . . . .	6
B-splines . . . . .	7
basic.probes . . . . .	8
blowflies . . . . .	10
bsmc2 . . . . .	12
Csnippet . . . . .	14
dacca . . . . .	14
eulermultinom . . . . .	15
gompertz . . . . .	17
logmeanexp . . . . .	18
LondonYorke . . . . .	19
mif . . . . .	20
mif-methods . . . . .	23
nlf . . . . .	24
ou2 . . . . .	26
parmat . . . . .	27
pfilter . . . . .	28
pfilter-methods . . . . .	30
plugins . . . . .	31
pmcmc . . . . .	34
pmcmc-methods . . . . .	36
pomp . . . . .	37
pomp-methods . . . . .	44
pompBuilder . . . . .	47
pompExample . . . . .	49
probe . . . . .	50
probed.pomp-methods . . . . .	53
profileDesign . . . . .	55
ricker . . . . .	56
rw2 . . . . .	56
sannbox . . . . .	57
simulate-pomp . . . . .	58
sir . . . . .	60
sliceDesign . . . . .	61
sobol . . . . .	62
spect . . . . .	63
traj.match . . . . .	66
trajectory . . . . .	68
verhulst . . . . .	70

## Description

The **pomp** package provides facilities for inference on time series data using partially-observed Markov processes (AKA state-space models or nonlinear stochastic dynamical systems). One can use **pomp** to fit nonlinear, non-Gaussian dynamic models to time-series data. The first step in using **pomp** is to encode one's model and data in an object of class `pomp`. One does this via a call to `pomp`, which involves specifying the process and measurement components of the model in one or more of a variety of ways. Details on this are given in the documentation for the `pomp` function. Examples are given in the “[Introduction to pomp](#)” document, in the demos (`demo(package=pomp)`), and via the `pompExample` function.

**pomp** version 0.55-1 provides algorithms for

1. simulation of stochastic dynamical systems; see [simulate](#)
2. particle filtering (AKA sequential Monte Carlo or sequential importance sampling); see [pfilter](#)
3. the iterated filtering method of Ionides et al. (2006, 2011); see [mif](#)
4. the nonlinear forecasting algorithm of Kendall et al. (2005); see [nlf](#)
5. the particle MCMC approach of Andrieu et al. (2010); see [pmcmc](#)
6. the probe-matching method of Kendall et al. (1999, 2005); see [probe.match](#)
7. a spectral probe-matching method (Reuman et al. 2006, 2008); see [spect.match](#)
8. synthetic likelihood a la Wood (2010); see [probe](#)
9. approximate Bayesian computation (Toni et al. 2009); see [abc](#)
10. the approximate Bayesian sequential Monte Carlo scheme of Liu & West (2001); see [bsmc](#)
11. basic trajectory matching; see [traj.match](#).

The package also provides various tools for plotting and extracting information on models and data as well as an API for algorithm development. Future support for additional algorithms is envisioned. Much of the groundwork for **pomp** was laid by a working group of the National Center for Ecological Analysis and Synthesis (NCEAS), “Inference for Mechanistic Models”.

**pomp** is provided under the GNU Public License (GPL). Contributions are welcome, as are comments, feature requests, and bug reports. See the package website <http://pomp.r-forge.r-project.org> for more information, access to the package mailing list, links to the authors' websites, references to the literature, and up-to-date versions of the package source and documentation.

## Classes

**pomp** makes extensive use of S4 classes. The basic class, `pomp`, encodes a partially-observed Markov process together with a uni- or multi-variate data set and (possibly) parameters.

## Documentation

The ‘**Introduction to pomp**’ document illustrates the facilities of the package using familiar stochastic processes. The ‘**Advanced topics in pomp**’ document discusses the low-level interface and some more advanced modeling techniques. These documents can be viewed at <http://pomp.r-forge.r-project.org>.

## Author(s)

Aaron A. King <kingaa at umich dot edu>

## References

See the package website, <http://pomp.r-forge.r-project.org>, for the references.

## See Also

[pomp](#), [pfilter](#), [simulate](#), [trajectory](#), [mif](#), [nlf](#), [probe.match](#), [traj.match](#), [bsmc](#), [pmcmc](#)

---

abc

*The ABC algorithm*

---

## Description

The approximate Bayesian computation (ABC) algorithm for estimating the parameters of a partially-observed Markov process.

## Usage

```
## S4 method for signature pomp
abc(object, Nabc = 1, start, pars,
     rw.sd, probes, scale, epsilon,
     verbose = getOption("verbose"), ...)
## S4 method for signature probed.pomp
abc(object, probes,
     verbose = getOption("verbose"), ...)
## S4 method for signature abc
abc(object, Nabc, start, pars,
     rw.sd, probes, scale, epsilon,
     verbose = getOption("verbose"), ...)
## S4 method for signature abc
continue(object, Nabc = 1, ...)
```

**Arguments**

<code>object</code>	An object of class <code>pomp</code> .
<code>Nabc</code>	The number of ABC iterations to perform.
<code>start</code>	named numeric vector; the starting guess of the parameters.
<code>pars</code>	optional character vector naming the ordinary parameters to be estimated. Every parameter named in <code>pars</code> must have a positive random-walk standard deviation specified in <code>rw.sd</code> . Leaving <code>pars</code> unspecified is equivalent to setting it equal to the names of all parameters with a positive value of <code>rw.sd</code> .
<code>rw.sd</code>	numeric vector with names; used to parameterize a Gaussian random walk MCMC proposal. The random walk is only applied to parameters named in <code>pars</code> . The algorithm requires that the random walk be nontrivial, so each element in <code>rw.sd[pars]</code> must be positive. The following must be satisfied: <code>names(rw.sd)</code> must be a subset of <code>names(start)</code> , <code>rw.sd</code> must be non-negative (zeros are simply ignored), the name of every positive element of <code>rw.sd</code> must be in <code>pars</code> .
<code>probes</code>	
<code>scale</code>	
<code>epsilon</code>	
<code>verbose</code>	logical; if TRUE, print progress reports.
<code>...</code>	Additional arguments. These are currently ignored.

**Value**

An object of class `abc`. This class inherits from class `probed.pomp` and contains the following additional slots:

**`pars`, `Nabc`, `dprior`, `hyperparams`, `scale`, `epsilon`** These slots hold the values of the corresponding arguments of the call to `abc`.

**`random.walk.sd`** a named numeric vector containing the random-walk variances used to parameterize a Gaussian random walk MCMC proposal.

**`probes`, `conv.rec`**

**Re-running ABC Iterations**

To re-run a sequence of ABC iterations, one can use the `abc` method on a `abc` object. By default, the same parameters used for the original ABC run are re-used (except for `tol`, `max.fail`, and `verbose`, the defaults of which are shown above). If one does specify additional arguments, these will override the defaults.

**Continuing ABC Iterations**

One can continue a series of ABC iterations from where one left off using the `continue` method. A call to `abc` to perform `Nabc=m` iterations followed by a call to `continue` to perform `Nabc=n` iterations will produce precisely the same effect as a single call to `abc` to perform `Nabc=m+n` iterations. By default, all the algorithmic parameters are the same as used in the original call to `abc`. Additional arguments will override the defaults.

**Details**

TO APPEAR.

**Author(s)**

Edward L. Ionides <ionides at umich dot edu>, Aaron A. King <kingaa at umich dot edu>

**References**

T. Toni and M. P. H. Stumpf, Simulation-based model selection for dynamical systems in systems and population biology, *Bioinformatics* 26:104–110, 2010.

T. Toni, D. Welch, N. Strelkowa, A. Ipsen, and M. P. H. Stumpf, Approximate Bayesian computation scheme for parameter inference and model selection in dynamical systems *Journal of the Royal Society, Interface* 6:187–202, 2009.

**See Also**

[abc-methods](#), [pomp](#), [probe](#). See the “intro\_to\_pomp” vignette for an example

---

abc-methods

*Methods of the "abc" class*

---

**Description**

Methods of the "abc" class.

**Usage**

```
## S4 method for signature abc
conv.rec(object, pars, ...)
## S4 method for signature abclList
conv.rec(object, ...)
## S4 method for signature abc
plot(x, y, pars, scatter = FALSE, ...)
## S4 method for signature abclList
plot(x, y, ...)
## S4 method for signature abc
c(x, ..., recursive = FALSE)
## S4 method for signature abclList
c(x, ..., recursive = FALSE)
```

**Arguments**

object, x	The abc object.
pars	Names of parameters.
y, recursive	Ignored.
scatter	optional logical; If TRUE, draw scatterplots. If FALSE, draw traceplots.
...	Further arguments (either ignored or passed to underlying functions).

**Methods**

**conv.rec** `conv.rec(object, pars)` returns the columns of the convergence-record matrix corresponding to the names in `pars`. By default, all rows are returned.

**c** Concatenates `abc` objects into an `abcList`.

**plot** Diagnostic plots.

**Author(s)**

Edward L. Ionides <ionides at umich dot edu>, Aaron A. King <kingaa at umich dot edu>

**See Also**

[abc](#), [pomp](#)

---

B-splines

*B-spline bases*


---

**Description**

These functions generate B-spline basis functions. `bspline.basis` gives a basis of spline functions. `periodic.bspline.basis` gives a basis of periodic spline functions.

**Usage**

```
bspline.basis(x, nbasis, degree = 3, names = NULL)
periodic.bspline.basis(x, nbasis, degree = 3, period = 1, names = NULL)
```

**Arguments**

<code>x</code>	Vector at which the spline functions are to be evaluated.
<code>nbasis</code>	The number of basis functions to return.
<code>degree</code>	Degree of requested B-splines.
<code>period</code>	The period of the requested periodic B-splines.
<code>names</code>	optional; the names to be given to the basis functions. These will be the column-names of the matrix returned. If the names are specified as a format string (e.g., "basis%d"), <a href="#">sprintf</a> will be used to generate the names from the column number. If a single non-format string is specified, the names will be generated by <a href="#">paste</a> -ing name to the column number. One can also specify each column name explicitly by giving a length- <code>nbasis</code> string vector. By default, no column-names are given.

**Details**

Direct access to the underlying C routines is available. See the header file "pomp.h" for details.

**Value**

`bspline.basis` Returns a matrix with `length(x)` rows and `nbasis` columns. Each column contains the values one of the spline basis functions.

`periodic.bspline.basis` Returns a matrix with `length(x)` rows and `nbasis` columns. The basis functions returned are periodic with period `period`.

**Author(s)**

Aaron A. King <kingaa at umich dot edu>

**Examples**

```
x <- seq(0,2,by=0.01)
y <- bspline.basis(x,degree=3,nbasis=9,names="basis")
matplot(x,y,type=l,ylim=c(0,1.1))
lines(x,apply(y,1,sum),lwd=2)

x <- seq(-1,2,by=0.01)
y <- periodic.bspline.basis(x,nbasis=5,names="spline%d")
matplot(x,y,type=l)
```

---

basic.probes

*Some probes for partially-observed Markov processes*

---

**Description**

Several simple and configurable probes are provided in the package. These can be used directly and as examples for building custom probes.

**Usage**

```
probe.mean(var, trim = 0, transform = identity, na.rm = TRUE)
probe.median(var, na.rm = TRUE)
probe.var(var, transform = identity, na.rm = TRUE)
probe.sd(var, transform = identity, na.rm = TRUE)
probe.marginal(var, ref, order = 3, diff = 1, transform = identity)
probe.nlar(var, lags, powers, transform = identity)
probe.acf(var, lags, type = c("covariance", "correlation"),
  transform = identity)
probe.ccf(vars, lags, type = c("covariance", "correlation"),
  transform = identity)
probe.period(var, kernel.width, transform = identity)
probe.quantile(var, prob, transform = identity)
```



**Arguments**

<code>var, vars</code>	character; the name(s) of the observed variable(s).
<code>trim</code>	the fraction of observations to be trimmed (see <a href="#">mean</a> ).
<code>transform</code>	transformation to be applied to the data before the probe is computed.
<code>na.rm</code>	if TRUE, remove all NA observations prior to computing the probe.
<code>kernel.width</code>	width of modified Daniell smoothing kernel to be used in power-spectrum computation: see <a href="#">kernel</a> .
<code>prob</code>	a single probability; the quantile to compute: see <a href="#">quantile</a> .
<code>lags</code>	In <code>probe.ccf</code> , a vector of lags between time series. Positive lags correspond to x advanced relative to y; negative lags, to the reverse.  In <code>probe.nlar</code> , a vector of lags present in the nonlinear autoregressive model that will be fit to the actual and simulated data. See Details, below, for a precise description.
<code>powers</code>	the powers of each term (corresponding to lags) in the the nonlinear autoregressive model that will be fit to the actual and simulated data. See Details, below, for a precise description.
<code>type</code>	Compute autocorrelation or autocovariance?
<code>ref</code>	empirical reference distribution. Simulated data will be regressed against the values of <code>ref</code> , sorted and, optionally, differenced. The resulting regression coefficients capture information about the shape of the marginal distribution. A good choice for <code>ref</code> is the data itself.
<code>order</code>	order of polynomial regression.
<code>diff</code>	order of differencing to perform.
<code>...</code>	Additional arguments to be passed through to the probe computation.

**Details**

Each of these functions is relatively simple. See the source code for a complete understanding of what each does.

`probe.mean`, `probe.median`, `probe.var`, `probe.sd` return functions that compute the mean, median, variance, and standard deviation of variable `var`, respectively.

`probe.period` returns a function that estimates the period of the Fourier component of the `var` series with largest power.

`probe.marginal` returns a function that regresses the marginal distribution of variable `var` against the reference distribution `ref`. If `diff>0`, the data and the reference distribution are first differenced `diff` times and centered. Polynomial regression of order `order` is used. This probe returns order regression coefficients (the intercept is zero).

`probe.nlar` returns a function that fit a nonlinear (polynomial) autoregressive model to the univariate series (variable `var`). Specifically, a model of the form  $y_t = \sum \beta_k y_{t-\tau_k}^{p_k} + \epsilon_t$  will be fit, where  $\tau_k$  are the lags and  $p_k$  are the powers. The data are first centered. This function returns the regression coefficients,  $\beta_k$ .

`probe.acf` returns a function that, if `type=="covariance"`, computes the autocovariance of variable `var` at lags `lags`; if `type=="correlation"`, computes the autocorrelation of variable `var` at lags `lags`.

`probe.ccf` returns a function that, if `type=="covariance"`, computes the cross covariance of the two variables named in `vars` at lags `lags`; if `type=="correlation"`, computes the cross correlation.

`probe.quantile` returns a function that estimates the `prob`-th quantile of variable `var`.

## Value

A call to any one of these functions returns a probe function, suitable for use in `probe` or `probe.match`. That is, the function returned by each of these takes a data array (such as comes from a call to `obs`) as input and returns a single numerical value.

## Author(s)

Daniel C. Reuman (d.reuman at imperial dot ac dot uk)

Aaron A. King (kingaa at umich dot edu)

## References

B. E. Kendall, C. J. Briggs, W. M. Murdoch, P. Turchin, S. P. Ellner, E. McCauley, R. M. Nisbet, S. N. Wood Why do populations cycle? A synthesis of statistical and mechanistic modeling approaches, *Ecology*, 80:1789–1805, 1999.

S. N. Wood Statistical inference for noisy nonlinear ecological dynamic systems, *Nature*, 466: 1102–1104, 2010.

## See Also

`pomp`

---

blowflies

*Model for Nicholson's blowflies.*

---

## Description

`blowflies1` and `blowflies2` are `pomp` objects encoding stochastic delay-difference models.

## Details

The data are from "population I", a control culture in one of A. J. Nicholson's experiments with the Australian sheep-blowfly *Lucilia cuprina*. The experiment is described on pp. 163–4 of Nicholson (1957). Unlimited quantities of larval food were provided; the adult food supply (ground liver) was constant at 0.4g per day. The data were taken from the table provided by Brillinger et al. (1980).

The models are discrete delay equations:

$$R(t+1) \sim \text{Poisson}(PN(t-\tau) \exp(-N(t-\tau)/N_0)e(t+1)\Delta t)$$

$$S(t+1) \sim \text{binomial}(N(t), \exp(-\delta\epsilon(t+1)\Delta t))$$

$$N(t) = R(t) + S(t)$$

where  $e(t)$  and  $\epsilon(t)$  are Gamma-distributed i.i.d. random variables with mean 1 and variances  $\sigma_p^2/\Delta t$ ,  $\sigma_d^2/\Delta t$ , respectively. `blowflies1` has a timestep ( $\Delta t$ ) of 1 day, and `blowflies2` has a timestep of 2 days. The process model in `blowflies1` thus corresponds exactly to that studied by Wood (2010). The measurement model in both cases is taken to be

$$y(t) \sim \text{negbin}(N(t), 1/\sigma_y^2)$$

, i.e., the observations are assumed to be negative-binomially distributed with mean  $N(t)$  and variance  $N(t) + (\sigma_y N(t))^2$ .

Do

```
file.show(system.file("examples", "blowflies.R", package="pomp"))
```

to view the code that constructs these `pomp` objects.

## References

- A. J. Nicholson (1957) The self-adjustment of populations to change. Cold Spring Harbor Symposia on Quantitative Biology, **22**, 153–173.
- Y. Xia and H. Tong (2011) Feature Matching in Time Series Modeling. *Statistical Science* **26**, 21–46.
- E. L. Ionides (2011) Discussion of “Feature Matching in Time Series Modeling” by Y. Xia and H. Tong. *Statistical Science* **26**, 49–52.
- S. N. Wood (2010) Statistical inference for noisy nonlinear ecological dynamic systems. *Nature* **466**, 1102–1104.
- W. S. C. Gurney, S. P. Blythe, and R. M. Nisbet (1980) Nicholson’s blowflies revisited. *Nature* **287**, 17–21.
- D. R. Brillinger, J. Guckenheimer, P. Guttorp and G. Oster (1980) Empirical modelling of population time series: The case of age and density dependent rates. in G. Oster (ed.), Some Questions in Mathematical Biology, vol. 13, pp. 65–90. American Mathematical Society, Providence.

## See Also

[pomp](#)

## Examples

```
pompExample(blowflies)
plot(blowflies1)
plot(blowflies2)
```

**Description**

Modified versions of the Liu and West (2001) algorithm.

**Usage**

```
## S4 method for signature pomp
bsmc(object, params, Np, est, smooth = 0.1,
      ntries = 1, tol = 1e-17, lower = -Inf, upper = Inf, seed = NULL,
      verbose = getOption("verbose"), max.fail = 0,
      transform = FALSE, ...)
## S4 method for signature pomp
bsmc2(object, params, Np, est, smooth = 0.1,
       tol = 1e-17, seed = NULL,
       verbose = getOption("verbose"), max.fail = 0,
       transform = FALSE, ...)
```

**Arguments**

object	An object of class pomp or inheriting class pomp.
params, Np	Specifications for the prior distribution of particles. See details below.
est	Names of the rows of params that are to be estimated. No updates will be made to the other parameters. If est is not specified, all parameters for which there is variation in params will be estimated.
smooth	Kernel density smoothing parameters. The compensating shrinkage factor will be $\sqrt{1-\text{smooth}^2}$ . Thus, smooth=0 means that no noise will be added to parameters. Generally, the value of smooth should be chosen close to 0 (i.e., shrink $\sim$ 0.1).
ntries	Number of draws from rprocess per particle used to estimate the expected value of the state process at time $t+1$ given the state and parameters at time $t$ .
tol	Particles with log likelihood below tol are considered to be “lost”. A filtering failure occurs when, at some time point, all particles are lost. When all particles are lost, the conditional log likelihood at that time point is set to be $\log(\text{tol})$ .
lower, upper	optional; lower and upper bounds on the priors. This is useful in case there are box constraints satisfied by the priors. The posterior is guaranteed to lie within these bounds.
seed	optional; an object specifying if and how the random number generator should be initialized (‘seeded’). If seed is an integer, it is passed to set.seed prior to any simulation and is returned as the “seed” element of the return list. By default, the state of the random number generator is not changed and the value of .Random.seed on the call is stored in the “seed” element of the return list.
verbose	logical; if TRUE, print diagnostic messages.

<code>max.fail</code>	The maximum number of filtering failures allowed. If the number of filtering failures exceeds this number, execution will terminate with an error.
<code>transform</code>	logical; if TRUE, the algorithm operates on the transformed scale.
<code>...</code>	currently ignored.

## Details

There are two ways to specify the prior distribution of particles. If `params` is unspecified or is a named vector, `Np` draws are made from the prior distribution, as specified by `rprior`. Alternatively, `params` can be specified as an `npars x Np` matrix (with rownames).

`bsmc` uses version of the original algorithm that includes a plug-and-play auxiliary particle filter. `bsmc2` discards this auxiliary particle filter and appears to give superior performance for the same amount of effort.

## Value

An object of class “`bsmcd.pomp`”. The “`params`” slot of this object will hold the parameter posterior medians. The slots of this class include:

<code>post</code>	A matrix containing draws from the approximate posterior distribution.
<code>prior</code>	A matrix containing draws from the prior distribution (identical to <code>params</code> on call).
<code>eff.sample.size</code>	A vector containing the effective number of particles at each time point.
<code>smooth</code>	The smoothing parameter used (see above).
<code>seed</code>	The state of the random number generator at the time <code>bsmc</code> was called. If the argument <code>seed</code> was specified, this is a copy; if not, this is the internal state of the random number generator at the time of call.
<code>nfail</code>	The number of filtering failures encountered.
<code>cond.log.evidence</code>	A vector containing the conditional log evidence scores at each time point.
<code>log.evidence</code>	The estimated log evidence.
<code>weights</code>	The resampling weights for each particle.

## Author(s)

Michael Lavine (lavine at math dot umass dot edu), Matthew Ferrari (mferrari at psu dot edu), Aaron A. King Edward L. Ionides

## References

Liu, J. and M. West. Combining Parameter and State Estimation in Simulation-Based Filtering. In A. Doucet, N. de Freitas, and N. J. Gordon, editors, Sequential Monte Carlo Methods in Practice, pages 197-224. Springer, New York, 2001.

**See Also**

[pomp-class](#)

**Examples**

```
## See the "Introducton to pomp" document for examples.
```

---

Csnippet

*C code snippets*


---

**Description**

For including snippets of C code in pomp objects.

**Usage**

```
Csnippet(text);
```

**Arguments**

text                      character; a snippet of C code.

**Value**

An object of class Csnippet.

**Author(s)**

Aaron A. King <kingaa at umich dot edu>

---

dacca

*Model of cholera transmission for historic Bengal.*


---

**Description**

dacca is a pomp object containing census and cholera mortality data from the Dacca district of the former British province of Bengal over the years 1891 to 1940 together with a stochastic differential equation transmission model. The model is that of King et al. (2008). The parameters are the MLE for the SIRS model with seasonal reservoir.

Data are provided courtesy of Dr. Menno J. Bouma, London School of Tropical Medicine and Hygiene.

## Details

dacca is a pomp object containing the model, data, and MLE parameters. Parameters that naturally range over the positive reals are log-transformed; parameters that range over the unit interval are logit-transformed; parameters that are naturally unbounded or take integer values are not transformed.

## References

King, A. A., Ionides, E. L., Pascual, M., and Bouma, M. J. Inapparent infections and cholera dynamics. *Nature* 454:877-880 (2008)

## See Also

[euler.sir](#), [pomp](#)

## Examples

```
pompExample(dacca)
plot(dacca)
#MLEs on the natural scale
coef(dacca)
#MLEs on the transformed scale
coef(dacca,transform=TRUE)
plot(simulate(dacca))
# now change eps and simulate again
coef(dacca,"eps") <- 1
plot(simulate(dacca))
```

---

eulermultinom

*Euler-multinomial death process*


---

## Description

Density and random-deviate generation for the Euler-multinomial death process with parameters size, rate, and dt.

## Usage

```
reulermultinom(n = 1, size, rate, dt)
deulermultinom(x, size, rate, dt, log = FALSE)
rgammawn(n = 1, sigma, dt)
```

## Arguments

n	integer; number of random variates to generate.
size	scalar integer; number of individuals at risk.
rate	numeric vector of hazard rates.

sigma	numeric scalar; intensity of the Gamma white noise process.
dt	numeric scalar; duration of Euler step.
x	matrix or vector containing number of individuals that have succumbed to each death process.
log	logical; if TRUE, return logarithm(s) of probabilities.

### Details

If  $N$  individuals face constant hazards of death in  $k$  ways at rates  $r_1, r_2, \dots, r_k$ , then in an interval of duration  $\Delta t$ , the number of individuals remaining alive and dying in each way is multinomially distributed:

$$(N - \sum_{i=1}^k \Delta n_i, \Delta n_1, \dots, \Delta n_k) \sim \text{multinomial}(N; p_0, p_1, \dots, p_k),$$

where  $\Delta n_i$  is the number of individuals dying in way  $i$  over the interval, the probability of remaining alive is  $p_0 = \exp(-\sum_i r_i \Delta t)$ , and the probability of dying in way  $j$  is

$$p_j = \frac{r_j}{\sum_i r_i} (1 - \exp(-\sum_i r_i \Delta t)).$$

In this case, we can say that

$$(\Delta n_1, \dots, \Delta n_k) \sim \text{eulermultinom}(N, r, \Delta t),$$

where  $r = (r_1, \dots, r_k)$ . Draw  $m$  random samples from this distribution by doing

```
dn <- reulermultinom(n=m, size=N, rate=r, dt=dt),
```

where  $r$  is the vector of rates. Evaluate the probability that  $x = (x_1, \dots, x_k)$  are the numbers of individuals who have died in each of the  $k$  ways over the interval  $\Delta t = dt$ , by doing

```
deulermultinom(x=x, size=N, rate=r, dt=dt).
```

Bret'o & Ionides discuss how an infinitesimally overdispersed death process can be constructed by compounding a binomial process with a Gamma white noise process. The Euler approximation of the resulting process can be obtained as follows. Let the increments of the equidispersed process be given by

```
reulermultinom(size=N, rate=r, dt=dt).
```

In this expression, replace the rate  $r$  with  $r \Delta W / \Delta t$ , where  $\Delta W \sim \text{Gamma}(dt/\sigma^2, \sigma^2)$  is the increment of an integrated Gamma white noise process with intensity  $\sigma$ . That is,  $\Delta W$  has mean  $\Delta t$  and variance  $\sigma^2 \Delta t$ . The resulting process is overdispersed and converges (as  $\Delta t$  goes to zero) to a well-defined process. The following lines of R code accomplish this:

```
dW <- rgammaawn(sigma=sigma, dt=dt)
dn <- reulermultinom(size=N, rate=r, dt=dW)
```

or

```
dn <- reulermultinom(size=N, rate=r*dW/dt, dt=dt).
```



He et al. use such overdispersed death processes in modeling measles.

For all of the functions described here, direct access to the underlying C routines is available: see the header file “pomp.h”, included with the package.

### Value

<code>reulermultinom</code>	Returns a <code>length(rate)</code> by <code>n</code> matrix. Each column is a different random draw. Each row contains the numbers of individuals succumbed to the corresponding process.
<code>deulermultinom</code>	Returns a vector (of length equal to the number of columns of <code>x</code> ) containing the probabilities of observing each column of <code>x</code> given the specified parameters ( <code>size</code> , <code>rate</code> , <code>dt</code> ).
<code>rgammawn</code>	Returns a vector of length <code>n</code> containing random increments of the integrated Gamma white noise process with intensity <code>sigma</code> .

### Author(s)

Aaron A. King <kingaa at umich dot edu>

### References

C. Bret'ô & E. L. Ionides, Compound Markov counting processes and their applications to modeling infinitesimally over-dispersed systems. *Stoch. Proc. Appl.*, 121:2571–2591, 2011.

D. He, E. L. Ionides, & A. A. King, Plug-and-play inference for disease dynamics: measles in large and small populations as a case study. *J. R. Soc. Interface*, 7:271–283, 2010.

### Examples

```
print(dn <- reulermultinom(5,size=100,rate=c(a=1,b=2,c=3),dt=0.1))
deulermultinom(x=dn,size=100,rate=c(1,2,3),dt=0.1)
## an Euler-multinomial with overdispersed transitions:
dt <- 0.1
dW <- rgammawn(sigma=0.1,dt=dt)
print(dn <- reulermultinom(5,size=100,rate=c(a=1,b=2,c=3),dt=dW))
```

---

gompertz

*Gompertz model with log-normal observations.*

---

### Description

`gompertz` is a `pomp` object encoding a stochastic Gompertz population model with log-normal measurement error.

## Details

The state process is  $X_{t+1} = K^{1-S} X_t^S \epsilon_t$ , where  $S = e^{-r}$  and the  $\epsilon_t$  are i.i.d. lognormal random deviates with variance  $\sigma^2$ . The observed variables  $Y_t$  are distributed as  $\text{lognormal}(\log X_t, \tau)$ . Parameters include the per-capita growth rate  $r$ , the carrying capacity  $K$ , the process noise s.d.  $\sigma$ , the measurement error s.d.  $\tau$ , and the initial condition  $X_0$ . The `pomp` object includes parameter transformations that log-transform the parameters for estimation purposes.

## See Also

the “[Introduction to \*\*pomp\*\*](#)” tutorial.

## Examples

```
pompExample(gompertz)
plot(gompertz)
coef(gompertz)
coef(gompertz, transform=TRUE)
```

---

logmeanexp

*The log-mean-exp trick*


---

## Description

logmeanexp computes the log-mean-exp of a set of numbers.

## Usage

```
logmeanexp(x, se = FALSE)
```

## Arguments

x	numeric
se	logical; give approximate standard error?

## Value

$\log(\text{mean}(\exp(x)))$  computed so as to avoid over- or underflow. If `se = FALSE`, the approximate standard error is returned as well.

## Author(s)

Aaron A. King <kingaa at umich dot edu>

### Examples

```
## generate a bifurcation diagram for the Ricker map
pompExample(ricker)
ll <- replicate(n=5, logLik(pfilter(ricker, Np=1000)))
## an estimate of the log likelihood:
logmeanexp(ll)
logmeanexp(ll, se=TRUE)
```

---

LondonYorke

*Historical childhood disease incidence data*


---

### Description

LondonYorke is a data-frame containing the monthly number of reported cases of chickenpox, measles, and mumps from two American cities (Baltimore and New York) in the mid-20th century (1928–1972).

### Usage

```
data(LondonYorke)
```

### References

W. P. London and J. A. Yorke, Recurrent Outbreaks of Measles, Chickenpox and Mumps: I. Seasonal Variation in Contact Rates, *American Journal of Epidemiology*, 98:453–468, 1973.

### Examples

```
data(LondonYorke)

plot(cases~time, data=LondonYorke, subset=disease=="measles", type=n, main="measles", bty=l)
lines(cases~time, data=LondonYorke, subset=disease=="measles"&town=="Baltimore", col="red")
lines(cases~time, data=LondonYorke, subset=disease=="measles"&town=="New York", col="blue")
legend("topright", legend=c("Baltimore", "New York"), lty=1, col=c("red", "blue"), bty=n)

plot(
  cases~time,
  data=LondonYorke,
  subset=disease=="chickenpox"&town=="New York",
  type=l, col="blue", main="chickenpox, New York",
  bty=l
)

plot(
  cases~time,
  data=LondonYorke,
  subset=disease=="mumps"&town=="New York",
  type=l, col="blue", main="mumps, New York",
  bty=l
)
```

mif

*Iterated filtering***Description**

Iterated filtering algorithms for estimating the parameters of a partially-observed Markov process.

**Usage**

```
## S4 method for signature pomp
mif(object, Nmif = 1, start, pars, ivps = character(0),
    particles, rw.sd, Np, ic.lag, var.factor,
    cooling.type, cooling.fraction, cooling.factor,
    method = c("mif", "unweighted", "fp", "mif2"),
    tol = 1e-17, max.fail = Inf,
    verbose = getOption("verbose"), transform = FALSE, ...)
## S4 method for signature pfilterd.pomp
mif(object, Nmif = 1, Np, tol, ...)
## S4 method for signature mif
mif(object, Nmif, start, ivps,
    particles, rw.sd, Np, ic.lag, var.factor,
    cooling.type, cooling.fraction,
    method, tol, transform, ...)
## S4 method for signature mif
continue(object, Nmif = 1, ...)
```

**Arguments**

object	An object of class pomp.
Nmif	The number of filtering iterations to perform.
start	named numerical vector; the starting guess of the parameters.
pars	optional character vector naming the ordinary parameters to be estimated. Every parameter named in pars must have a positive random-walk standard deviation specified in rw.sd. Leaving pars unspecified is equivalent to setting it equal to the names of all parameters with a positive value of rw.sd that are not ivps.
ivps	optional character vector naming the initial-value parameters (IVPs) to be estimated. Every parameter named in ivps must have a positive random-walk standard deviation specified in rw.sd. If pars is empty, i.e., only IVPs are to be estimated, see below “Using MIF to estimate initial-value parameters only”.
particles	Function of prototype particles(Np, center, sd, ...) which sets up the starting particle matrix by drawing a sample of size Np from the starting particle distribution centered at center and of width sd. If particles is not supplied by the user, the default behavior is to draw the particles from a multivariate normal distribution with mean center and standard deviation sd.

<code>rw.sd</code>	numeric vector with names; the intensity of the random walk to be applied to parameters. The random walk is only applied to parameters named in <code>pars</code> (i.e., not to those named in <code>ivps</code> ). The algorithm requires that the random walk be nontrivial, so each element in <code>rw.sd[pars]</code> must be positive. <code>rw.sd</code> is also used to scale the initial-value parameters (via the <code>particles</code> function). Therefore, each element of <code>rw.sd[ivps]</code> must be positive. The following must be satisfied: <code>names(rw.sd)</code> must be a subset of <code>names(start)</code> , <code>rw.sd</code> must be non-negative (zeros are simply ignored), the name of every positive element of <code>rw.sd</code> must be in either <code>pars</code> or <code>ivps</code> .
<code>Np</code>	the number of particles to use in filtering. This may be specified as a single positive integer, in which case the same number of particles will be used at each timestep. Alternatively, if one wishes the number of particles to vary across timestep, one may specify <code>Np</code> either as a vector of positive integers (of length <code>length(time(object, t0=TRUE))</code> ) or as a function taking a positive integer argument. In the latter case, <code>Np(k)</code> must be a single positive integer, representing the number of particles to be used at the $k$ -th timestep: <code>Np(0)</code> is the number of particles to use going from <code>timezero(object)</code> to <code>time(object)[1]</code> , <code>Np(1)</code> , from <code>timezero(object)</code> to <code>time(object)[1]</code> , and so on, while when <code>T=length(time(object, t0=TRUE))</code> , <code>Np(T)</code> is the number of particles to sample at the end of the time-series.
<code>ic.lag</code>	a positive integer; the timepoint for fixed-lag smoothing of initial-value parameters. The <code>mif</code> update for initial-value parameters consists of replacing them by their filtering mean at time <code>times[ic.lag]</code> , where <code>times=time(object)</code> . It makes no sense to set <code>ic.lag&gt;length(times)</code> ; if it is so set, <code>ic.lag</code> is set to <code>length(times)</code> with a warning. For <code>method="mif2"</code> , the default is <code>ic.lag=length(times)</code> .
<code>var.factor</code>	a positive number; the scaling coefficient relating the width of the starting particle distribution to <code>rw.sd</code> . In particular, the width of the distribution of particles at the start of the first MIF iteration will be <code>random.walk.sd*var.factor</code> .
<code>cooling.type</code> , <code>cooling.fraction</code> , <code>cooling.factor</code>	specifications for the cooling schedule, i.e., the manner in which the intensity of the parameter perturbations is reduced with successive filtering iterations. <code>cooling.type</code> specifies the nature of the cooling schedule. When <code>cooling.type="geometric"</code> , on the $n$ -th MIF iteration, the relative perturbation intensity is <code>cooling.fraction<sup>(n/50)</sup></code> . When <code>cooling.type="hyperbolic"</code> , on the $n$ -th MIF iteration, the relative perturbation intensity is $(s+1)/(s+n)$ , where $(s+1)/(s+50)=\text{cooling.fraction}$ . <code>cooling.fraction</code> is the relative magnitude of the parameter perturbations after 50 MIF iterations. <code>cooling.factor</code> is now deprecated: to achieve the old behavior, use <code>cooling.type="geometric"</code> and <code>cooling.fraction=(cooling.factor)<sup>50</sup></code> .
<code>method</code>	<code>method</code> sets the update rule used in the algorithm. <code>method="mif"</code> uses the iterated filtering update rule (Ionides 2006, 2011); <code>method="unweighted"</code> updates the parameter to the unweighted average of the filtering means of the parameters at each time; <code>method="fp"</code> updates the parameter to the filtering mean at the end of the time series.
<code>tol</code>	See the description under <a href="#">pfilter</a> .
<code>max.fail</code>	See the description under <a href="#">pfilter</a> .
<code>verbose</code>	logical; if TRUE, print progress reports.

transform        logical; if TRUE, optimization is performed on the transformed scale.  
 ...              additional arguments that override the defaults.

### Re-running MIF Iterations

To re-run a sequence of MIF iterations, one can use the `mif` method on a `mif` object. By default, the same parameters used for the original MIF run are re-used (except for `weighted`, `tol`, `max.fail`, and `verbose`, the defaults of which are shown above). If one does specify additional arguments, these will override the defaults.

### Continuing MIF Iterations

One can resume a series of MIF iterations from where one left off using the `continue` method. A call to `mif` to perform  $N_{\text{mif}}=m$  iterations followed by a call to `continue` to perform  $N_{\text{mif}}=n$  iterations will produce precisely the same effect as a single call to `mif` to perform  $N_{\text{mif}}=m+n$  iterations. By default, all the algorithmic parameters are the same as used in the original call to `mif`. Additional arguments will override the defaults.

### Using MIF to estimate initial-value parameters only

One can use MIF's fixed-lag smoothing to estimate only initial value parameters (IVPs). In this case, `pars` is left empty and the IVPs to be estimated are named in `ivps`. If `theta` is the current parameter vector, then at each MIF iteration,  $N_p$  particles are drawn from a distribution centered at `theta` and with width proportional to `var.factor*rw.sd`, a particle filtering operation is performed, and `theta` is replaced by the filtering mean at `time(object)[ic.lag]`. Note the implication that, when `mif` is used in this way on a time series any longer than `ic.lag`, unnecessary work is done. If the time series in `object` is longer than `ic.lag`, consider replacing `object` with `window(object, end=ic.lag)`.

### Details

If `particles` is not specified, the default behavior is to draw the particles from a multivariate normal distribution. **It is the user's responsibility to ensure that, if the optional `particles` argument is given, that the `particles` function satisfies the following conditions:**

`particles` has at least the following arguments: `Np`, `center`, `sd`, and ... `Np` may be assumed to be a positive integer; `center` and `sd` will be named vectors of the same length. Additional arguments may be specified; these will be filled with the elements of the `userdata` slot of the underlying `pomp` object (see [pomp](#)).

`particles` returns a `length(center) x Np` matrix with rownames matching the names of `center` and `sd`. Each column represents a distinct particle.

The center of the particle distribution returned by `particles` should be `center`. The width of the particle distribution should vary monotonically with `sd`. In particular, when `sd=0`, the `particles` should return matrices with `Np` identical columns, each given by the parameters specified in `center`.

### Author(s)

Aaron A. King <kingaa at umich dot edu>

## References

- E. L. Ionides, C. Bret\'o, & A. A. King, Inference for nonlinear dynamical systems, *Proc. Natl. Acad. Sci. U.S.A.*, 103:18438–18443, 2006.
- E. L. Ionides, A. Bhadra, Y. Atchad\'e, & A. A. King, Iterated filtering, *Annals of Statistics*, 39:1776–1802, 2011.
- A. A. King, E. L. Ionides, M. Pascual, and M. J. Bouma, Inapparent infections and cholera dynamics, *Nature*, 454:877–880, 2008.

## See Also

[mif-methods](#), [pomp](#), [pfilter](#). See the “intro\_to\_pomp” vignette for examples.

---

mif-methods

*Methods of the "mif" class*


---

## Description

Methods of the mif class.

## Usage

```
## S4 method for signature mif
logLik(object, ...)
## S4 method for signature mif
conv.rec(object, pars, transform = FALSE, ...)
## S4 method for signature mifList
conv.rec(object, ...)
## S4 method for signature mif
plot(x, y, ...)
## S4 method for signature mifList
plot(x, y, ...)
## S4 method for signature mif
c(x, ..., recursive = FALSE)
## S4 method for signature mifList
c(x, ..., recursive = FALSE)
compare.mif(z)
```

## Arguments

object	The mif object.
pars	Names of parameters.
x	The mif object.
y, recursive	Ignored.
z	A mif object or list of mif objects.
transform	optional logical; should the parameter transformations be applied? See <a href="#">coef</a> for details.
...	Further arguments (either ignored or passed to underlying functions).

## Methods

**conv.rec** `conv.rec(object, pars = NULL)` returns the columns of the convergence-record matrix corresponding to the names in `pars`. By default, all rows are returned.

**logLik** Returns the value in the `loglik` slot.

**c** Concatenates `mif` objects into an `mifList`.

**plot** Plots a series of diagnostic plots.

**compare.mif** Deprecated: use `plot` instead.

## Author(s)

Aaron A. King <kingaa at umich dot edu>

## See Also

[mif](#), [pomp](#), [pfilter](#)

---

nlf

*Fit Model to Data Using Nonlinear Forecasting (NLF)*


---

## Description

Calls an optimizer to maximize the nonlinear forecasting (NLF) goodness of fit, by simulating data from a model, fitting a nonlinear autoregressive model to the simulated time series (which may be multivariate) and using the fitted model to predict some or all variables in the data time series. NLF is an ‘indirect inference’ method using a quasi-likelihood as the objective function.

## Usage

```
## S4 method for signature pomp
nlf(object, start, est, lags, period = NA, tensor = FALSE,
     nconverge=1000, nasymp=1000, seed = 1066,
     transform.data, nrbf = 4,
     method = c("subplex", "Nelder-Mead", "BFGS", "CG", "L-BFGS-B", "SANN", "Brent"),
     skip.se = FALSE, verbose = getOption("verbose"),
     bootstrap=FALSE, bootsamp = NULL,
     lql.frac = 0.1, se.par.frac = 0.1, eval.only = FALSE,
     transform.params = FALSE, transform, ...)
## S4 method for signature nlfd.pomp
nlf(object, start, est, lags, period, tensor,
     nconverge, nasymp, seed, transform.data, nrbf, method,
     lql.frac, se.par.frac, transform.params, ...)
```



**Arguments**

<code>object</code>	A pomp object, with the data and model to fit to it.
<code>start</code>	Named numeric vector with guessed parameters.
<code>est</code>	Vector containing the names or indices of parameters to be estimated.
<code>lags</code>	A vector specifying the lags to use when constructing the nonlinear autoregressive prediction model. The first lag is the prediction interval.
<code>period</code>	numeric; <code>period=NA</code> means the model is nonseasonal. <code>period&gt;0</code> is the period of seasonal forcing in 'real time'.
<code>tensor</code>	logical; if <code>FALSE</code> , the fitted model is a generalized additive model with time mod period as one of the predictors, i.e., a gam with time-varying intercept. If <code>TRUE</code> , the fitted model is a gam with lagged state variables as predictors and time-periodic coefficients, constructed using tensor products of basis functions of state variables with basis functions of time.
<code>nconverge</code>	Number of convergence timesteps to be discarded from the model simulation.
<code>nasymp</code>	Number of asymptotic timesteps to be recorded from the model simulation.
<code>seed</code>	Integer specifying the random number seed to use. When fitting, it is usually best to always run the simulations with the same sequence of random numbers, which is accomplished by setting <code>seed</code> to an integer. If you want a truly random simulation, set <code>seed=NULL</code> .
<code>transform.data, transform</code>	optional function. If specified, forecasting is performed using data and model simulations transformed by this function. By default, <code>transform.data</code> is the identity function, i.e., no transformation is performed. The main purpose of <code>transform.data</code> is to achieve approximately multivariate normal forecasting errors. If data are univariate, <code>transform.data</code> should take a scalar and return a scalar. If data are multivariate, <code>transform.data</code> should assume a vector input and return a vector of the same length.
<code>nrbf</code>	A scalar specifying the number of radial basis functions to be used at each lag.
<code>method</code>	Optimization method. Choices are <code>subplex</code> and any of the methods used by <code>optim</code> .
<code>skip.se</code>	Logical; if <code>TRUE</code> , skip the computation of standard errors.
<code>verbose</code>	Logical; if <code>TRUE</code> , the negative log quasiliikelihood and parameter values are printed at each iteration of the optimizer.
<code>bootstrap</code>	Logical; if <code>TRUE</code> the indices in <code>bootsamp</code> will determine which of the conditional likelihood values be used in computing the quasi-loglikelihood.
<code>bootsamp</code>	Vector of integers; used to have the quasi-loglikelihood evaluated using a bootstrap re-sampling of the data set.
<code>lql.frac</code>	target fractional change in log quasi-likelihood for quadratic standard error estimate
<code>se.par.frac</code>	initial parameter-change fraction for quadratic standard error estimate
<code>eval.only</code>	logical; if <code>TRUE</code> , no optimization is attempted and the quasi-loglikelihood value is evaluated at the start parameters.
<code>transform.params</code>	logical; if <code>TRUE</code> , parameters are optimized on the transformed scale.
<code>...</code>	Arguments that will be passed to <code>optim</code> or <code>subplex</code> in the control list.

## Details

This runs an optimizer to maximize `nlf.objfun`.

## Value

An object of class `nlf.d.pomp`. `logLik` applied to such an object returns the log quasi likelihood. The `$` method allows extraction of arbitrary slots from the `nlf.d.pomp` object.

## Author(s)

Stephen P. Ellner <spe2 at cornell dot edu>, Bruce E. Kendall <kendall at bren dot ucsb dot edu>, Aaron A. King <kingaa at umich dot edu>

## References

The following papers describe and motivate the NLF approach to model fitting:

Ellner, S. P., Bailey, B. A., Bobashev, G. V., Gallant, A. R., Grenfell, B. T. and Nychka D. W. (1998) Noise and nonlinearity in measles epidemics: combining mechanistic and statistical approaches to population modeling. *American Naturalist* **151**, 425–440.

Kendall, B. E., Briggs, C. J., Murdoch, W. W., Turchin, P., Ellner, S. P., McCauley, E., Nisbet, R. M. and Wood S. N. (1999) Why do populations cycle? A synthesis of statistical and mechanistic modeling approaches. *Ecology* **80**, 1789–1805.

Kendall, B. E., Ellner, S. P., McCauley, E., Wood, S. N., Briggs, C. J., Murdoch, W. W. and Turchin, P. (2005) Population cycles in the pine looper moth (*Bupalus piniarius*): dynamical tests of mechanistic hypotheses. *Ecological Monographs* **75**, 259–276.

---

ou2

---

Two-dimensional discrete-time Ornstein-Uhlenbeck process

---

## Description

ou2 is a pomp object encoding a bivariate discrete-time Ornstein-Uhlenbeck process.

## Details

If the state process is  $X(t) = (x_1(t), x_2(t))$ , then

$$X(t+1) = \alpha X(t) + \sigma \epsilon(t),$$

where  $\alpha$  and  $\sigma$  are 2x2 matrices,  $\sigma$  is lower-triangular, and  $\epsilon(t)$  is standard bivariate normal. The observation process is  $Y(t) = (y_1(t), y_2(t))$ , where  $y_i(t) \sim \text{normal}(x_i(t), \tau)$ . The functions `rprocess`, `dprocess`, `rmeasure`, `dmeasure`, and `skeleton` are implemented using compiled C code for computational speed: see the source code for details. This object is demonstrated in the vignette "Advanced topics in pomp".

**See Also**

[pomp](#) and the vignettes

**Examples**

```
pompExample(ou2)
plot(ou2)
coef(ou2)
x <- simulate(ou2)
plot(x)
pf <- pfilter(ou2,Np=1000)
logLik(pf)
```

---

parmat

*Create a matrix of parameters*


---

**Description**

parmat is a utility that makes a vector of parameters suitable for use in **pomp** functions.

**Usage**

```
parmat(params, nrep = 1)
```

**Arguments**

params	named numeric vector or matrix of parameters.
nrep	number of replicates (columns) desired.

**Value**

parmat returns a matrix consisting of nrep copies of params.

**Author(s)**

Aaron A. King <kingaa at umich dot edu>

**Examples**

```
## generate a bifurcation diagram for the Ricker map
pompExample(ricker)
p <- parmat(coef(ricker),nrep=500)
p["r",] <- exp(seq(from=1.5,to=4,length=500))
x <- trajectory(ricker,times=seq(from=1000,to=2000,by=1),params=p)
matplot(p["r",],x["N",,],pch=.,col=black,xlab="log(r)",ylab="N",log=x)
```

pfilter

*Particle filter***Description**

Run a plain vanilla particle filter. Resampling is performed at each observation.

**Usage**

```
## S4 method for signature pomp
pfilter(object, params, Np, tol = 1e-17,
        max.fail = Inf, pred.mean = FALSE, pred.var = FALSE,
        filter.mean = FALSE, save.states = FALSE,
        save.params = FALSE, seed = NULL,
        verbose = getOption("verbose"), ...)
## S4 method for signature pfilterd.pomp
pfilter(object, params, Np, tol, ...)
```

**Arguments**

object	An object of class <code>pomp</code> or inheriting class <code>pomp</code> .
params	A $n_{\text{pars}} \times N_p$ numeric matrix containing the parameters corresponding to the initial state values in <code>xstart</code> . This must have a ‘rownames’ attribute. If it desired that all particles should share the same parameter values, one may supply <code>params</code> as a named numeric vector.
Np	the number of particles to use. This may be specified as a single positive integer, in which case the same number of particles will be used at each timestep. Alternatively, if one wishes the number of particles to vary across timesteps, one may specify <code>Np</code> either as a vector of positive integers (of length <code>length(time(object, t0=TRUE))</code> ) or as a function taking a positive integer argument. In the latter case, <code>Np(k)</code> must be a single positive integer, representing the number of particles to be used at the $k$ -th timestep: <code>Np(0)</code> is the number of particles to use going from <code>timezero(object)</code> to <code>time(object)[1]</code> , <code>Np(1)</code> , from <code>timezero(object)</code> to <code>time(object)[1]</code> , and so on, while when <code>T=length(time(object, t0=TRUE))</code> , <code>Np(T)</code> is the number of particles to sample at the end of the time-series. When <code>object</code> is of class <code>mif</code> , this is by default the same number of particles used in the <code>mif</code> iterations.
tol	positive numeric scalar; particles with likelihood less than <code>tol</code> are considered to be “lost”. A filtering failure occurs when, at some time point, all particles are lost. When all particles are lost, the conditional likelihood at that time point is set to <code>tol</code> .
max.fail	integer; the maximum number of filtering failures allowed. If the number of filtering failures exceeds this number, execution will terminate with an error. By default, <code>max.fail</code> is set to infinity, so no error can be triggered.
pred.mean	logical; if <code>TRUE</code> , the prediction means are calculated for the state variables and parameters.

<code>pred.var</code>	logical; if TRUE, the prediction variances are calculated for the state variables and parameters.
<code>filter.mean</code>	logical; if TRUE, the filtering means are calculated for the state variables and parameters.
<code>save.states, save.params</code>	logical. If <code>save.states=TRUE</code> , the state-vector for each particle at each time is saved in the <code>saved.states</code> slot of the returned <code>pfilterd.pomp</code> object. If <code>save.params=TRUE</code> , the parameter-vector for each particle at each time is saved in the <code>saved.params</code> slot of the returned <code>pfilterd.pomp</code> object.
<code>seed</code>	optional; an object specifying if and how the random number generator should be initialized ('seeded'). If <code>seed</code> is an integer, it is passed to <code>set.seed</code> prior to any simulation and is returned as the "seed" element of the return list. By default, the state of the random number generator is not changed and the value of <code>.Random.seed</code> on the call is stored in the "seed" element of the return list.
<code>verbose</code>	logical; if TRUE, progress information is reported as <code>pfilter</code> works.
<code>...</code>	By default, when <code>pfilter</code> is run on a <code>pfilterd.pomp</code> object, the settings in the original call are re-used. This default behavior can be overridden by changing the settings (see Examples below).

## Value

An object of class `pfilterd.pomp`. This class inherits from class `pomp` and contains the following additional slots:

**pred.mean, pred.var, filter.mean** matrices of prediction means, variances, and filter means, respectively. In each of these, the rows correspond to states and parameters (if appropriate), in that order, the columns to successive observations in the time series contained in object.

**eff.sample.size** numeric vector containing the effective number of particles at each time point.

**cond.loglik** numeric vector containing the conditional log likelihoods at each time point.

**saved.states** If `pfilter` was called with `save.states=TRUE`, this is the list of state-vectors at each time point, for each particle. It is a length-`ntimes` list of `nvars`-by-`Np` arrays. In particular, `saved.states[[t]][,i]` can be considered a sample from  $f[X_t|y_{1:t}]$ .

**saved.params** If `pfilter` was called with `save.params=TRUE`, this is the list of parameter-vectors at each time point, for each particle. It is a length-`ntimes` list of `npars`-by-`Np` arrays. In particular, `saved.params[[t]][,i]` is the parameter portion of the *i*-th particle at time *t*.

**seed** the state of the random number generator at the time `pfilter` was called. If the argument `seed` was specified, this is a copy; if not, this is the internal state of the random number generator at the time of call.

**Np, tol, nfail** the number of particles used, failure tolerance, and number of filtering failures, respectively.

**loglik** the estimated log-likelihood.

These can be accessed using the `$` operator as if the returned object were a list. In addition, `logLik` returns the log likelihood. Note that if the argument `params` is a named vector, then these parameters are included in the `params` slot of the returned `pfilterd.pomp` object. That is `coef(pfilter(obj, params=theta))==theta` if `theta` is a named vector of parameters.

**Author(s)**

Aaron A. King <kingaa at umich dot edu>

**References**

M. S. Arulampalam, S. Maskell, N. Gordon, & T. Clapp. A Tutorial on Particle Filters for Online Nonlinear, Non-Gaussian Bayesian Tracking. IEEE Trans. Sig. Proc. 50:174–188, 2002.

**See Also**

[pomp](#), [mif](#), [pmcmc](#), [bsmc](#)

**Examples**

```
pompExample(gompertz)
pf <- pfilter(gompertz,Np=1000) ## use 1000 particles
logLik(pf)
cond.logLik(pf) ## conditional log-likelihoods
eff.sample.size(pf)
logLik(pfilter(gompertz))      ## run it again with 1000 particles
logLik(pfilter(gompertz,Np=2000)) ## run it with 2000 particles and get the filtering means

## See the vignettes for more examples.
```

---

pfilter-methods

*Methods of the "pfilterd.pomp" class*


---

**Description**

Methods of the "pfilterd.pomp" class.

**Usage**

```
## S4 method for signature pfilterd.pomp
logLik(object, ...)
## S4 method for signature pfilterd.pomp
pred.mean(object, pars, ...)
## S4 method for signature pfilterd.pomp
pred.var(object, pars, ...)
## S4 method for signature pfilterd.pomp
filter.mean(object, pars, ...)
## S4 method for signature pfilterd.pomp
eff.sample.size(object, ...)
## S4 method for signature pfilterd.pomp
cond.logLik(object, ...)
## S4 method for signature pfilterd.pomp
as(object, class)
## S4 method for signature pfilterd.pomp,data.frame
```

```
coerce(from, to = "data.frame", strict = TRUE)
## S3 method for class pfilterd.pomp
as.data.frame(x, row.names, optional, ...)
```

### Arguments

object, x	An object of class pfilterd.pomp or inheriting class pfilterd.pomp.
pars	Names of parameters.
class	character; name of the class to which object should be coerced.
from, to	the classes between which coercion should be performed.
strict	ignored.
row.names, optional	ignored.
...	Additional arguments unused at present.

### Author(s)

Aaron A. King <kingaa at umich dot edu>

### See Also

[pfilter, pomp-class](#)

---

plugins

*Plug-ins for dynamical models based on stochastic Euler algorithms*

---

### Description

Plug-in facilities for implementing discrete-time Markov processes and continuous-time Markov processes using the Euler algorithm. These can be used in the rprocess and dprocess slots of pomp.

### Usage

```
onestep.sim(step.fun, PACKAGE)
euler.sim(step.fun, delta.t, PACKAGE)
discrete.time.sim(step.fun, delta.t = 1, PACKAGE)
gillespie.sim(rate.fun, v, d, PACKAGE)
onestep.dens(dens.fun, PACKAGE)
```

## Arguments

<code>step.fun</code>	<p>This can be either an R function, a <a href="#">Csnippet</a>, or the name of a compiled, dynamically loaded native function containing the model simulator. It should be written to take a single Euler step from a single point in state space.</p> <p>If it is an R function, it should have prototype <code>step.fun(x, t, params, delta.t, ...)</code>. Here, <code>x</code> is a named numeric vector containing the value of the state process at time <code>t</code>, <code>params</code> is a named numeric vector containing parameters, and <code>delta.t</code> is the length of the Euler time-step.</p> <p>For examples on the use of <a href="#">Csnippet</a> to write fast simulators easily, see the “Introduction to <b>pomp</b>” tutorial vignette, available on the <a href="#">package website</a>.</p> <p>If <code>step.fun</code> is the name of a native function, it must be of type “<code>pomp_onestep_sim</code>” as defined in the header “<code>pomp.h</code>”, which is included with the <b>pomp</b> package. For details on how to write such codes, see Details.</p>
<code>rate.fun</code>	<p>This can be either an R function, a <a href="#">Csnippet</a>, or the name of a compiled, dynamically loaded native function that computes the transition rates. If it is an R function, it should be of the form <code>rate.fun(j, x, t, params, ...)</code>. Here, <code>j</code> is the number of the event, <code>x</code> is a named numeric vector containing the value of the state process at time <code>t</code> and <code>params</code> is a named numeric vector containing parameters.</p> <p>For examples on the use of <a href="#">Csnippet</a> to write fast simulators easily, see the “Introduction to <b>pomp</b>” tutorial vignette, available on the <a href="#">package website</a>.</p> <p>If <code>rate.fun</code> is a native function, it must be of type “<code>pomp_ssa_rate_fn</code>” as defined in the header “<code>pomp.h</code>”, which is included with the package. For details on how to write such codes, see Details.</p>
<code>v, d</code>	<p>Matrices that specify the continuous-time Markov process in terms of its elementary events. Each should have dimensions <code>nvar</code> x <code>nevent</code>, where <code>nvar</code> is the number of state variables and <code>nevent</code> is the number of elementary events. <code>v</code> describes the changes that occur in each elementary event: it will usually comprise the values 1, -1, and 0 according to whether a state variable is incremented, decremented, or unchanged in an elementary event. <code>d</code> is a binary matrix that describes the dependencies of elementary event rates on state variables: <code>d[i, j]</code> will have value 1 if event rate <code>j</code> must be updated as a result of a change in state variable <code>i</code> and 0 otherwise.</p>
<code>dens.fun</code>	<p>This can be either an R function, a <a href="#">Csnippet</a>, or a compiled, dynamically loaded native function containing the model transition log probability density function.</p> <p>If it is an R function, it should be of the form <code>dens.fun(x1, x2, t1, t2, params, ...)</code>. Here, <code>x1</code> and <code>x2</code> are named numeric vectors containing the values of the state process at times <code>t1</code> and <code>t2</code>, <code>params</code> is a named numeric vector containing parameters.</p> <p>If <code>dens.fun</code> is the name of a native function, it should be of type “<code>pomp_onestep_pdf</code>” as defined in the header “<code>pomp.h</code>”, which is included with the <b>pomp</b> package. This function should return the log likelihood of a transition from <code>x1</code> at time <code>t1</code> to <code>x2</code> at time <code>t2</code>, assuming that no intervening transitions have occurred. For details on how to write such codes, see Details.</p>
<code>delta.t</code>	<p>Size of Euler time-steps.</p>



`PACKAGE` an optional argument that specifies to which dynamically loaded library we restrict the search for the native routines. If this is “base”, we search in the R executable itself. This argument is ignored if `step.fun`, `rate.fn`, or `dens.fun` is provided as an R function or a [Csnippet](#).

## Details

`onestep.sim` is the appropriate choice when it is possible to simulate the change in state from one time to another, regardless of how large the interval between them is. To use `onestep.sim`, you must write a function `step.fun` that will advance the state process from one arbitrary time to another. `euler.sim` is appropriate when one cannot do this but can compute the change in state via a sequence of smaller steps. This is desirable, for example, if one is simulating a continuous time process but is willing to approximate it using an Euler approach. `discrete.time.sim` is appropriate when the process evolves in discrete time. In this case, by default, the intervals between observations are integers.

To use `euler.sim` or `discrete.time.sim`, you must write a function `step.fun` that will take a single Euler step, of size at most `delta.t`. `euler.sim` and `discrete.time.sim` will create simulators that take as many steps as needed to get from one time to another. See below for information on how `euler.sim` chooses the actual step size it uses.

`gillespie.sim` allows exact simulation of a continuous-time, discrete-state Markov process using Gillespie’s algorithm. This is an “event-driven” approach: correspondingly, to use `gillespie.sim`, you must write a function `rate.fun` that computes the rates of each elementary event and specify two matrices (`d`, `v`) that describe, respectively, the dependencies of each rate and the consequences of each event.

`onestep.dens` will generate a suitable `dprocess` function when one can compute the likelihood of a given state transition simply by knowing the states at two times under the assumption that the state has not changed between the times. This is typically possible, for instance, when the `rprocess` function is implemented using `onestep.sim`, `euler.sim`, or `discrete.time.sim`. [NB: currently, there are no high-level algorithms in **pomp** that use `dprocess`. This function is provided for completeness only, and with an eye toward future development.]

If `step.fun` is written as an R function, it must have at least the arguments `x`, `t`, `params`, `delta.t`, and `...`. On a call to this function, `x` will be a named vector of state variables, `t` a scalar time, and `params` a named vector of parameters. The length of the Euler step will be `delta.t`. If the argument `covars` is included and a covariate table has been included in the `pomp` object, then on a call to this function, `covars` will be filled with the values, at time `t`, of the covariates. This is accomplished via interpolation of the covariate table. Additional arguments may be given: these will be filled by the correspondingly-named elements in the `userdata` slot of the `pomp` object (see [pomp](#)). If `step.fun` is written in a native language, it must be a function of type “`pomp_onestep_sim`” as specified in the header “`pomp.h`” included with the package (see the directory “`include`” in the installed package directory).

If `rate.fun` is written as an R function, it must have at least the arguments `j`, `x`, `t`, `params`, and `...`. Here, `j` is the an integer that indicates which specific elementary event we desire the rate of. `x` is a named vector containing the value of the state process at time `t`, and `params` is a named vector containing parameters. If the argument `covars` is included and a covariate table has been included in the `pomp` object, then on a call to this function, `covars` will be filled with the values, at time `t`, of the covariates. This is accomplished via interpolation of the covariate table. If `rate.fun` is a

native function, it must be of type “pomp\_ssa\_rate\_fn” as defined in the header “pomp.h”, which is included with the package.

In writing `dens.fun`, you must assume that no state transitions have occurred between `t1` and `t2`. If `dens.fun` is written as an R function, it must have at least the arguments `x1`, `x2`, `t1`, `t2`, `params`, and `...`. On a call to this function, `x1` and `x2` will be named vectors of state variables at times `t1` and `t2`, respectively. The named vector `params` contains the parameters. If the argument `covars` is included and a covariate table has been included in the `pomp` object, then on a call to this function, `covars` will be filled with the values, at time `t1`, of the covariates. If the argument `covars` is included and a covariate table has been included in the `pomp` object, then on a call to this function, `covars` will be filled with the values, at time `t1`, of the covariates. This is accomplished via interpolation of the covariate table. As above, any additional arguments will be filled by the correspondingly-named elements in the `userdata` slot of the `pomp` object (see [pomp](#)). If `dens.fun` is written in a native language, it must be a function of type “pomp\_onestep\_pdf” as defined in the header “pomp.h” included with the package (see the directory “include” in the installed package directory).

## Value

`onestep.sim`, `euler.sim`, `discrete.time.sim`, and `gillespie.sim` each return functions suitable for use as the argument `rprocess` argument in [pomp](#).

`onestep.dens` returns a function suitable for use as the argument `dprocess` in [pomp](#).

## Author(s)

Aaron A. King <kingaa at umich dot edu>

## See Also

[eulermultinom](#), [pomp](#)

## Examples

```
## examples showing how to use these functions
## are provided in the "intro_to_pomp" vignette
```

---

pmcmc

*The PMCMC algorithm*

---

## Description

The Particle MCMC algorithm for estimating the parameters of a partially-observed Markov process.

**Usage**

```
## S4 method for signature pomp
pmcmc(object, Npmcmc = 1, start, pars, rw.sd, Np,
      tol = 1e-17, max.fail = 0, verbose = getOption("verbose"), ...)
## S4 method for signature pfilterd.pomp
pmcmc(object, Npmcmc = 1, Np, tol, ...)
## S4 method for signature pmcmc
pmcmc(object, Npmcmc, start, pars, rw.sd, Np,
      tol, max.fail = 0, verbose = getOption("verbose"), ...)
## S4 method for signature pmcmc
continue(object, Npmcmc = 1, ...)
```

**Arguments**

<code>object</code>	An object of class <code>pomp</code> .
<code>Npmcmc</code>	The number of PMCMC iterations to perform.
<code>start</code>	named numeric vector; the starting guess of the parameters.
<code>pars</code>	optional character vector naming the ordinary parameters to be estimated. Every parameter named in <code>pars</code> must have a positive random-walk standard deviation specified in <code>rw.sd</code> . Leaving <code>pars</code> unspecified is equivalent to setting it equal to the names of all parameters with a positive value of <code>rw.sd</code> .
<code>rw.sd</code>	numeric vector with names; used to parameterize a Gaussian random walk MCMC proposal. The random walk is only applied to parameters named in <code>pars</code> . The algorithm requires that the random walk be nontrivial, so each element in <code>rw.sd[pars]</code> must be positive. The following must be satisfied: <code>names(rw.sd)</code> must be a subset of <code>names(start)</code> , <code>rw.sd</code> must be non-negative (zeros are simply ignored), the name of every positive element of <code>rw.sd</code> must be in <code>pars</code> .
<code>Np</code>	a positive integer; the number of particles to use in each filtering operation.
<code>tol</code>	numeric scalar; particles with log likelihood below <code>tol</code> are considered to be “lost”. A filtering failure occurs when, at some time point, all particles are lost.
<code>max.fail</code>	integer; maximum number of filtering failures permitted. If the number of failures exceeds this number, execution will terminate with an error.
<code>verbose</code>	logical; if TRUE, print progress reports.
<code>...</code>	Additional arguments. These are currently ignored.

**Value**

An object of class `pmcmc`.

**Re-running PMCMC Iterations**

To re-run a sequence of PMCMC iterations, one can use the `pmcmc` method on a `pmcmc` object. By default, the same parameters used for the original PMCMC run are re-used (except for `tol`, `max.fail`, and `verbose`, the defaults of which are shown above). If one does specify additional arguments, these will override the defaults.

## Continuing PMCMC Iterations

One can continue a series of PMCMC iterations from where one left off using the `continue` method. A call to `pmcmc` to perform  $N_{\text{mcmc}}=m$  iterations followed by a call to `continue` to perform  $N_{\text{mcmc}}=n$  iterations will produce precisely the same effect as a single call to `pmcmc` to perform  $N_{\text{mcmc}}=m+n$  iterations. By default, all the algorithmic parameters are the same as used in the original call to `pmcmc`. Additional arguments will override the defaults.

## Details

`pmcmc` implements an MCMC algorithm in which the true likelihood of the data is replaced by an unbiased estimate computed by a particle filter. This gives an asymptotically correct Bayesian procedure for parameter estimation (Andrieu and Roberts, 2009). An extension to give a correct Bayesian posterior distribution of unobserved state variables (as in Andrieu et al, 2010) has not yet been implemented.

## Author(s)

Edward L. Ionides <ionides at umich dot edu>, Aaron A. King <kingaa at umich dot edu>

## References

C. Andrieu, A. Doucet and R. Holenstein, Particle Markov chain Monte Carlo methods, J. R. Stat. Soc. B, to appear, 2010.  
C. Andrieu and G.O. Roberts, The pseudo-marginal approach for efficient computation, Ann. Stat. 37:697-725, 2009.

## See Also

[pmcmc-class](#), [pmcmc-methods](#), [pomp](#), [pomp-class](#), [pfilter](#).

---

pmcmc-methods

*Methods of the "pmcmc" class*

---

## Description

Methods of the "pmcmc" class.

## Usage

```
## S4 method for signature pmcmc
logLik(object, ...)
## S4 method for signature pmcmc
conv.rec(object, pars, ...)
## S4 method for signature pmcmcList
conv.rec(object, ...)
## S4 method for signature pmcmc
plot(x, y, ...)
```

```
## S4 method for signature pmcmcList
plot(x, y, ...)
## S4 method for signature pmcmc
c(x, ..., recursive = FALSE)
## S4 method for signature pmcmcList
c(x, ..., recursive = FALSE)
```

### Arguments

<code>object, x</code>	The pmcmc or pmcmcList object.
<code>pars</code>	Names of parameters.
<code>y, recursive</code>	Ignored.
<code>...</code>	Further arguments (either ignored or passed to underlying functions).

### Methods

**conv.rec** `conv.rec(object, pars)` returns the columns of the convergence-record matrix corresponding to the names in `pars` as an object of class `mcmc` or `mcmc.list`.

**plot** Diagnostic plots.

**logLik** Returns the value in the loglik slot.

**c** Concatenates pmcmc objects into a pmcmcList.

### Author(s)

Edward L. Ionides <ionides at umich dot edu>, Aaron A. King <kingaa at umich dot edu>

### References

C. Andrieu, A. Doucet and R. Holenstein, Particle Markov chain Monte Carlo methods, J. Roy. Stat. Soc B, to appear, 2010.

C. Andrieu and G.O. Roberts, The pseudo-marginal approach for efficient computation, Ann Stat 37:697-725, 2009.

### See Also

[pmcmc](#), [pomp](#), [pomp-class](#), [pfilter](#)

---

pomp

*Partially-observed Markov process object.*

---

### Description

This function creates a pomp object, encoding a partially-observed Markov process model together with a uni- or multi-variate time series.

## Usage

```
## S4 method for signature data.frame
pomp(data, times, t0, ..., rprocess, dprocess, rmeasure, dmeasure,
      measurement.model,
      skeleton, skeleton.type = c("map", "vectorfield"), skelmap.delta.t = 1,
      initializer, rprior, dprior, params, covar, tcovar,
      obsnames, statenames, paramnames, covarnames, zeronames,
      PACKAGE, parameter.transform, parameter.inv.transform, globals)

## S4 method for signature numeric
pomp(data, times, t0, ..., rprocess, dprocess, rmeasure, dmeasure,
      measurement.model,
      skeleton, skeleton.type = c("map", "vectorfield"), skelmap.delta.t = 1,
      initializer, rprior, dprior, params, covar, tcovar,
      obsnames, statenames, paramnames, covarnames, zeronames,
      PACKAGE, parameter.transform, parameter.inv.transform, globals)

## S4 method for signature matrix
pomp(data, times, t0, ..., rprocess, dprocess, rmeasure, dmeasure,
      measurement.model,
      skeleton, skeleton.type = c("map", "vectorfield"), skelmap.delta.t = 1,
      initializer, rprior, dprior, params, covar, tcovar,
      obsnames, statenames, paramnames, covarnames, zeronames,
      PACKAGE, parameter.transform, parameter.inv.transform, globals)

## S4 method for signature pomp
pomp(data, times, t0, ..., rprocess, dprocess, rmeasure, dmeasure,
      measurement.model, skeleton, skeleton.type, skelmap.delta.t,
      initializer, rprior, dprior, params, covar, tcovar,
      obsnames, statenames, paramnames, covarnames, zeronames,
      PACKAGE, parameter.transform, parameter.inv.transform, globals)
```

## Arguments

<code>data, times</code>	<p>The time series data and times at which observations are made. <code>data</code> can be specified as a vector, a matrix, a data-frame, or a <code>pomp</code> object.</p> <p>If <code>data</code> is a numeric vector, <code>times</code> must be a numeric vector of the same length.</p> <p>If <code>data</code> is a matrix, it should have dimensions <code>nobs</code> x <code>ntimes</code>, where <code>nobs</code> is the number of observed variables and <code>ntimes</code> is the number of times at which observations were made (i.e., each column is a distinct observation of the <code>nobs</code> variables). In this case, <code>times</code> must be given as a numeric vector (of length <code>ntimes</code>).</p> <p>If <code>data</code> is a data-frame, <code>times</code> must name the column of observation times. Note that, in this case, <code>data</code> will be internally coerced to an array with storage-mode ‘double’. Note that the <code>times</code> must be numeric and strictly increasing.</p>
<code>t0</code>	<p>The zero-time: the stochastic dynamical system is initialized at time <code>t0</code>. This must be no later than the time of the first observation, i.e., <code>t0 &lt;= times[1]</code>.</p>
<code>rprocess</code>	<p>optional function; a function of prototype</p> <pre>rprocess(xstart, times, params, ...)</pre>

that simulates from the unobserved process. The easiest way to specify `rprocess` is to use one of the [plugins](#) provided as part of the **pomp** package. See below for details.

`dprocess` optional function; a function of prototype

```
dprocess(x, times, params, log, ...)
```

that evaluates the likelihood of a sequence of consecutive state transitions. The easiest way to specify `dprocess` is to use one of the [plugins](#) provided as part of the **pomp** package. It is not typically necessary (or even feasible) to define `dprocess`. See below for details.

`rmeasure` optional; the measurement model simulator. This can be specified in one of four ways: (1) as a function of prototype

```
rmeasure(x, t, params, ...)
```

that makes a draw from the observation process given states `x`, time `t`, and parameters `params`. (2) as a snippet of C code (via [Csnippet](#)) that draws from the observation process as above. (3) as the name of a native (compiled) routine with prototype “`pomp_measure_model_simulator`” as defined in the header file “`pomp.h`”. In the above cases, if the measurement model depends on covariates, the optional argument `covars` will be filled with interpolated values at each call. (4) using the formula-based `measurement.model` facility (see below).

`dmeasure` optional; the measurement model probability density function. This can be specified in one of four ways: (1) as a function of prototype

```
dmeasure(y, x, t, params, log, ...)
```

that computes the p.d.f. of `y` given `x`, `t`, and `params`. (2) as a snippet of C code (via [Csnippet](#)) that computes the p.d.f. as above. (3) as the name of a native (compiled) routine with prototype “`pomp_measure_model_density`” as defined in the header file “`pomp.h`”. In the above cases, if the measurement model depends on covariates, the optional argument `covars` will be filled with interpolated values at each call. (4) using the formula-based `measurement.model` facility (see below). As might be expected, if `log=TRUE`, this function should return the log likelihood.

`measurement.model`

optional; a formula or list of formulae, specifying the measurement model. These formulae are parsed internally to generate `rmeasure` and `dmeasure` functions. If `measurement.model` is given it overrides any specification of `rmeasure` or `dmeasure`. **NB:** This is a convenience function, primarily designed to facilitate exploration; it will typically be possible to accelerate measurement model computations by writing `dmeasure` and/or `rmeasure` functions directly.

`skeleton`, `skeleton.type`, `skelmap.delta.t`

The function `skeleton` specifies the deterministic skeleton of the unobserved Markov process. If we are dealing with a discrete-time Markov process, its deterministic skeleton is a map: indicate this by specifying `skeleton.type="map"`. If we are dealing with a continuous-time Markov process, its deterministic skeleton is a vectorfield: indicate this by specifying `skeleton.type="vectorfield"`. The skeleton function can be specified in one of three ways: (1) as an R function of prototype

	<code>skeleton(x,t,params,...)</code> that evaluates the deterministic skeleton at state $x$ and time $t$ given the parameters <code>params</code> , (2) as a snippet of C code (via <a href="#">Csnippet</a> ) that performs this evaluation, or (3) as the name of a native (compiled) routine with prototype “ <code>pomp_skeleton</code> ” as defined in the header file “ <code>pomp.h</code> ”. If the deterministic skeleton depends on covariates, the optional argument <code>covars</code> will be filled with interpolated values of the covariates at the time $t$ . With a discrete-time skeleton, the default assumption is that time advances 1 unit per iteration of the map; to change this, set <code>skelmap.delta.t</code> to the appropriate time-step.
<code>initializer</code>	optional function of prototype <code>initializer(params,t0,...)</code> that yields initial conditions for the state process when given a vector, <code>params</code> , of parameters. By default (i.e., if it is unspecified when <code>pomp</code> is called), the initializer assumes any parameters in <code>params</code> the names of which end in “.0” are initial values. These are simply copied over as initial conditions when <code>init.state</code> is called (see <a href="#">init.state-pomp</a> ). The names of the state variables are the same as the corresponding initial value parameters, but with the “.0” dropped.
<code>rprior</code>	optional; function drawing a sample from a prior distribution on parameters. This can be specified in one of three ways: (1) as an R function of prototype <code>rprior(params,...)</code> that makes a draw from the prior distribution given <code>params</code> , (2) as a snippet of C code (via <a href="#">Csnippet</a> ) that draws from the prior, or (3) as the name of a native (compiled) routine with prototype “ <code>pomp_rprior</code> ” as defined in the header file “ <code>pomp.h</code> ”.
<code>dprior</code>	optional; function evaluating the prior distribution. This can be specified in one of three ways: (1) as an R function of prototype <code>dprior(params,log=FALSE,...)</code> that evaluates the prior probability density, (2) as a snippet of C code (via <a href="#">Csnippet</a> ) that computes this p.d.f., (3) as the name of a native (compiled) routine with prototype “ <code>pomp_dprior</code> ” as defined in the header file “ <code>pomp.h</code> ”.
<code>params</code>	optional named numeric vector of parameters. This will be coerced internally to storage mode <code>double</code> .
<code>covar, tcovar</code>	An optional table of covariates: <code>covar</code> is the table (one column per variable); <code>tcovar</code> the corresponding times (one entry per row of <code>covar</code> ). <code>covar</code> can be specified as either a matrix or a data frame. In either case the columns are taken to be distinct covariates. If <code>covar</code> is a data frame, <code>tcovar</code> can be either the name or the index of the time variable. If a covariate table is supplied, then the value of each of the covariates is interpolated as needed, i.e., whenever <code>rprocess</code> , <code>dprocess</code> , <code>rmeasure</code> , <code>dmeasure</code> , <code>skeleton</code> , <code>rprior</code> , <code>dprior</code> , or <code>init.state</code> is evaluated. The resulting interpolated values are passed to the corresponding functions as a numeric vector named <code>covars</code> .



obsnames, statenames, paramnames, covarnames

Optional character vectors specifying the names of observables, state variables, parameters, and covariates, respectively. These are only used in the event that one or more of the basic functions (`rprocess`, `dprocess`, `rmeasure`, `dmeasure`, `skeleton`, `rprior`, `dprior`) are defined using [Csnippet](#) or native routines. In these cases, these name vectors are matched against the corresponding names and the indices of the names are passed to the native routines. These vectors should list the parameters in the order that the native code expects them. Using this facility allows one to write one or more of the basic functions in native code in a way that does not depend on the order of states, parameters, and covariates at run time. See the “Advanced topics in pomp” vignette for more on this topic, including examples.

zernames      Optional character vector specifying the names of accumulator variables. See the “Advanced topics in pomp” vignette for a discussion of accumulator variables.

PACKAGE      An optional string giving the name of the dynamically loaded library in which any native routines are to be found.

`parameter.transform`, `parameter.inv.transform`

Optional functions specifying parameter transformations. These functions must have arguments `params` and `...`. `parameter.transform` should transform parameters from the user’s scale to the scale that `rprocess`, `dprocess`, `rmeasure`, `dmeasure`, `skeleton`, and `initializer` will use internally. `parameter.inv.transform` should be the inverse of `parameter.transform`. The parameter transformations can be defined (as in the case of `rmeasure`, `dmeasure`, `skeleton`, `rprior`, `dprior` above) using R functions, [Csnippets](#), or native routines. Note that it is the user’s responsibility to make sure this holds. If `obj` is the constructed pomp object, and `coef(obj)` is non-empty, a simple check of this is

```
x <- coef(obj, transform=TRUE)
obj1 <- obj
coef(obj1, transform=TRUE) <- x
identical(coef(obj), coef(obj1))
identical(coef(obj1, transform=TRUE), x).
```

By default, both functions are the identity transformation. See the “introduction\_to\_pomp” vignette for an example.

globals      optional character; C code that will be included in the source for (and therefore hard-coded into) the shared-object library created when the call to `pomp` uses [Csnippets](#). If no [Csnippets](#) are used, `globals` has no effect.

...      Any additional arguments given to `pomp` will be stored in the [pomp](#) object and passed as arguments to each of the basic functions whenever they are evaluated.

## Details

**It is not typically necessary (or even feasible) to define all of the functions `rprocess`, `dprocess`, `rmeasure`, `dmeasure`, and `skeleton` in any given problem. Each algorithm makes use of a different subset of these functions.** Specification of process-model codes `rprocess` and/or

dprocess in most cases is facilitated by so-called [plugins](#) that have been developed to handle common use-cases. Currently, if one's process model evolves in discrete time or one is willing to make such an approximation (e.g., via an Euler approximation), then the [euler.sim](#), [discrete.time.sim](#), or [onestep.sim](#) plugin for rprocess and [onestep.dens](#) plugin for dprocess are available. For exact simulation of certain continuous-time Markov chains, an implementation of Gillespie's algorithm is available (see [gillespie.sim](#)). To use the plugins, consult the help documentation ([?plugins](#)) and the vignettes.

In specific cases, it may be possible to obtain increased computational efficiency by writing custom versions of rprocess and/or dprocess. See the "Advanced topics in pomp" vignette for a discussion of this. If such custom versions are desired, the following describes how each of these functions should be written in this case.

**rprocess** If the plugins are not used rprocess must have at least the following arguments: `xstart`, `times`, `params`, and `...`. It can also take additional arguments. It is guaranteed that these will be filled with the corresponding elements the user has included as additional arguments in the construction of the pomp object.

In calls to rprocess, `xstart` can be assumed to be a rank-2 array (matrix) with rows corresponding to state variables and columns corresponding to independent realizations of the process. `params` will similarly be a rank-2 array with rows corresponding to parameters and columns corresponding to independent realizations. The columns of `params` correspond to those of `xstart`; in particular, they will agree in number. Both `xstart` and `params` will have rownames, which are available for use by the user.

rprocess must return a rank-3 array with rownames. Suppose `x` is the array returned. Then `dim(x)=c(nvars,nreps,ntimes)`, where `nvars` (`=nrow(xstart)`) is the number of state variables, `nreps` (`=ncol(xstart)`) is the number of independent realizations simulated, and `ntimes` is the length of the vector `times`. `x[,j,k]` is the value of the state process in the `j`-th realization at time `times[k]`. In particular, `x[, ,1]` must be identical to `xstart`. The rownames of `x` must correspond to those of `xstart`.

**dprocess** If the plugins are not used, dprocess must have at least the following arguments: `x`, `times`, `params`, `log`, and `...`. It may take additional arguments. It is guaranteed that these will be filled with the corresponding elements the user has included as additional arguments in the construction of the pomp object.

In calls to dprocess, `x` may be assumed to be an `nvars x nreps x ntimes` array, where these terms have the same meanings as above. `params` will be a rank-2 array with rows corresponding to individual parameters and columns corresponding to independent realizations. The columns of `params` correspond to those of `x`; in particular, they will agree in number. Both `x` and `params` will have rownames, available for use by the user.

dprocess must return a rank-2 array (matrix). Suppose `d` is the array returned. Then `dim(d)=c(nreps,ntimes-1)`. `d[j,k]` is the probability density of the transition from state `x[,j,k-1]` at time `times[k-1]` to state `x[,j,k]` at time `times[k]`. If `log=TRUE`, then the log of the pdf is returned.

**In writing this function, you may assume that the transitions are consecutive.** It should be quite clear that, but for this assumption, it would be quite difficult in general to write the transition probabilities. In fact, from one perspective, the algorithms in **pomp** are designed to overcome just this difficulty.

**At present, no methods in pomp make use of dprocess.**

The following is a guide to writing the measurement-model, deterministic skeleton, and initializer components.

- rmeasure** if provided, must take at least the arguments `x`, `t`, `params`, and `...`. It may take additional arguments, which will be filled with user-specified data as above. `x` may be assumed to be a named numeric vector of length `nvars`, (which has the same meanings as above). `t` is a scalar quantity, the time at which the measurement is made. `params` may be assumed to be a named numeric vector of length `nparams`.
- rmeasure** must return a named numeric vector. If `y` is the returned vector, then `length(y)=nobs`, where `nobs` is the number of observable variables.
- dmeasure** if provided, must take at least the arguments `y`, `x`, `t`, `params`, `log`, and `...`. `y` may be assumed to be a named numeric vector of length `nobs` containing (actual or simulated) values of the observed variables; `x` will be a named numeric vector of length `nvar` containing state variables `params`, a named numeric vector containing parameters; and `t`, a scalar, the corresponding observation time. It may take additional arguments which will be filled with user-specified data as above. **dmeasure** must return a single numeric value, the pdf of `y` given `x` at time `t`. If `log=TRUE`, then the log of the pdf is returned.
- skeleton** If **skeleton** is an R function, it must have at least the arguments `x`, `t`, `params`, and `...`. `x` is a numeric vector containing the coordinates of a point in state space at which evaluation of the skeleton is desired. `t` is a numeric value giving the time at which evaluation of the skeleton is desired. Of course, these will be irrelevant in the case of an autonomous skeleton. `params` is a numeric vector holding the parameters. The optional argument `covars` is a numeric vector containing the values of the covariates at the time `t`. `covars` will have one value for each column of the covariate table specified when the **pomp** object was created. `covars` is constructed from the covariate table (see `covar`, below) by interpolation. **skeleton** may take additional arguments, which will be filled, as above, with user-specified data. **skeleton** must return a numeric vector of the same length as `x`. The return value is interpreted as the vectorfield (if the dynamical system is continuous) or the value of the map (if the dynamical system is discrete), at the point `x` at time `t`.
- If **skeleton** is the name of a native routine, this routine must be of prototype “**pomp\_skeleton**” as defined in the header “**pomp.h**” (see the “include” directory in the installed package directory).
- initializer** if provided, must have at least the arguments `params`, `t0`, and `...`. `params` is a named numeric vector of parameters. `t0` will be the time at which initial conditions are desired. **initializer** must return a named numeric vector of initial states.

## Value

An object of class **pomp**. If `data` is an object of class **pomp**, then by default the returned **pomp** object is identical to `data`. If additional arguments are given, these override the defaults.

## Warning

Some error checking is done by **pomp**, but complete error checking is impossible. If the user-specified functions do not conform to the above specifications (see Details), then the results may be invalid. In particular, if both **rmeasure** and **dmeasure** are specified, the user should verify that these two functions correspond to the same probability distribution and if **skeleton** is specified, the user is responsible for verifying that it corresponds to the true deterministic skeleton of the model. Each **pomp**-package algorithm uses some subset of the five basic functions (**rprocess**, **dprocess**, **rmeasure**, **dmeasure**, **skeleton**). If an algorithm requires a component that has not been specified, an informative error will be generated.

**Author(s)**

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**See Also**

[pomp-methods](#), [plugins](#), [time](#), [time<-](#), [timezero](#), [timezero<-](#), [coef](#), [coef<-](#), [obs](#), [states](#), [window](#), [as.data.frame.pomp](#)

**Examples**

```
## For examples, see the "Introduction to pomp"
## and "Advanced topics in pomp" documents,
## the demos, and the examples provided with the package, e.g.:
## Not run:
pompExample()
pomp.home <- system.file("examples",package="pomp")
pomp.examples <- list.files(pomp.home)
file.show(
  file.path(pomp.home,pomp.examples),
  header=paste("=====",pomp.examples,"=====")
)

## End(Not run)
```

---

pomp-methods

*Methods of the "pomp" class*


---

**Description**

Methods of the pomp class.

**Usage**

```
## S3 method for class pomp
as.data.frame(x, row.names, optional, ...)
## S4 method for signature pomp
coef(object, pars, transform = FALSE, ...)
## S4 replacement method for signature pomp
coef(object, pars, transform = FALSE, ...) <- value
## S4 method for signature pomp
obs(object, vars, ...)
## S4 method for signature pomp
data.array(object, vars, ...)
## S4 method for signature pomp
partrans(object, params, dir = c("forward","inverse"), ...)
## S4 method for signature pomp
plot(x, y, variables, panel = lines,
      nc = NULL, yax.flip = FALSE,
```

```

        mar = c(0, 5.1, 0, if (yax.flip) 5.1 else 2.1),
        oma = c(6, 0, 5, 0), axes = TRUE, ...)
## S4 method for signature pomp
print(x, ...)
## S4 method for signature pomp
show(object)
## S4 method for signature pomp
states(object, vars, ...)
## S4 method for signature pomp
time(x, t0 = FALSE, ...)
## S4 replacement method for signature pomp
time(object, t0 = FALSE, ...) <- value
## S4 method for signature pomp
timezero(object, ...)
## S4 replacement method for signature pomp
timezero(object, ...) <- value
## S4 method for signature pomp
window(x, start, end, ...)
## S4 method for signature pomp
as(object, class)
## S4 method for signature pomp,data.frame
coerce(from, to = "data.frame", strict = TRUE)

```

## Arguments

<code>object, x</code>	The pomp object.
<code>pars</code>	optional character; names of parameters to be retrieved or set.
<code>vars</code>	optional character; names of observed variables to be retrieved.
<code>transform</code>	optional logical; should the parameter transformations be applied?
<code>value</code>	numeric; values to be assigned.
<code>params</code>	a vector or matrix of parameters to be transformed.
<code>dir</code>	direction of the transformation. <code>dir="forward"</code> applies the transformation from the “natural” scale to the “internal” scale. This is the transformation specified by the <code>parameter.transform</code> argument to <code>pomp</code> ; it is stored in the <code>‘par.trans’</code> slot of object. <code>dir="inverse"</code> applies the inverse transformation (stored in the <code>‘par.untrans’</code> slot).
<code>t0</code>	logical; if TRUE on a call to <code>time</code> , the zero time is prepended to the time vector; if TRUE on a call to <code>time&lt;-</code> , the first element in <code>value</code> is taken to be the initial time.
<code>start, end</code>	start and end times of the window.
<code>class</code>	character; name of the class to which object should be coerced.
<code>from, to</code>	the classes between which coercion should be performed.
<code>strict</code>	ignored.
<code>y</code>	ignored.
<code>variables</code>	optional character; names of variables to plot.

<code>panel</code>	a function of prototype <code>panel(x, col, bg, pch, type, ...)</code> which gives the action to be carried out in each panel of the display.
<code>nc</code>	the number of columns to use. Defaults to 1 for up to 4 series, otherwise to 2.
<code>yax.flip</code>	logical; if TRUE, the y-axis (ticks and numbering) should flip from side 2 (left) to 4 (right) from series to series.
<code>mar, oma</code>	the 'par' settings for 'mar' and 'oma' to use. Modify with care!
<code>axes</code>	logical; indicates if x- and y- axes should be drawn.
<code>row.names, optional</code>	ignored.
<code>...</code>	Further arguments (either ignored or passed to underlying functions).

## Details

**coef** `coef(object)` returns the contents of the `params` slot of `object`. `coef(object, pars)` returns only those parameters named in `pars`. `coef(object, transform=TRUE)` returns `parameter.inv.transform(coef(object, transform=TRUE))` where `parameter.inv.transform` is the user parameter inverse transformation function specified when `object` was created. Likewise, `coef(object, pars, transform=TRUE)` returns `parameter.inv.transform(coef(object, pars, transform=TRUE))`.

**coef<-** Assigns values to the `params` slot of the `pomp` object. `coef(object) <- value` has the effect of replacing the parameters of `object` with `value`. If `coef(object)` exists, then `coef(object, pars) <- value` replaces those parameters of `object` named in `pars` with the elements of `value`; the names of `value` are ignored. If some of the names in `pars` do not already name parameters in `coef(object)`, then they are concatenated. If `coef(object)` does not exist, then `coef(object, pars) <- value` assigns `value` to the parameters of `object`; in this case, the names of `object` will be `pars` and the names of `value` will be ignored. `coef(object, transform=TRUE) <- value` assigns `parameter.transform(value)` to the `params` slot of `object`. Here, `parameter.transform` is the parameter transformation function specified when `object` was created. `coef(object, pars, transform=TRUE) <- value` first, discards any names the `value` may have, sets `names(value) <- pars`, and then replaces the elements of `object's params` slot `parameter.transform(value)`. In this case, if some of the names in `pars` do not already name parameters in `coef(object, transform=TRUE)`, then they are concatenated.

**obs, data.array** These functions are synonymous. `obs(object)` returns the array of observations. `obs(object, vars)` gives just the observations of variables named `vars`. `vars` may specify the variables by position or by name.

**states** `states(object)` returns the array of states. `states(object, vars)` gives just the state variables named in `vars`. `vars` may specify the variables by position or by name.

**time** `time(object)` returns the vector of observation times. `time(object, t0=TRUE)` returns the vector of observation times with the zero-time `t0` prepended.

**time<-** `time(object) <- value` replaces the observation times slot (`times`) of `object` with `value`. `time(object, t0=TRUE) <- value` has the same effect, but the first element in `value` is taken to be the initial time. The second and subsequent elements of `value` are taken to be the observation times. Those data and states (if they exist) corresponding to the new times are retained.

**timezero, timezero<-** `timezero(object)` returns the zero-time `t0`. `timezero(object) <- value` sets the zero-time to `value`.

- window** `window(x, start=t1, end=t2)` returns a new `pomp` object, identical to `x` but with only the data in the window between times `t1` and `t2` (inclusive). By default, `start` is the time of the first observation and `end` is the time of the last.
- show** Displays the `pomp` object.
- plot** Plots the data and state trajectories (if the latter exist). Additional arguments are passed to the low-level plotting routine.
- print** Prints the `pomp` object in a nice way.
- as, coerce** The `coerce` method should typically not be used directly. It is defined by `setAs` as a method to be used by `as`. A `pomp` object can be coerced to a data frame via `as(object, "data.frame")`. The data frame contains the times, the data, and the state trajectories, if they exist.
- rprocess** simulates the process model. See [rprocess-pomp](#).
- dprocess** evaluates the process model density. See [dprocess-pomp](#).
- rmeasure** simulates the measurement model. See [rmeasure-pomp](#).
- dmeasure** evaluates the measurement-model density. See [dmeasure-pomp](#).
- skeleton** evaluates the deterministic skeleton (be it a vector field or a map). See [skeleton-pomp](#).
- init.state** returns a vector of initialial conditions. See [init.state-pomp](#).
- simulate** `simulate` can be used to simulate state and observation trajectories. See documentation under [simulate-pomp](#).

### Author(s)

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### See Also

[pomp](#), [pomp-class](#), [rprocess](#), [dprocess](#), [rmeasure](#), [dmeasure](#), [init.state](#), [simulate](#)

---

pompBuilder

*Write, compile, link, and build a pomp object using native codes*

---

### Description

`pompBuilder` is a facility for producing compiled `pomp` objects.

### Usage

```
pompBuilder(data, times, t0, name, statenames, paramnames,
            tcovar, covar,
            rmeasure, dmeasure, step.fn, step.fn.delta.t,
            skeleton, skeleton.type = c("map", "vectorfield"),
            skelmap.delta.t = 1,
            parameter.transform, parameter.inv.transform,
            rprior, dprior,
            globals, ..., link = TRUE, save = FALSE)
```

## Arguments

<code>data, times, t0</code>	The data, times, and zero-time. See <a href="#">pomp</a> for more information. <code>data</code> must be a data-frame.
<code>name</code>	character; the stem of the name for the files that will be produced.
<code>statenames, paramnames</code>	names of state-variables and parameters, respectively
<code>tcovar, covar</code>	optional. <code>covar</code> is a data-frame containing covariates (variables in columns, timepoints in rows); <code>tcovar</code> is the name of the column containing time.
<code>rmeasure, dmeasure</code>	C codes implementing the measurement model
<code>step.fn, step.fn.delta.t</code>	<code>step.fn</code> is a C code that implements an Euler step function. The Euler time-step is <code>step.fn.delta.t</code> , which should be a positive number.
<code>skeleton, skeleton.type, skelmap.delta.t</code>	<code>skeleton</code> is a C code that implements the deterministic skeleton. As in <a href="#">pomp</a> , <code>skeleton.type</code> indicates whether the skeleton is a map (discrete-time) or vectorfield (continuous-time). If the former, <code>skelmap.delta.t</code> is the time-step of the map.
<code>parameter.transform, parameter.inv.transform</code>	optional C codes that implement parameter transformations. <code>parameter.transform</code> maps parameters from the estimation scale to the natural scale; <code>parameter.inv.transformation</code> maps them from the natural scale to the estimation scale.
<code>rprior, dprior</code>	C codes implementing the prior distribution
<code>globals</code>	optional. C codes here will be included verbatim in the generated code and compiled into the shared-object library.
<code>...</code>	additional arguments are passed to <a href="#">pomp</a>
<code>link</code>	logical; if TRUE, the resulting code will be linked after compilation.
<code>save</code>	logical; if TRUE, the resulting C code will be saved in the current working directory. The shared-object library will also be created in this directory. If FALSE, the C code and shared-object library will be created in the temporary directory.

## Details

`pompBuilder` with `save=TRUE` assumes that files can be written to the current working directory and that dynamic shared objects can be compiled and linked, i.e., that R CMD SHLIB will work. This will not typically be the case in out-of-the-box Windows installations.

## Value

The constructed `pomp` object. A side-effect is the writing and compilation of a C code into a dynamics shared object. These files will reside in the current working directory (see [getwd](#)). If `pompBuilder` has been called with `link=FALSE`, this dynamic shared object must be linked (see [dyn.load](#)) before the `pomp` object can be used.



**Parallel computing caution:** note that, since a side-effect of running `pompBuilder` is the writing and compilation of a file, caution must be used when running parallel computations. Simultaneous execution of `pompBuilder` on nodes sharing a common disk will cause all nodes to attempt to write the same file at the same time; the results will be undefined. If multiple nodes are to work on the same `pomp` object built by `pompBuilder`, first run `pompBuilder` once (perhaps with `link=FALSE`) to write the C file and compile it into a dynamic shared object file. The `pomp` object returned by `pompBuilder` can then be shared with all worker nodes. Note, however, that all worker nodes must dynamically load (using `dyn.load`) the dynamic shared object file before anything can be done with the `pomp` object.

### Author(s)

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### See Also

[pomp](#) and the demos.

### Examples

```
## see the demos
```

---

pompExample

*Pre-built examples of pomp objects.*

---

### Description

`pompExample` loads pre-built example `pomp` objects.

### Usage

```
pompExample(example, envir = .GlobalEnv)
```

### Arguments

<code>example</code>	example to load given as a name or literal character string. Evoked without an argument, <code>pompExample</code> lists all available examples.
<code>envir</code>	the environment into which the objects should be loaded.

### Value

`pompExample` has the side effect of creating one or more `pomp` objects in the global workspace.

### Author(s)

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**See Also**

[blowflies](#), [dacca](#), [gompertz](#), [ou2](#), [ricker](#), [rw2](#), [euler.sir](#), [gillespie.sir](#), [bbs](#), [verhulst](#)

**Examples**

```
pompExample()
pompExample(euler.sir)
pompExample("gompertz")
file.show(system.file("include/pomp.h", package="pomp"))
```

---

probe

*Probe a partially-observed Markov process.*

---

**Description**

probe applies one or more “probes” to time series data and model simulations and compares the results. It can be used to diagnose goodness of fit and/or as the basis for “probe-matching”, a generalized method-of-moments approach to parameter estimation. `probe.match` calls an optimizer to adjust model parameters to do probe-matching, i.e., to minimize the discrepancy between simulated and actual data. This discrepancy is measured using the “synthetic likelihood” as defined by Wood (2010). `probe.match.objfun` constructs an objective function for probe-matching suitable for use in optim-like optimizers.

**Usage**

```
## S4 method for signature pomp
probe(object, probes, params, nsim, seed = NULL, ...)
## S4 method for signature probed.pomp
probe(object, probes, params, nsim, seed, ...)
## S4 method for signature pomp
probe.match.objfun(object, params, est, probes, nsim,
  seed = NULL, fail.value = NA, transform = FALSE, ...)
## S4 method for signature probed.pomp
probe.match.objfun(object, probes, nsim, seed, ...)
## S4 method for signature pomp
probe.match(object, start, est = character(0),
  probes, nsim, seed = NULL,
  method = c("subplex", "Nelder-Mead", "SANN", "BFGS",
    "sannbox", "nloptr"),
  verbose = getOption("verbose"),
  fail.value = NA, transform = FALSE, ...)
## S4 method for signature probed.pomp
probe.match(object, probes, nsim, seed,
  ..., verbose = getOption("verbose"))
## S4 method for signature probe.matched.pomp
probe.match(object, est, probes,
  nsim, seed, transform, fail.value, ...,
  verbose = getOption("verbose"))
```

## Arguments

<code>object</code>	An object of class <code>pomp</code> .
<code>probes</code>	A single probe or a list of one or more probes. A probe is simply a scalar- or vector-valued function of one argument that can be applied to the data array of a <code>pomp</code> . A vector-valued probe must always return a vector of the same size. A number of basic examples are provided with the package (see <a href="#">basic.probes</a> ).
<code>params</code>	optional named numeric vector of model parameters. By default, <code>params=coef(object)</code> .
<code>nsim</code>	The number of model simulations to be computed.
<code>seed</code>	optional; if non-NULL, the random number generator will be initialized with this seed for simulations. See <a href="#">simulate-pomp</a> .
<code>start</code>	named numeric vector; the initial guess of parameters.
<code>est</code>	character vector; the names of parameters to be estimated.
<code>method</code>	Optimization method. Choices refer to algorithms used in <a href="#">optim</a> , <a href="#">subplex</a> , and <a href="#">nloptr</a> .
<code>verbose</code>	logical; print diagnostic messages?
<code>fail.value</code>	optional numeric scalar; if non-NA, this value is substituted for non-finite values of the objective function. It should be a large number (i.e., bigger than any legitimate values the objective function is likely to take).
<code>transform</code>	logical; if TRUE, optimization is performed on the transformed scale.
<code>...</code>	Additional arguments. In the case of <code>probe</code> , these are currently ignored. In the case of <code>probe.match</code> , these are passed to the optimizer (one of <a href="#">optim</a> , <a href="#">subplex</a> , <a href="#">nloptr</a> , or <a href="#">sannbox</a> ). These are passed via the optimizer's control list (in the case of <code>optim</code> , <code>subplex</code> , and <code>sannbox</code> ) or the opts list (in the case of <code>nloptr</code> ).

## Details

A call to `probe` results in the evaluation of the probe(s) in `probes` on the data. Additionally, `nsim` simulated data sets are generated (via a call to [simulate](#)) and the probe(s) are applied to each of these. The results of the probe computations on real and simulated data are stored in an object of class `probed.pomp`.

A call to `probe.match` results in an attempt to optimize the agreement between model and data, as measured by the specified probes, over the parameters named in `est`. The results, including coefficients of the fitted model and values of the probes for data and fitted-model simulations, are stored in an object of class [probe.matched.pomp](#).

The objective function minimized by `probe.match` — in a form suitable for use with `optim`-like optimizers — is created by a call to `probe.match.objfun`. Specifically, `probe.match.objfun` will return a function that takes a single numeric-vector argument that is assumed to contain the parameters named in `est`, in that order. This function will return the negative synthetic log likelihood for the probes specified.

## Value

`probe` returns an object of class `probed.pomp`. `probed.pomp` is derived from the [pomp](#) class and therefore have all the slots of `pomp`. In addition, a `probed.pomp` class has the following slots:

**probes** list of the probes applied.

**datvals, simvals** values of each of the probes applied to the real and simulated data, respectively.

**quantiles** fraction of simulations with probe values less than the value of the probe of the data.

**pvals** two-sided p-values: fraction of the simvals that deviate more extremely from the mean of the simvals than does datavals.

**synth.loglik** the log synthetic likelihood (Wood 2010). This is the likelihood assuming that the probes are multivariate-normally distributed.

`probe.match` returns an object of class `probe.matched.pomp`, which is derived from class `probed.pomp`. `probe.matched.pomp` objects therefore have all the slots above plus the following:

**est, transform, fail.value** values of the corresponding arguments in the call to `probe.match`.

**value** value of the objective function at the optimum.

**evals** number of function and gradient evaluations by the optimizer. See [optim](#).

**convergence, msg** Convergence code and message from the optimizer. See [optim](#) and [nloptr](#).

`probe.match.objfun` returns a function suitable for use as an objective function in an [optim](#)-like optimizer.

## Author(s)

Daniel C. Reuman, Aaron A. King

## References

B. E. Kendall, C. J. Briggs, W. M. Murdoch, P. Turchin, S. P. Ellner, E. McCauley, R. M. Nisbet, S. N. Wood Why do populations cycle? A synthesis of statistical and mechanistic modeling approaches, *Ecology*, 80:1789–1805, 1999.

S. N. Wood Statistical inference for noisy nonlinear ecological dynamic systems, *Nature*, 466: 1102–1104, 2010.

## See Also

[pomp-class](#), [pomp-methods](#), [basic.probes](#), [probe.match](#)

## Examples

```
pompExample(ou2)
good <- probe(
  ou2,
  probes=list(
    y1.mean=probe.mean(var="y1"),
    y2.mean=probe.mean(var="y2"),
    y1.sd=probe.sd(var="y1"),
    y2.sd=probe.sd(var="y2"),
    extra=function(x)max(x["y1",])
  ),
  nsim=500
)
```

```

summary(good)
plot(good)

bad <- probe(
  ou2,
  params=c(alpha.1=0.1,alpha.4=0.2,x1.0=0,x2.0=0,
            alpha.2=-0.5,alpha.3=0.3,
            sigma.1=3,sigma.2=-0.5,sigma.3=2,
            tau=1),
  probes=list(
    y1.mean=probe.mean(var="y1"),
    y2.mean=probe.mean(var="y2"),
    y1.sd=probe.sd(var="y1"),
    y2.sd=probe.sd(var="y2"),
    extra=function(x)range(x["y1",])
  ),
  nsim=500
)
summary(bad)
plot(bad)

```

---

probed.pomp-methods	<i>Methods of the "probed.pomp", "probe.matched.pomp", "spect.pomp", and "spect.matched.pomp" classes</i>
---------------------	---------------------------------------------------------------------------------------------------------------

---

## Description

Methods of the `probed.pomp`, `probe.matched.pomp`, `spect.pomp`, and `spect.matched.pomp` classes

## Usage

```

## S4 method for signature probed.pomp
summary(object, ...)
## S4 method for signature probed.pomp
plot(x, y, ...)
## S4 method for signature probe.matched.pomp
summary(object, ...)
## S4 method for signature probe.matched.pomp
plot(x, y, ...)
## S4 method for signature spect.pomp
summary(object, ...)
## S4 method for signature probed.pomp
logLik(object, ...)
## S4 method for signature probed.pomp
values(object, ...)
## S4 method for signature spect.pomp
plot(x, y, max.plots.per.page = 4,
     plot.data = TRUE,
     quantiles = c(.025, .25, .5, .75, .975),

```

```

        quantile.styles = list(lwd=1, lty=1, col="gray70"),
        data.styles = list(lwd=2, lty=2, col="black"))
## S4 method for signature spect.matched.pomp
summary(object, ...)
## S4 method for signature spect.matched.pomp
plot(x, y, ...)
## S4 method for signature probed.pomp
as(object, class)

```

### Arguments

<code>object, x</code>	the object to be summarized or plotted.
<code>y</code>	ignored.
<code>max.plots.per.page</code>	maximum number of plots per page
<code>plot.data</code>	plot the data spectrum?
<code>quantiles</code>	quantiles to plot
<code>quantile.styles</code>	plot style parameters for the quantiles
<code>data.styles</code>	plot style parameters for the data spectrum
<code>class</code>	character; name of the class to which object should be coerced.
<code>...</code>	Further arguments (either ignored or passed to underlying functions).

### Methods

**plot** displays diagnostic plots.

**summary** displays summary information.

**values** extracts the realized values of the probes on the data and on the simulations as a data frame in long format. The variable `.id` indicates whether the probes are from the data or simulations.

**logLik** returns the synthetic likelihood for the probes. NB: in general, this is not the same as the likelihood.

**as** when a ‘probed.pomp’ is coerced to a ‘data.frame’, the first row gives the probes applied to the data; the rest of the rows give the probes evaluated on simulated data. The rownames of the result can be used to distinguish these.

In addition, slots of this object can be accessed via the `$` operator.

### Author(s)

Daniel C. Reuman, Aaron A. King

### See Also

[probe](#), [probed.pomp](#), [probe.matched.pomp](#), [probe.match](#)

---

profileDesign*Design matrices for likelihood profile calculations.*

---

**Description**

profileDesign generates a data-frame where each row can be used as the starting point for a profile likelihood calculation.

**Usage**

```
profileDesign(..., lower, upper, nprof,  
              stringsAsFactors = default.stringsAsFactors())
```

**Arguments**

...	Specifies the parameters over which to profile.
lower, upper	Named numeric vectors, specifying the range over which the other parameters are to be sampled.
nprof	The number of starts per profile point.
stringsAsFactors	should character vectors be converted to factors?

**Value**

profileDesign returns a data frame with nprof points per profile point. The other parameters in vars are sampled using sobol.

**Author(s)**

Aaron A. King <kingaa at umich dot edu>

**See Also**

[sobol](#)

**Examples**

```
## A one-parameter profile design:  
x <- profileDesign(p=1:10, lower=c(a=0, b=0), upper=c(a=1, b=5), nprof=20)  
dim(x)  
plot(x)  
## A two-parameter profile design:  
x <- profileDesign(p=1:10, q=3:5, lower=c(a=0, b=0), upper=c(b=5, a=1), nprof=20)  
dim(x)  
plot(x)
```

---

ricker

*Ricker model with Poisson observations.*


---

### Description

ricker is a pomp object encoding a stochastic Ricker model with Poisson measurement error.

### Details

The state process is  $N_{t+1} = rN_t \exp(-N_t + e_t)$ , where the  $e_t$  are i.i.d. normal random deviates with zero mean and variance  $\sigma^2$ . The observed variables  $y_t$  are distributed as  $\text{Poisson}(\phi N_t)$ .

### See Also

[pomp](#) and the vignettes

### Examples

```
pompExample(ricker)
plot(ricker)
coef(ricker)
```

---

rw2

*Two-dimensional random-walk process*


---

### Description

rw2 is a pomp object encoding a 2-D normal random walk.

### Details

The random-walk process is fully but noisily observed.

### See Also

[pomp](#) and the vignettes

### Examples

```
pompExample(rw2)
plot(rw2)
x <- simulate(rw2, nsim=10, seed=20348585L, params=c(x1.0=0, x2.0=0, s1=1, s2=3, tau=1))
plot(x[[1]])
```



sannbox

*Simulated annealing with box constraints.***Description**

sannbox is a straightforward implementation of simulated annealing with box constraints.

**Usage**

```
sannbox(par, fn, control = list(), ...)
```

**Arguments**

par	Initial values for the parameters to be optimized over.
fn	A function to be minimized, with first argument the vector of parameters over which minimization is to take place. It should return a scalar result.
control	A named list of control parameters. See ‘Details’.
...	ignored.

**Details**

The control argument is a list that can supply any of the following components:

**trace** Non-negative integer. If positive, tracing information on the progress of the optimization is produced. Higher values may produce more tracing information.

**fnscale** An overall scaling to be applied to the value of fn during optimization. If negative, turns the problem into a maximization problem. Optimization is performed on  $fn(par)/fnscale$ .

**parscale** A vector of scaling values for the parameters. Optimization is performed on  $par/parscale$  and these should be comparable in the sense that a unit change in any element produces about a unit change in the scaled value.

**maxit** The total number of function evaluations: there is no other stopping criterion. Defaults to 10000.

**temp** starting temperature for the cooling schedule. Defaults to 1.

**tmax** number of function evaluations at each temperature. Defaults to 10.

**candidate.dist** function to randomly select a new candidate parameter vector. This should be a function with three arguments, the first being the current parameter vector, the second the temperature, and the third the parameter scaling. By default, candidate.dist is

```
function(par, temp, scale) rnorm(n=length(par), mean=par, sd=scale*temp)
```

.

**sched** cooling schedule. A function of a three arguments giving the temperature as a function of iteration number and the control parameters temp and tmax. By default, sched is

```
function(k, temp, tmax) temp/log(((k-1)/tmax)*tmax+exp(1))
```

.

Alternatively, one can supply a numeric vector of temperatures. This must be of length at least maxit.

**Value**

sannbox returns a list with components:

**counts** two-element integer vector. The first number gives the number of calls made to fn. The second number is provided for compatibility with `optim` and will always be NA.

**convergence** provided for compatibility with `optim`; will always be 0.

**final.params** last tried value of par.

**final.value** value of fn corresponding to final.params.

**par** best tried value of par.

**value** value of fn corresponding to par.

**Author(s)**

Daniel Reuman, Imperial College London and Aaron A. King <kingaa at umich dot edu>

**See Also**

[traj.match](#), [probe.match](#).

---

simulate-pomp

*Running simulations of a partially-observed Markov process*

---

**Description**

simulate can be used to generate simulated data sets and/or to simulate the state process.

**Usage**

```
## S4 method for signature pomp
simulate(object, nsim = 1, seed = NULL, params,
         states = FALSE, obs = FALSE, times, t0,
         as.data.frame = FALSE, ...)
```

**Arguments**

object	An object of class pomp.
nsim	The number of simulations to perform. Note that the number of replicates will be nsim times ncol(xstart).
seed	optional; if set, the pseudorandom number generator (RNG) will be initialized with seed. the random seed to use. The RNG will be restored to its original state afterward.
params	either a named numeric vector or a numeric matrix with rownames. The parameters to use in simulating the model. If params is not given, then the contents of the params slot of object will be used, if they exist.
states	Do we want the state trajectories?

<code>obs</code>	Do we want data-frames of the simulated observations?
<code>times, t0</code>	<code>times</code> specifies the times at which simulated observations will be made. <code>t0</code> specifies the start time (the time at which the initial conditions hold). The default for <code>times</code> is <code>times=time(object,t0=FALSE)</code> and <code>t0=timezero(object)</code> , respectively.
<code>as.data.frame</code>	logical; if TRUE, return the result as a data-frame.
<code>...</code>	further arguments that are currently ignored.

## Details

Simulation of the state process and of the measurement process are each accomplished by a single call to the user-supplied `rprocess` and `rmeasure` functions, respectively. This makes it possible for the user to write highly optimized code for these potentially expensive computations.

## Value

If `states=FALSE` and `obs=FALSE` (the default), a list of `nsim` pomp objects is returned. Each has a simulated data set, together with the parameters used (in slot `params`) and the state trajectories also (in slot `states`). If `times` is specified, then the simulated observations will be at times `times`.

If `nsim=1`, then a single pomp object is returned (and not a singleton list).

If `states=TRUE` and `obs=FALSE`, simulated state trajectories are returned as a rank-3 array with dimensions `nvar` x `(ncol(params)*nsim)` x `ntimes`. Here, `nvar` is the number of state variables and `ntimes` the length of the argument `times`. The measurement process is not simulated in this case.

If `states=FALSE` and `obs=TRUE`, simulated observations are returned as a rank-3 array with dimensions `nobs` x `(ncol(params)*nsim)` x `ntimes`. Here, `nobs` is the number of observables.

If both `states=TRUE` and `obs=TRUE`, then a named list is returned. It contains the state trajectories and simulated observations as above.

## Author(s)

Aaron A. King <kingaa at umich dot edu>

## See Also

[pomp](#)

## Examples

```
pompExample(ou2)
x <- simulate(ou2,seed=3495485,nsim=10)
x <- simulate(ou2,seed=3495485,nsim=10,states=TRUE,obs=TRUE)
```

---

*sir**SIR models.*

---

## Description

`euler.sir` is a `pomp` object encoding a simple seasonal SIR model. Simulation is performed using an Euler multinomial approximation. `gillespie.sir` has the same model implemented using Gillespie's algorithm. `bbs` is a nonseasonal SIR model together with data from a 1978 outbreak of influenza in a British boarding school.

## Details

This example is discussed extensively in the “Introduction to **pomp**” and “Advanced topics in **pomp**” vignettes, available on the [package website](#).

The codes that construct these `pomp` objects can be found in the “examples” directory in the installed package. Do `system.file("examples", package="pomp")` to find this directory. For the basic `rprocess`, `dmeasure`, `rmeasure`, and `skeleton` functions, these codes use compiled native routines built into the package's library. View “`src/sir.c`” in the package source or `file.show("examples/sir.c")` from an R session to view these codes.

The boarding school influenza outbreak is described in Anonymous (1978).

## References

Anonymous (1978). Influenza in a boarding school. *British Medical Journal* 1:587

## See Also

[pomp-class](#) and the vignettes

## Examples

```
pompExample(euler.sir)
plot(euler.sir)
plot(simulate(euler.sir, seed=20348585))
coef(euler.sir)

pompExample(gillespie.sir)
plot(gillespie.sir)
plot(simulate(gillespie.sir, seed=20348585))
coef(gillespie.sir)

pompExample(bbs)
plot(bbs)
coef(bbs)
```

---

`sliceDesign`*Design matrices for likelihood slices.*

---

**Description**

`sliceDesign` generates a data-frame representing points taken along one or more slices through a point in a multidimensional space.

**Usage**

```
sliceDesign(center, ...)
```

**Arguments**

<code>center</code>	<code>center</code> is a named numeric vector specifying the point through which the slice(s) is (are) to be taken.
<code>...</code>	Additional numeric vector arguments specify the slices.

**Value**

`sliceDesign` returns a data frame with one row per point along a slice. The column `slice` is a factor that tells which slice each point belongs to.

**Author(s)**

Aaron A. King <kingaa at umich dot edu>

**See Also**

[profileDesign](#)

**Examples**

```
## A single 11-point slice through the point c(A=3,B=8,C=0) along the B direction.
x <- sliceDesign(center=c(A=3,B=8,C=0),B=seq(0,10,by=1))
dim(x)
plot(x)
## Two slices through the same point along the A and C directions.
x <- sliceDesign(c(A=3,B=8,C=0),A=seq(0,5,by=1),C=seq(0,5,length=11))
dim(x)
plot(x)
```

---

sobol	<i>Sobol' low-discrepancy sequence</i>
-------	----------------------------------------

---

## Description

Generate a data-frame containing a Sobol' low-discrepancy sequence.

## Usage

```
sobol(vars, n)
sobolDesign(lower, upper, nseq)
```

## Arguments

vars	Named list of ranges of variables.
lower, upper	named numeric vectors giving the lower and upper bounds of the ranges, respectively.
n, nseq	Number of vectors requested.

## Value

sobol	Returns a data frame with n 'observations' of the variables in vars.
sobolDesign	Returns a data frame with nseq 'observations' of the variables over the range specified.

## Author(s)

Aaron A. King <kingaa at umich dot edu>

## References

W. H. Press, S. A. Teukolsky, W. T. Vetterling, \& B. P. Flannery, Numerical Recipes in C, Cambridge University Press, 1992

## See Also

[sliceDesign](#), [profileDesign](#)

## Examples

```
plot(sobol(vars=list(a=c(0,1),b=c(100,200)),100))
plot(sobolDesign(lower=c(a=0,b=100),upper=c(b=200,a=1),100))
```

---

spect	<i>Power spectrum computation for partially-observed Markov processes.</i>
-------	----------------------------------------------------------------------------

---

## Description

spect estimates the power spectrum of time series data and model simulations and compares the results. It can be used to diagnose goodness of fit and/or as the basis for frequency-domain parameter estimation (spect.match).

spect.match tries to match the power spectrum of the model to that of the data. It calls an optimizer to adjust model parameters to minimize the discrepancy between simulated and actual data.

## Usage

```
## S4 method for signature pomp
spect(object, params, vars, kernel.width, nsim, seed = NULL,
      transform = identity,
      detrend = c("none", "mean", "linear", "quadratic"),
      ...)
## S4 method for signature spect.pomp
spect(object, params, vars, kernel.width, nsim, seed = NULL, transform,
      detrend, ...)
spect.match(object, start, est = character(0),
            vars, nsim, seed = NULL,
            kernel.width, transform = identity,
            detrend = c("none", "mean", "linear", "quadratic"),
            weights, method = c("subplex", "Nelder-Mead", "SANN"),
            verbose = getOption("verbose"),
            eval.only = FALSE, fail.value = NA, ...)
```

## Arguments

object	An object of class pomp.
params	optional named numeric vector of model parameters. By default, params=coef(object).
vars	optional; names of observed variables for which the power spectrum will be computed. This must be a subset of rownames(obs(object)). By default, the spectrum will be computed for all observables.
kernel.width	width parameter for the smoothing kernel used for calculating the estimate of the spectrum.
nsim	number of model simulations to be computed.
seed	optional; if non-NULL, the random number generator will be initialized with this seed for simulations. See <a href="#">simulate-pomp</a> .
transform	function; this transformation will be applied to the observables prior to estimation of the spectrum, and prior to any detrending.

<code>detrend</code>	de-trending operation to perform. Options include no detrending, and subtraction of constant, linear, and quadratic trends from the data. Detrending is applied to each data series and to each model simulation independently.
<code>weights</code>	optional. The mismatch between model and data is measured by a weighted average of mismatch at each frequency. By default, all frequencies are weighted equally. <code>weights</code> can be specified either as a vector (which must have length equal to the number of frequencies) or as a function of frequency. If the latter, <code>weights(freq)</code> must return a nonnegative weight for each frequency.
<code>start</code>	named numeric vector; the initial guess of parameters.
<code>est</code>	character vector; the names of parameters to be estimated.
<code>method</code>	Optimization method. Choices are <code>subplex</code> and any of the methods used by <code>optim</code> .
<code>verbose</code>	logical; print diagnostic messages?
<code>eval.only</code>	logical; if TRUE, no optimization is attempted. Instead, the probe-mismatch value is simply evaluated at the <code>start</code> parameters.
<code>fail.value</code>	optional scalar; if non-NA, this value is substituted for non-finite values of the objective function.
<code>...</code>	Additional arguments. In the case of <code>spect</code> , these are currently ignored. In the case of <code>spect.match</code> , these are passed to <code>optim</code> or <code>subplex</code> in the control list.

## Details

A call to `spect` results in the estimation of the power spectrum for the (transformed, detrended) data and `nsim` model simulations. The results of these computations are stored in an object of class `spect.pomp`.

A call to `spect.match` results in an attempt to optimize the agreement between model and data spectrum over the parameters named in `est`. The results, including coefficients of the fitted model and power spectra of fitted model and data, are stored in an object of class `spect.matched.pomp`.

## Value

`spect` returns an object of class `spect.pomp`, which is derived from class `pomp` and therefore has all the slots of that class. In addition, `spect.pomp` objects have the following slots:

**kernel.width** width parameter of the smoothing kernel used.

**transform** transformation function used.

**freq** numeric vector of the frequencies at which the power spectrum is estimated.

**datspec, simspec** estimated power spectra for data and simulations, respectively.

**pvals** one-sided p-values: fraction of the simulated spectra that differ more from the mean simulated spectrum than does the data. The metric used is  $L^2$  distance.

**detrend** detrending option used.

`spect.match` returns an object of class `spect.matched.pomp`, which is derived from class `{spect.pomp}` and therefore has all the slots of that class. In addition, `spect.matched.pomp` objects have the following slots:



**est, weights, fail.value** values of the corresponding arguments in the call to `spect.match`.

**evals** number of function and gradient evaluations by the optimizer. See [optim](#).

**value** Value of the objective function.

**convergence, msg** Convergence code and message from the optimizer. See [optim](#).

### Author(s)

Daniel C. Reuman, Cai GoGwilt, Aaron A. King

### References

D.C. Reuman, R.A. Desharnais, R.F. Costantino, O. Ahmad, J.E. Cohen (2006) Power spectra reveal the influence of stochasticity on nonlinear population dynamics. *Proceedings of the National Academy of Sciences* **103**, 18860-18865.

D.C. Reuman, R.F. Costantino, R.A. Desharnais, J.E. Cohen (2008) Color of environmental noise affects the nonlinear dynamics of cycling, stage-structured populations. *Ecology Letters*, **11**, 820-830.

### See Also

[pomp-class](#), [pomp-methods](#), [probe](#), [probe.match](#)

### Examples

```
pompExample(ou2)
good <- spect(
  ou2,
  vars=c("y1", "y2"),
  kernel.width=3,
  detrend="mean",
  nsim=500
)
summary(good)
plot(good)

ou2.bad <- ou2
coef(ou2.bad, c("x1.0", "x2.0", "alpha.1", "alpha.4")) <- c(0, 0, 0.1, 0.2)
bad <- spect(
  ou2.bad,
  vars=c("y1", "y2"),
  kernel.width=3,
  detrend="mean",
  nsim=500
)
summary(bad)
plot(bad)
```

traj.match

*Trajectory matching*

## Description

Facilities for matching trajectories to data. Trajectory matching is equivalent to maximum likelihood estimation under the assumption that process noise is entirely absent, i.e., that all stochasticity is measurement error.

## Usage

```
## S4 method for signature pomp
traj.match(object, start, est = character(0),
           method = c("Nelder-Mead", "subplex", "SANN", "BFGS",
                      "sannbox", "nloptr"),
           transform = FALSE, ...)
## S4 method for signature traj.matched.pomp
traj.match(object, est, transform, ...)
## S4 method for signature pomp
traj.match.objfun(object, params, est, transform = FALSE, ...)
```

## Arguments

object	A <a href="#">pomp</a> object. If object has no skeleton slot, an error will be generated.
start	named numeric vector containing an initial guess for parameters. By default start=coef(object) if the latter exists.
params	optional named numeric vector of parameters. This should contain all parameters needed by the skeleton and dmeasure slots of object. In particular, any parameters that are to be treated as fixed should be present here. Parameter values given in params for parameters named in est will be ignored. By default, params=coef(object) if the latter exists.
est	character vector containing the names of parameters to be estimated. In the case of traj.match.objfun, the objective function that is constructed will assume that its argument contains the parameters in this order.
method	Optimization method. Choices are <a href="#">subplex</a> , “sannbox”, and any of the methods used by <a href="#">optim</a> .
transform	logical; if TRUE, optimization is performed on the transformed scale.
...	Extra arguments that will be passed either to the optimizer ( <a href="#">optim</a> , <a href="#">subplex</a> , <a href="#">nloptr</a> , or <a href="#">sannbox</a> , via their control (optim, subplex, sannbox) or opts (nloptr) lists) or to the ODE integrator. In traj.match, extra arguments will be passed to the optimizer. In traj.match.objfun, extra arguments are passed to <a href="#">trajectory</a> . If extra arguments are needed by both optimizer and <a href="#">trajectory</a> , construct an objective function first using traj.match.objfun, then give this objective function to the optimizer.

## Details

In **pomp**, trajectory matching is the term used for maximizing the likelihood of the data under the assumption that there is no process noise. Specifically, `traj.match` calls an optimizer (`optim`, `subplex`, and `sannbox` are the currently supported options) to minimize an objective function. For any value of the model parameters, this objective function is calculated by

1. computing the deterministic trajectory of the model given the parameters. This is the trajectory returned by `trajectory`, which relies on the model's deterministic skeleton as specified in the construction of the `pomp` object.
2. evaluating the negative log likelihood of the data under the measurement model given the deterministic trajectory and the model parameters. This is accomplished via the model's `dmeasure` slot. The negative log likelihood is the objective function's value.

The objective function itself — in a form suitable for use with `optim`-like optimizers — is created by a call to `traj.match.objfun`. Specifically, `traj.match.objfun` will return a function that takes a single numeric-vector argument that is assumed to contain the parameters named in `est`, in that order.

## Value

`traj.match` returns an object of class `traj.matched.pomp`. This class inherits from class `pomp` and contains the following additional slots:

**transform, est** the values of these arguments on the call to `traj.match`.

**evals** number of function and gradient evaluations by the optimizer. See `optim`.

**value** value of the objective function. Larger values indicate better fit (i.e., `traj.match` attempts to maximize this quantity).

**convergence, msg** convergence code and message from the optimizer. See `optim`.

Available methods for objects of this type include `summary` and `logLik`. The other slots of this object can be accessed via the `$` operator.

`traj.match.objfun` returns a function suitable for use as an objective function in an `optim`-like optimizer.

## See Also

`trajectory`, `pomp`, `optim`, `subplex`

## Examples

```
pompExample(ou2)
true.p <- c(
  alpha.1=0.9, alpha.2=0, alpha.3=-0.4, alpha.4=0.99,
  sigma.1=2, sigma.2=0.1, sigma.3=2,
  tau=1,
  x1.0=50, x2.0=-50
)
simdata <- simulate(ou2, nsim=1, params=true.p, seed=43553)
guess.p <- true.p
```

```

res <- traj.match(
  simdata,
  start=guess.p,
  est=c(alpha.1,alpha.3,alpha.4,x1.0,x2.0,tau),
  maxit=2000,
  method="Nelder-Mead",
  reltol=1e-8
)

summary(res)

plot(range(time(res)),range(c(obs(res),states(res))),type=n,xlab="time",ylab="x,y")
points(y1~time,data=as(res,"data.frame"),col=blue)
points(y2~time,data=as(res,"data.frame"),col=red)
lines(x1~time,data=as(res,"data.frame"),col=blue)
lines(x2~time,data=as(res,"data.frame"),col=red)

pompExample(ricker)
ofun <- traj.match.objfun(ricker,est=c("r","phi"),transform=TRUE)
optim(fn=ofun,par=c(2,0),method="BFGS")

pompExample(bbs)
## some options are passed to the ODE integrator
ofun <- traj.match.objfun(bbs,est=c("beta","gamma"),transform=TRUE,hmax=0.001,rtol=1e-6)
optim(fn=ofun,par=c(0,-1),method="Nelder-Mead",control=list(reltol=1e-10))

```

---

trajectory

---

*Compute trajectories of the deterministic skeleton.*


---

## Description

The method `trajectory` computes a trajectory of the deterministic skeleton of a Markov process. In the case of a discrete-time system, the deterministic skeleton is a map and a trajectory is obtained by iterating the map. In the case of a continuous-time system, the deterministic skeleton is a vectorfield; `trajectory` integrates the vectorfield to obtain a trajectory.

## Usage

```

## S4 method for signature pomp
trajectory(object, params, times, t0, as.data.frame = FALSE, ...)

```

## Arguments

<code>object</code>	an object of class <code>pomp</code> .
<code>params</code>	a rank-2 array of parameters. Each column of <code>params</code> is a distinct parameter vector.
<code>times, t0</code>	<code>times</code> is a numeric vector specifying the times at which a trajectory is desired. <code>t0</code> specifies the start time (the time at which the initial conditions hold). The default for <code>times</code> is <code>times=time(object, t0=FALSE)</code> and <code>t0=timezero(object)</code> , respectively.

`as.data.frame` logical; if TRUE, return the result as a data-frame.

... additional arguments are passed to the ODE integrator if the skeleton is a vectorfield and ignored if it is a map. See [ode](#) for a description of the additional arguments accepted.

## Details

This function makes repeated calls to the user-supplied skeleton of the `pomp` object. For specifications on supplying this, see [pomp](#).

When the skeleton is a vectorfield, `trajectory` integrates it using [ode](#).

When the skeleton is a map, `trajectory` iterates it. By default, time is advanced 1 unit per iteration. The user can change this behavior by specifying the desired timestep using the argument `skelmap.delta.t` in the construction of the `pomp` object.

## Value

Returns an array of dimensions `nvar x nreps x ntimes`. If `x` is the returned matrix, `x[i, j, k]` is the *i*-th component of the state vector at time `times[k]` given parameters `params[, j]`.

## Author(s)

Aaron A. King <kingaa at umich dot edu>

## See Also

[pomp](#), [traj.match](#), [ode](#)

## Examples

```
pompExample(euler.sir)
x <- trajectory(euler.sir)
plot(time(euler.sir), x["I", 1, ], type="l", xlab="time", ylab="I")
lines(time(euler.sir), x["cases", 1, ], col="red")

coef(euler.sir, c("gamma")) <- log(12)
x <- trajectory(euler.sir)
plot(time(euler.sir), x["I", 1, ], type="l", xlab="time", ylab="I")
lines(time(euler.sir), x["cases", 1, ], col="red")

x <- trajectory(euler.sir, as.data.frame=TRUE)
```

---

verhulst	<i>Simple Verhulst-Pearl (logistic) model.</i>
----------	------------------------------------------------

---

## Description

verhulst is a `pomp` object encoding a univariate stochastic logistic model with measurement error.

## Details

The model is written as an Ito diffusion,  $dn = rn(1 - n/K)dt + \sigma ndW$ , where  $W$  is a Wiener process. It is implemented using the [euler.sim](#) plug-in.

## See Also

[pomp-class](#) and the vignettes

## Examples

```
pompExample(verhulst)
plot(verhulst)
coef(verhulst)
params <- cbind(
  c(n.0=100,K=10000,r=0.2,sigma=0.4,tau=0.1),
  c(n.0=1000,K=11000,r=0.1,sigma=0.4,tau=0.1)
)
x <- simulate(verhulst,params=params,states=TRUE)
matplot(time(verhulst),t(x[n,,]),type='l')
y <- trajectory(verhulst,params=params)
matlines(time(verhulst),t(y[n,,]),type='l',lwd=2)
```

# Index

## \*Topic **datasets**

- blowflies, [10](#)
- dacca, [14](#)
- gompertz, [17](#)
- LondonYorke, [19](#)
- ou2, [26](#)
- ricker, [56](#)
- rw2, [56](#)
- sir, [60](#)
- verhulst, [70](#)

## \*Topic **design**

- profileDesign, [55](#)
- sliceDesign, [61](#)
- sobol, [62](#)

## \*Topic **distribution**

- eulermultinom, [15](#)

## \*Topic **interface**

- Csnippet, [14](#)

## \*Topic **models**

- basic.probes, [8](#)
- mif-methods, [23](#)
- pfilter, [28](#)
- pfilter-methods, [30](#)
- plugins, [31](#)
- pmcmc-methods, [36](#)
- pomp, [37](#)
- pomp-methods, [44](#)
- pomp-package, [3](#)
- probe, [50](#)
- probed.pomp-methods, [53](#)
- simulate-pomp, [58](#)
- spect, [63](#)
- traj.match, [66](#)
- trajectory, [68](#)

## \*Topic **optimize**

- sannbox, [57](#)

## \*Topic **programming**

- Csnippet, [14](#)

## \*Topic **smooth**

- B-splines, [7](#)

## \*Topic **ts**

- abc, [4](#)
- abc-methods, [6](#)
- basic.probes, [8](#)
- bsmc2, [12](#)
- mif, [20](#)
- mif-methods, [23](#)
- nlf, [24](#)
- pfilter, [28](#)
- pfilter-methods, [30](#)
- pmcmc, [34](#)
- pmcmc-methods, [36](#)
- pomp, [37](#)
- pomp-methods, [44](#)
- pomp-package, [3](#)
- probe, [50](#)
- probed.pomp-methods, [53](#)
- simulate-pomp, [58](#)
- spect, [63](#)
- traj.match, [66](#)
- trajectory, [68](#)

- [,abcList-method (abc-methods), [6](#)
- [,mifList-method (mif-methods), [23](#)
- [,pmcmcList-method (pmcmc-methods), [36](#)
- [-abcList (abc-methods), [6](#)
- [-mifList (mif-methods), [23](#)
- [-pmcmcList (pmcmc-methods), [36](#)
- \$.bsmcd.pomp-method (bsmc2), [12](#)
- \$.nlf.pomp-method (nlf), [24](#)
- \$.pfilter.pomp-method (pfilter-methods), [30](#)
- \$.probe.matched.pomp-method (probed.pomp-methods), [53](#)
- \$.probed.pomp-method (probed.pomp-methods), [53](#)
- \$.traj.matched.pomp-method (traj.match), [66](#)
- \$.bsmcd.pomp (bsmc2), [12](#)

- `$-nlfd.pomp (nlfd)`, 24
- `$-pfilterd.pomp (pfilter-methods)`, 30
- `$-probe.matched.pomp`
  - `(probed.pomp-methods)`, 53
- `$-probed.pomp (probed.pomp-methods)`, 53
- `$-traj.matched.pomp (traj.match)`, 66
- `abc`, 3, 4, 7
- `abc, abc-method (abc)`, 4
- `abc, pomp-method (abc)`, 4
- `abc, probed.pomp-method (abc)`, 4
- `abc-abc (abc)`, 4
- `abc-class (abc)`, 4
- `abc-methods`, 6, 6
- `abc-pomp (abc)`, 4
- `abc-probed.pomp (abc)`, 4
- `abcList-class (abc-methods)`, 6
- `as, pfilterd.pomp-method`
  - `(pfilter-methods)`, 30
- `as, pomp-method (pomp-methods)`, 44
- `as, probed.pomp-method`
  - `(probed.pomp-methods)`, 53
- `as.data.frame.pfilterd.pomp`
  - `(pfilter-methods)`, 30
- `as.data.frame.pomp`, 44
- `as.data.frame.pomp (pomp-methods)`, 44
- `B-splines`, 7
- `basic.probes`, 8, 51, 52
- `bbs`, 50
- `bbs (sir)`, 60
- `blowflies`, 10, 50
- `blowflies1 (blowflies)`, 10
- `blowflies2 (blowflies)`, 10
- `bsmc`, 3, 4, 30
- `bsmc (bsmc2)`, 12
- `bsmc, pomp-method (bsmc2)`, 12
- `bsmc-pomp (bsmc2)`, 12
- `bsmc2`, 12
- `bsmc2, pomp-method (bsmc2)`, 12
- `bsmc2-pomp (bsmc2)`, 12
- `bspline.basis (B-splines)`, 7
- `c, abc-method (abc-methods)`, 6
- `c, abcList-method (abc-methods)`, 6
- `c, mif-method (mif-methods)`, 23
- `c, mifList-method (mif-methods)`, 23
- `c, pmcmc-method (pmcmc-methods)`, 36
- `c, pmcmcList-method (pmcmc-methods)`, 36
- `c-abc (abc-methods)`, 6
- `c-abcList (abc-methods)`, 6
- `c-mif (mif-methods)`, 23
- `c-mifList (mif-methods)`, 23
- `c-pmcmc (pmcmc-methods)`, 36
- `c-pmcmcList (pmcmc-methods)`, 36
- `coef`, 23, 44
- `coef, pomp-method (pomp-methods)`, 44
- `coef-pomp (pomp-methods)`, 44
- `coef<- (pomp-methods)`, 44
- `coef<- , pomp-method (pomp-methods)`, 44
- `coef<--pomp (pomp-methods)`, 44
- `coerce, pfilterd.pomp, data.frame-method`
  - `(pfilter-methods)`, 30
- `coerce, pomp, data.frame-method`
  - `(pomp-methods)`, 44
- `coerce, probed.pomp, data.frame-method`
  - `(probed.pomp-methods)`, 53
- `compare.mif (mif-methods)`, 23
- `cond.logLik (pfilter-methods)`, 30
- `cond.logLik, pfilterd.pomp-method`
  - `(pfilter-methods)`, 30
- `cond.logLik-pfilterd.pomp`
  - `(pfilter-methods)`, 30
- `continue (mif)`, 20
- `continue, abc-method (abc)`, 4
- `continue, mif-method (mif)`, 20
- `continue, pmcmc-method (pmcmc)`, 34
- `continue-abc (abc)`, 4
- `continue-mif (mif)`, 20
- `continue-pmcmc (pmcmc)`, 34
- `conv.rec (mif-methods)`, 23
- `conv.rec, abc-method (abc-methods)`, 6
- `conv.rec, abcList-method (abc-methods)`, 6
- `conv.rec, mif-method (mif-methods)`, 23
- `conv.rec, mifList-method (mif-methods)`, 23
- `conv.rec, pmcmc-method (pmcmc-methods)`, 36
- `conv.rec, pmcmcList-method`
  - `(pmcmc-methods)`, 36
- `conv.rec-abc (abc-methods)`, 6
- `conv.rec-abcList (abc-methods)`, 6
- `conv.rec-mif (mif-methods)`, 23
- `conv.rec-mifList (mif-methods)`, 23
- `conv.rec-pmcmc (pmcmc-methods)`, 36
- `conv.rec-pmcmcList (pmcmc-methods)`, 36
- `Csnippet`, 14, 32, 33, 39–41



- Csnippet-class (Csnippet), 14
- dacca, 14, 50
- data.array (pomp-methods), 44
- data.array, pomp-method (pomp-methods), 44
- data.array-pomp (pomp-methods), 44
- data.frame-pomp (pomp), 37
- deulermultinom (eulermultinom), 15
- discrete.time.sim, 42
- discrete.time.sim (plugins), 31
- dmeasure, 47
- dprocess, 47
- dyn.load, 48, 49
- eff.sample.size (pfilter-methods), 30
- eff.sample.size, pfilterd.pomp-method (pfilter-methods), 30
- eff.sample.size-pfilterd.pomp (pfilter-methods), 30
- euler.sim, 42, 70
- euler.sim (plugins), 31
- euler.sir, 15, 50
- euler.sir (sir), 60
- eulermultinom, 15, 34
- filter.mean (pfilter-methods), 30
- filter.mean, pfilterd.pomp-method (pfilter-methods), 30
- filter.mean-pfilterd.pomp (pfilter-methods), 30
- getwd, 48
- gillespie.sim, 42
- gillespie.sim (plugins), 31
- gillespie.sir, 50
- gillespie.sir (sir), 60
- gompertz, 17, 50
- init.state, 47
- kernel, 9
- logLik, mif-method (mif-methods), 23
- logLik, nlfd.pomp-method (nlf), 24
- logLik, pfilterd.pomp-method (pfilter-methods), 30
- logLik, pmcmc-method (pmcmc-methods), 36
- logLik, probed.pomp-method (probed.pomp-methods), 53
- logLik, traj.matched.pomp-method (traj.match), 66
- logLik-mif (mif-methods), 23
- logLik-nlfd.pomp (nlf), 24
- logLik-pfilterd.pomp (pfilter-methods), 30
- logLik-pmcmc (pmcmc-methods), 36
- logLik-probed.pomp (probed.pomp-methods), 53
- logLik-traj.matched.pomp (traj.match), 66
- logmeanexp, 18
- LondonYorke, 19
- matrix-pomp (pomp), 37
- mcmc, 37
- mcmc.list, 37
- mean, 9
- mif, 3, 4, 20, 24, 30
- mif, mif-method (mif), 20
- mif, pfilterd.pomp-method (mif), 20
- mif, pomp-method (mif), 20
- mif-class (mif), 20
- mif-methods, 23
- mif-mif (mif), 20
- mif-pfilterd.pomp (mif), 20
- mif-pomp (mif), 20
- mifList-class (mif-methods), 23
- nlf, 3, 4, 24
- nlf, nlfd.pomp-method (nlf), 24
- nlf, pomp-method (nlf), 24
- nlf-nlfd.pomp (nlf), 24
- nlf-pomp (nlf), 24
- nlfd.pomp-class (nlf), 24
- nloptr, 51, 52, 66
- numeric-pomp (pomp), 37
- obs, 10, 44
- obs (pomp-methods), 44
- obs, pomp-method (pomp-methods), 44
- obs-pomp (pomp-methods), 44
- ode, 69
- onestep.dens, 42
- onestep.dens (plugins), 31
- onestep.sim, 42
- onestep.sim (plugins), 31
- optim, 25, 51, 52, 58, 64–67
- ou2, 26, 50

- parmat, 27
- partrans (pomp-methods), 44
- partrans, pomp-method (pomp-methods), 44
- partrans-pomp (pomp-methods), 44
- paste, 7
- periodic.bspline.basis (B-splines), 7
- pfilter, 3, 4, 21, 23, 24, 28, 31, 36, 37
- pfilter, pfilterd.pomp-method (pfilter), 28
- pfilter, pomp-method (pfilter), 28
- pfilter-methods, 30
- pfilter-pfilterd.pomp (pfilter), 28
- pfilter-pomp (pfilter), 28
- pfilterd.pomp, 29
- pfilterd.pomp-class (pfilter), 28
- plot, abc-method (abc-methods), 6
- plot, abcList-method (abc-methods), 6
- plot, bsmcd.pomp-method (bsmc2), 12
- plot, mif-method (mif-methods), 23
- plot, mifList-method (mif-methods), 23
- plot, pmcmc-method (pmcmc-methods), 36
- plot, pmcmcList-method (pmcmc-methods), 36
- plot, pomp-method (pomp-methods), 44
- plot, probe.matched.pomp-method (probed.pomp-methods), 53
- plot, probed.pomp-method (probed.pomp-methods), 53
- plot, spect.matched.pomp-method (probed.pomp-methods), 53
- plot, spect.pomp-method (probed.pomp-methods), 53
- plot-abc (abc-methods), 6
- plot-abcList (abc-methods), 6
- plot-bsmcd.pomp (bsmc2), 12
- plot-mif (mif-methods), 23
- plot-mifList (mif-methods), 23
- plot-pmcmc (pmcmc-methods), 36
- plot-pmcmcList (pmcmc-methods), 36
- plot-pomp (pomp-methods), 44
- plot-probe.matched.pomp (probed.pomp-methods), 53
- plot-probed.pomp (probed.pomp-methods), 53
- plot-spect.pomp (probed.pomp-methods), 53
- plugins, 31, 39, 42, 44
- pmcmc, 3, 4, 30, 34, 37
- pmcmc, pfilterd.pomp-method (pmcmc), 34
- pmcmc, pmcmc-method (pmcmc), 34
- pmcmc, pomp-method (pmcmc), 34
- pmcmc-class (pmcmc), 34
- pmcmc-methods, 36
- pmcmc-pfilterd.pomp (pmcmc), 34
- pmcmc-pmcmc (pmcmc), 34
- pmcmc-pomp (pmcmc), 34
- pmcmcList-class (pmcmc-methods), 36
- pomp, 3, 4, 6, 7, 10, 11, 15, 22–24, 27, 29, 30, 33, 34, 36, 37, 37, 41, 43, 47–49, 51, 56, 59, 64, 66, 67, 69
- pomp, data.frame-method (pomp), 37
- pomp, matrix-method (pomp), 37
- pomp, numeric-method (pomp), 37
- pomp, pomp-method (pomp), 37
- pomp-class, 14, 31, 47, 52, 65
- pomp-class (pomp), 37
- pomp-methods, 44, 44, 52, 65
- pomp-package, 3
- pomp-pomp (pomp), 37
- pompBuilder, 47
- pompExample, 3, 49
- pred.mean (pfilter-methods), 30
- pred.mean, pfilterd.pomp-method (pfilter-methods), 30
- pred.mean-pfilterd.pomp (pfilter-methods), 30
- pred.var (pfilter-methods), 30
- pred.var, pfilterd.pomp-method (pfilter-methods), 30
- pred.var-pfilterd.pomp (pfilter-methods), 30
- print, pomp-method (pomp-methods), 44
- print-pomp (pomp-methods), 44
- probe, 3, 6, 10, 50, 54, 65
- probe, pomp-method (probe), 50
- probe, probed.pomp-method (probe), 50
- probe-pomp (probe), 50
- probe-probed.pomp (probe), 50
- probe.acf (basic.probes), 8
- probe.ccf (basic.probes), 8
- probe.marginal (basic.probes), 8
- probe.match, 3, 4, 10, 52, 54, 58, 65
- probe.match (probe), 50
- probe.match, pomp-method (probe), 50
- probe.match, probe.matched.pomp-method (probe), 50

- probe.match, probed.pomp-method (probe), 50
- probe.match-pomp (probe), 50
- probe.match-probe.matched.pomp (probe), 50
- probe.match-probed.pomp (probe), 50
- probe.match.objfun (probe), 50
- probe.match.objfun, pomp-method (probe), 50
- probe.match.objfun, probed.pomp-method (probe), 50
- probe.match.objfun-pomp (probe), 50
- probe.match.objfun-probed.pomp (probe), 50
- probe.matched.pomp, 51, 54
- probe.matched.pomp-class (probe), 50
- probe.matched.pomp-methods (probed.pomp-methods), 53
- probe.mean (basic.probes), 8
- probe.median (basic.probes), 8
- probe.nlar (basic.probes), 8
- probe.period (basic.probes), 8
- probe.quantile (basic.probes), 8
- probe.sd (basic.probes), 8
- probe.var (basic.probes), 8
- probed.pomp, 5, 54
- probed.pomp-class (probe), 50
- probed.pomp-methods, 53
- profileDesign, 55, 61, 62
- quantile, 9
- reulermultinom (eulermultinom), 15
- rgammawn (eulermultinom), 15
- ricker, 50, 56
- rmeasure, 47
- rprior, 13
- rprocess, 47
- rw2, 50, 56
- sannbox, 51, 57, 66, 67
- show, pomp-method (pomp-methods), 44
- show-pomp (pomp-methods), 44
- simulate, 3, 4, 47, 51
- simulate, pomp-method (simulate-pomp), 58
- simulate-pomp, 51, 58, 63
- sir, 60
- sliceDesign, 61, 62
- sobol, 55, 62
- sobolDesign (sobol), 62
- spect, 63
- spect, pomp-method (spect), 63
- spect, spect.pomp-method (spect), 63
- spect-pomp (spect), 63
- spect-spect.pomp (spect), 63
- spect.match, 3
- spect.match (spect), 63
- spect.match, pomp-method (spect), 63
- spect.match, spect.pomp-method (spect), 63
- spect.match-pomp (spect), 63
- spect.match-spect.pomp (spect), 63
- spect.matched.pomp, 64
- spect.matched.pomp-class (spect), 63
- spect.matched.pomp-methods (probed.pomp-methods), 53
- spect.pomp, 64
- spect.pomp-class (spect), 63
- spect.pomp-methods (probed.pomp-methods), 53
- sprintf, 7
- states, 44
- states (pomp-methods), 44
- states, pomp-method (pomp-methods), 44
- states-pomp (pomp-methods), 44
- subplex, 25, 51, 64, 66, 67
- summary, probe.matched.pomp-method (probed.pomp-methods), 53
- summary, probed.pomp-method (probed.pomp-methods), 53
- summary, spect.matched.pomp-method (probed.pomp-methods), 53
- summary, spect.pomp-method (probed.pomp-methods), 53
- summary, traj.matched.pomp-method (traj.match), 66
- summary-probe.matched.pomp (probed.pomp-methods), 53
- summary-probed.pomp (probed.pomp-methods), 53
- summary-spect.matched.pomp (probed.pomp-methods), 53
- summary-spect.pomp (probed.pomp-methods), 53
- summary-traj.matched.pomp (traj.match), 66
- time, 44

time, pomp-method (pomp-methods), 44  
time-pomp (pomp-methods), 44  
time<- (pomp-methods), 44  
time<-, pomp-method (pomp-methods), 44  
time<--pomp (pomp-methods), 44  
timezero, 44  
timezero (pomp-methods), 44  
timezero, pomp-method (pomp-methods), 44  
timezero-pomp (pomp-methods), 44  
timezero<- (pomp-methods), 44  
timezero<-, pomp-method (pomp-methods),  
44  
timezero<--pomp (pomp-methods), 44  
traj.match, 3, 4, 58, 66, 69  
traj.match, pomp-method (traj.match), 66  
traj.match, traj.matched.pomp-method  
(traj.match), 66  
traj.match-pomp (traj.match), 66  
traj.match-traj.matched.pomp  
(traj.match), 66  
traj.match.objfun (traj.match), 66  
traj.match.objfun, pomp-method  
(traj.match), 66  
traj.match.objfun-pomp (traj.match), 66  
traj.matched.pomp-class (traj.match), 66  
trajectory, 4, 66, 67, 68  
trajectory, pomp-method (trajectory), 68  
trajectory-pomp (trajectory), 68  
  
values (probed.pomp-methods), 53  
values, probe.matched.pomp-method  
(probed.pomp-methods), 53  
values, probed.pomp-method  
(probed.pomp-methods), 53  
values-probe.matched.pomp  
(probed.pomp-methods), 53  
values-probed.pomp  
(probed.pomp-methods), 53  
verhulst, 50, 70  
  
window, 44  
window, pomp-method (pomp-methods), 44  
window-pomp (pomp-methods), 44