

Package ‘rootSolve’

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Title Nonlinear root finding, equilibrium and steady-state analysis of ordinary differential equations

Author Karline Soetaert <k.soetaert@nioo.knaw.nl>

Maintainer Karline Soetaert <k.soetaert@nioo.knaw.nl>

Depends R (>= 2.01)

Description Routines to find the root of nonlinear functions, and to perform steady-state and equilibrium analysis of ordinary differential equations (ODE). Includes routines that: (1) generate gradient and Jacobian matrices (full and banded), (2) find roots of non-linear equations by the Newton-Raphson method, (3) estimate steady-state conditions of a system of (differential) equations in full, banded or sparse form, using the Newton-Raphson method, or by dynamically running, (4) solve the steady-state conditions for uni-and multicomponent 1-D, 2-D, and 3-D partial differential equations, that have been converted to ODEs by numerical differencing (using the method-of-lines approach). Includes fortran code.

License GPL

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rootSolve-package *Roots and steady-states*

Description

Functions that:

- (1) generate gradient and Jacobian matrices (full and banded),
- (2) find roots of non-linear equations by the Newton-Raphson method,
- (3) estimate steady-state conditions of a system of (differential) equations in full, banded or sparse form, using the Newton-Raphson method or by a dynamic run,
- (4) solve the steady-state conditions for uni- and multicomponent 1-D, 2-D and 3-D partial differential equations, that have been converted to ODEs by numerical differencing (using the method-of-lines approach).

Details

Package: rootSolve
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rootSolve was created to solve the examples from chapter 7 (stability and steady-state) from the book of Soetaert and Herman, 2009.

Please cite this work when using rootSolve.

Author(s)

Karline Soetaert

References

Soetaert, K and Herman, PMJ, 2009. A Practical Guide to Ecological Modelling. Using R as a Simulation Platform. Springer, 372pp, ISBN 978-1-4020-8623-6.

See Also

`uniroot.all`, to solve for all roots of one (nonlinear) equation
`multiroot`, to solve n roots of n (nonlinear) equations
`steady`, for a general interface to most of the steady-state solvers
`steady.band`, to find the steady-state of ODE models with a banded Jacobian
`steady.1D`, `steady.2D`, `steady.3D`, steady-state solvers for 1-D, 2-D and 3-D partial differential equations.
`stode`, iterative steady-state solver for ODEs with full or banded Jacobian.
`stodes`, iterative steady-state solver for ODEs with arbitrary sparse Jacobian.
`runsteady`, steady-state solver by dynamically running to steady-state
`jacobian.full`, `jacobian.band`, estimates the Jacobian matrix assuming a full or banded structure.
`gradient`, `hessian`, estimates the gradient matrix or the Hessian.
package vignette rootSolve

Examples

```
## Not run:

## run demos
demo("Jacobandroots")
demo("Steadystate")

## open the directory with documents
browseURL(paste(system.file(package="rootSolve"), "/doc", sep=""))

## main package vignette
vignette("rootSolve")
## End(Not run)
```

gradient

Estimates the gradient matrix for a simple function

Description

Given a vector of variables (x), and a function (f) that estimates one function value or a set of function values ($f(x)$), estimates the gradient matrix, containing, on rows i and columns j

$$d(f(x)_i)/d(x_j)$$

The gradient matrix is not necessarily square.

Usage

```
gradient(f, x, centered = FALSE, pert=1e-8, ...)
```

Arguments

<code>f</code>	function returning one function value, or a vector of function values.
<code>x</code>	either one value or a vector containing the x-value(s) at which the gradient matrix should be estimated.
<code>centered</code>	if TRUE, uses a centered difference approximation, else a forward difference approximation.
<code>pert</code>	numerical perturbation factor; increase depending on precision of model solution.
<code>...</code>	other arguments passed to function <code>f</code> .

Details

the function `f` that estimates the function values will be called as `f(x, ...)`. If `x` is a vector, then the first argument passed to `f` should also be a vector.

The gradient is estimated numerically, by perturbing the x-values.

Value

The gradient matrix where the number of rows equals the length of `f` and the number of columns equals the length of `x`.

the elements on i-th row and j-th column contain: $d((f(x))_i)/d(x_j)$

Note

`gradient` can be used to calculate so-called sensitivity functions, that estimate the effect of parameters on output variables.

Author(s)

Karline Soetaert <k.soetaert@nioo.knaw.nl>

References

Soetaert, K. and P.M.J. Herman (2008). A practical guide to ecological modelling - using R as a simulation platform. Springer.

See Also

[jacobian.full](#), for generating a full and **square** gradient (jacobian) matrix and where the function call is more complex

[hessian](#), for generating the Hessian matrix

Examples

```
#####
# 1. Sensitivity analysis of the logistic differential equation
#  $dN/dt = r \cdot (1 - N/K) \cdot N$  ,  $N(t_0) = N_0$ .

# analytical solution of the logistic equation:
logistic <- function (x,times)
{
  with (as.list(x),
    {
      N=K/(1+(K-N0)/N0*exp(-r*times))
      return(c(N=N))
    })
}

# parameters for the US population from 1900
x=c(N0=76.1,r=0.02,K=500)

# Sensitivity function: SF: dfi/dxj at
# output intervals from 1900 to 1950
SF<-gradient(f=logistic,x,times=0:50)

# sensitivity, scaled for the value of the parameter:
#  $[dfi/(dxj/xj)] = SF \cdot x$  (columnwise multiplication)
sSF<-(t(t(SF)*x))
matplot(sSF,xlab="time",ylab="relative sensitivity ",
        main = "logistic equation",pch=1:3)
legend("topleft",names(x),pch=1:3,col=1:3)

# mean scaled sensitivity
colMeans(sSF)

#####
# 2. Stability of the budworm model, as a function of its
# rate of increase.
#
# Example from the book of Soetaert and Herman(2009)
# A practical guide to ecological modelling,
# using R as a simulation platform. Springer
# code and theory are explained in this book

r <- 0.05
K <- 10
bet <- 0.1
alf <- 1

# density-dependent growth and sigmoid-type mortality rate
rate <- function(x,r=0.05) r*x*(1-x/K)-bet*x^2/(x^2+alf^2)

# Stability of a root ~ sign of eigenvalue of Jacobian
stability <- function (r)
{
```

```

Eq <- uniroot.all(rate,c(0,10),r=r)
eig <- vector()
for (i in 1:length(Eq))
  eig[i] <- sign (gradient (rate,Eq[i],r=r))
return(list (Eq=Eq,Eigen=eig))
}

# bifurcation diagram
rseq <- seq(0.01,0.07,by=0.0001)

plot(0,xlim=range(rseq),ylim=c(0,10),type="n",
     xlab="r",ylab="B*",main="Budworm model, bifurcation",
     sub="Example from Soetaert and Herman, 2009")

for (r in rseq) {
  st <- stability(r)
  points(rep(r,length(st$Eq)),st$Eq,pch=22,
        col=c("darkblue","black","lightblue")[st$Eigen+2],
        bg =c("darkblue","black","lightblue")[st$Eigen+2])
}

legend("topleft",pch=22,pt.cex=2,c("stable","unstable"),
      col=c("darkblue","lightblue"),pt.bg=c("darkblue","lightblue"))

```

hessian

Estimates the hessian matrix

Description

Given a vector of variables (x), and a function (f) that estimates one function value, estimates the hessian matrix by numerical differencing. The hessian matrix is a square matrix of second-order partial derivatives of the function f with respect to x. It contains, on rows i and columns j

$$d^2(f(x))/d(x_i)/d(x_j)$$

Usage

```
hessian(f, x, centered = FALSE, pert=1e-8, ...)
```

Arguments

f	function returning one function value, or a vector of function values.
x	either one value or a vector containing the x-value(s) at which the hessian matrix should be estimated.
centered	if TRUE, uses a centered difference approximation, else a forward difference approximation.
pert	numerical perturbation factor; increase depending on precision of model solution.
...	other arguments passed to function f.

Details

Function `hessian(f, x)` returns a forward or centered difference approximation of the gradient, which itself is also estimated by differencing. Because of that, it is not very precise.

Value

The gradient matrix where the number of rows equals the length of `f` and the number of columns equals the length of `x`.

the elements on *i*-th row and *j*-th column contain: $d((f(x))_i)/d(x_j)$

Author(s)

Karline Soetaert <k.soetaert@nioo.knaw.nl>

See Also

[gradient](#), for a full (not necessarily square) gradient matrix

Examples

```
# the banana function
fun <- function(x) 100*(x[2] - x[1]^2)^2 + (1 - x[1])^2
mm <- nlm(fun, p=c(0,0))$estimate
(Hes <- hessian(fun,mm))
# can also be estimated by nlm(fun, p=c(0,0), hessian=TRUE)
solve(Hes) # estimate of parameter uncertainty
```

jacobian.band	<i>Banded jacobian matrix for a system of ODEs (ordinary differential equations)</i>
---------------	--

Description

Given a vector of (state) variables `y`, and a function that estimates a function value for each (state) variable (e.g. the rate of change), estimates the Jacobian matrix $(d(f(y))/d(y))$.

Assumes a banded structure of the Jacobian matrix, i.e. where the non-zero elements are restricted to a number of bands above and below the diagonal.

Usage

```
jacobian.band(y, func, bandup=1, banddown=1,
  dy=NULL, time=0, parms=NULL, pert=1e-8, ...)
```

Arguments

<code>y</code>	(state) variables, a vector; if <code>y</code> has a name attribute, the names will be used to label the jacobian matrix columns.
<code>func</code>	function that calculates one function value for each element of <code>y</code> ; if an ODE system, <code>func</code> calculates the rate of change (see details).
<code>bandup</code>	number of nonzero bands above the diagonal of the Jacobian matrix.
<code>banddown</code>	number of nonzero bands below the diagonal of the Jacobian matrix.
<code>dy</code>	reference function value; if not specified, it will be estimated by calling <code>func</code> .
<code>time</code>	time, passed to function <code>func</code> .
<code>parms</code>	parameter values, passed to function <code>func</code> .
<code>pert</code>	numerical perturbation factor; increase depending on precision of model solution.
<code>...</code>	other arguments passed to function <code>func</code> .

Details

The function `func` that estimates the rate of change of the state variables has to be consistent with functions called from R-package `deSolve`, which contains integration routines.

This function call is as: **function(time,y,parms,...)** where

- `y`: (state) variable values at which the Jacobian is estimated.
- `parms`: parameter vector - need not be used.
- `time`: time at which the Jacobian is estimated - in general, `time` will not be used.
- `...`: (optional) any other arguments

The Jacobian is estimated numerically, by perturbing the `x`-values.

Value

Jacobian matrix, in banded format, i.e. only the nonzero bands near the diagonal form the rows of the Jacobian.

this matrix has `bandup+banddown+1` rows, while the number of columns equal the length of `y`.

Thus, if the full Jacobian is given by:

	[,1],	[,2],	[,3],	[,4]
[,1]	1	2	0	0
[,2]	3	4	5	0
[,3]	0	6	7	8
[,4]	0	0	9	10

the banded jacobian will be:

	[,1],	[,2],	[,3],	[,4]
[,1]	0	2	5	8

```

[2] 1 4 7 10
[3] 3 6 9 0

```

Author(s)

Karline Soetaert <k.soetaert@nioo.knaw.nl>

See Also

[jacobian.full](#), estimates the Jacobian matrix assuming a full matrix.

[hessian](#), estimates the Hessian matrix.

[gradient](#), for a full (not necessarily square) gradient matrix and where the function call is simpler.

[uniroot.all](#), to solve for all roots of one (nonlinear) equation

[multiroot](#), to solve n roots of n (nonlinear) equations

Examples

```

mod <- function (t=0, y, parms=NULL, ...)
{
  dy1<- y[1] + 2*y[2]
  dy2<-3*y[1] + 4*y[2] + 5*y[3]
  dy3<-      6*y[2] + 7*y[3] + 8*y[4]
  dy4<-      9*y[3] +10*y[4]
  return(as.list(c(dy1, dy2, dy3, dy4)))
}

jacobian.band(y=c(1, 2, 3, 4), func=mod)

```

jacobian.full	<i>Full square jacobian matrix for a system of ODEs (ordinary differential equations)</i>
---------------	---

Description

Given a vector of (state) variables, and a function that estimates one function value for each (state) variable (e.g. the rate of change), estimates the Jacobian matrix $(d(f(x))/d(x))$

Assumes a full and square Jacobian matrix

Usage

```
jacobian.full(y, func, dy =NULL, time=0, parms=NULL, pert=1e-8, ...)
```

Arguments

<code>y</code>	(state) variables, a vector; if <code>y</code> has a name attribute, the names will be used to label the Jacobian matrix columns.
<code>func</code>	function that calculates one function value for each element of <code>y</code> ; if an ODE system, <code>func</code> calculates the rate of change (see details).
<code>dy</code>	reference function value; if not specified, it will be estimated by calling <code>func</code> .
<code>time</code>	time, passed to function <code>func</code> .
<code>parms</code>	parameter values, passed to function <code>func</code> .
<code>pert</code>	numerical perturbation factor; increase depending on precision of model solution.
<code>...</code>	other arguments passed to function <code>func</code> .

Details

The function `func` that estimates the rate of change of the state variables has to be consistent with functions called from R-package `deSolve`, which contains integration routines.

This function call is as: **function(time,y,parms,...)** where

- `y`: (state) variable values at which the Jacobian is estimated.
- `parms`: parameter vector - need not be used.
- `time`: time at which the Jacobian is estimated - in general, `time` will not be used.
- `...`: (optional) any other arguments.

The Jacobian is estimated numerically, by perturbing the `x`-values.

Value

The square jacobian matrix; the elements on `i`-th row and `j`-th column are given by: $d(f(x)_i)/d(x_j)$

Note

This function is useful for stability analysis of ODEs, which start by estimating the Jacobian at equilibrium points. The type of equilibrium then depends on the eigenvalue of the Jacobian.

Author(s)

Karline Soetaert <k.soetaert@nioo.knaw.nl>

See Also

[jacobian.band](#), estimates the Jacobian matrix assuming a banded structure.

[hessian](#), estimates the Hessian matrix.

[gradient](#), for a full (not necessarily square) gradient matrix and where the function call is simpler.

[uniroot.all](#), to solve for all roots of one (nonlinear) equation

[multiroot](#), to solve n roots of n (nonlinear) equations

Examples

```

# 1. Structure of the Jacobian
#-----
mod <- function (t=0,y, parms=NULL,...)
{
  dy1<- y[1] + 2*y[2]
  dy2<-3*y[1] + 4*y[2] + 5*y[3]
  dy3<-      6*y[2] + 7*y[3] + 8*y[4]
  dy4<-      9*y[3] +10*y[4]
  return(as.list(c(dy1,dy2,dy3,dy4)))
}
jacobian.full(y=c(1,2,3,4),func=mod)

# 2. Stability properties of a physical model
#-----
coriolis <- function (t,velocity,parms,f)
{
  dvelx <- f*velocity[2]
  dvely <- -f*velocity[1]
  list(c(dvelx,dvely))
}

# neutral stability; f is coriolis parameter
Jac <- jacobian.full(y=c(velx=0,vely=0),func=coriolis,
                    parms=NULL,f=1e-4)

print(Jac)
eigen(Jac)$values

# 3. Type of equilibrium
#-----
# From Soetaert and Herman (2008). A practical guide to ecological
# modelling. Using R as a simulation platform. Springer

eqn <- function (t,state,parms)
{
  with (as.list(c(state,parms)),
  {
    dx<-a*x + cc*y
    dy<-b*y + dd*x
    list(c(dx,dy))
  })
}

# stable equilibrium
A<-eigen(jacobian.full(y=c(x=0,y=0),func=eqn,
                      parms=c(a=-0.1,b=-0.3,cc=0,dd=0)))$values

# unstable equilibrium
B<-eigen(jacobian.full(y=c(x=0,y=0),func=eqn,
                      parms=c(a=0.2,b=0.2,cc=0.0,dd=0.2)))$values

# saddle point
C<-eigen(jacobian.full(y=c(x=0,y=0),func=eqn,
                      parms=c(a=-0.1,b=0.1,cc=0,dd=0)))$values

```

```

# neutral stability
D<-eigen(jacobian.full(y=c(x=0,y=0),func=eqn,
                        parms=c(a=0,b=0,cc=-0.1,dd=0.1)))$values
# stable focal point
E<-eigen(jacobian.full(y=c(x=0,y=0),func=eqn,
                        parms=c(a=0,b=-0.1,cc=-0.1,dd=0.1)))$values
# unstable focal point
F<-eigen(jacobian.full(y=c(x=0,y=0),func=eqn,
                        parms=c(a=0.,b=0.1,cc=0.1,dd=-0.1)))$values

data.frame(type=c("stable","unstable","saddle","neutral",
                  "stable focus","unstable focus"),
           eigenvalue_1=c(A[1],B[1],C[1],D[1],E[1],F[1]),
           eigenvalue_2=c(A[2],B[2],C[2],D[2],E[2],F[2]))

# 4. Limit cycles
#-----
# From Soetaert and Herman (2008). A practical guide to ecological
# modelling. Using R as a simulation platform. Springer

eqn2 <- function (t,state,parms)
{
  with (as.list(c(state,parms)),
        {
          dx<- a*y +e*x*(x^2+y^2-1)
          dy<- b*x +f*y*(x^2+y^2-1)
          list(c(dx,dy))
        })
}

# stable limit cycle with unstable focus
eigen(jacobian.full(c(x=0,y=0),eqn2,parms=c(a=-1,b=1,e=-1,f=-1)))$values
# unstable limit cycle with stable focus
eigen(jacobian.full(c(x=0,y=0),eqn2,parms=c(a=-1,b=1,e=1,f=1)))$values

```

multiroot

Solves for n roots of n (nonlinear) equations.

Description

Given a vector of n variables, and a set of n (nonlinear) equations in these variables, estimates the root of the equations, i.e. the variable values where all function values = 0. Assumes a full Jacobian matrix, uses the Newton-Raphson method.

Usage

```

multiroot(f, start, maxiter=100,
          rtol=1e-6, atol=1e-8, ctol=1e-8,
          useFortran=TRUE, positive=FALSE,

```

```
jacfunc=NULL, jactype="fullint",
verbose=FALSE, bandup=1, banddown=1, ...)
```

Arguments

<code>f</code>	function for which the root is sought; it must return a vector with as many values as the length of <code>start</code> .
<code>start</code>	vector containing initial guesses for the unknown <code>x</code> ; if <code>start</code> has a name attribute, the names will be used to label the output vector.
<code>maxiter</code>	maximal number of iterations allowed.
<code>rtol</code>	relative error tolerance, either a scalar or a vector, one value for each element in the unknown <code>x</code> .
<code>atol</code>	absolute error tolerance, either a scalar or a vector, one value for each element in <code>x</code> .
<code>ctol</code>	a scalar. If between two iterations, the maximal change in the variable values is less than this amount, then it is assumed that the root is found.
<code>useFortran</code>	logical, if <code>FALSE</code> , then an R -implementation of the Newton-Raphson method is used - see details.
<code>positive</code>	if <code>TRUE</code> , the unknowns <code>y</code> are forced to be non-negative numbers.
<code>jacfunc</code>	if not <code>NULL</code> , a user-supplied R function that estimates the Jacobian of the system of differential equations $dy(i)/dy(j)$. In some circumstances, supplying <code>jacfunc</code> can speed up the computations. The R calling sequence for <code>jacfunc</code> is identical to that of <code>func</code> . If the Jacobian is a full matrix, <code>jacfunc</code> should return a matrix $dydot/dy$, where the i th row contains the derivative of dy_i/dt with respect to y_j , or a vector containing the matrix elements by columns. If the Jacobian is banded, <code>jacfunc</code> should return a matrix containing only the nonzero bands of the jacobian, ($dydot/dy$), rotated row-wise.
<code>jactype</code>	the structure of the Jacobian, one of "fullint", "fullusr", "bandusr", "bandint", or "sparse" - either full or banded and estimated internally or by the user, or arbitrary sparse. If the latter, then the solver will call, <code>stodes</code> , else <code>stode</code> If the Jacobian is arbitrarily "sparse", then it will be calculated by the solver (i.e. it is not possible to also specify <code>jacfunc</code>).
<code>verbose</code>	if <code>TRUE</code> : full output to the screen, e.g. will output the steady-state settings.
<code>bandup</code>	number of non-zero bands above the diagonal, in case the Jacobian is banded.
<code>banddown</code>	number of non-zero bands below the diagonal, in case the jacobian is banded.
<code>...</code>	additional arguments passed to function <code>f</code> .

Details

`start` gives the initial guess for each variable; different initial guesses may return different roots.

The input parameters `rtol`, and `atol` determine the **error control** performed by the solver.

The solver will control the vector `e` of estimated local errors in `f`, according to an inequality of the form $\max\text{-norm of } (e/ewt) \leq 1$, where `ewt` is a vector of positive error weights. The values of `rtol` and `atol` should all be non-negative.

The form of `ewt` is:

$$\mathbf{rtol} \times \mathbf{abs}(\mathbf{f}) + \mathbf{atol}$$

where multiplication of two vectors is element-by-element.

In addition, the solver will stop if between two iterations, the maximal change in the values of `x` is less than `ctol`.

There is no checking whether the requested precision exceeds the capabilities of the machine.

Value

a list containing:

<code>root</code>	the location (x-values) of the root.
<code>f.root</code>	the value of the function evaluated at the <code>root</code> .
<code>iter</code>	the number of iterations used.
<code>estim.precis</code>	the estimated precision for <code>root</code> . It is defined as the mean of the absolute function values (<code>mean(abs(f.root))</code>).

Note

The Fortran implementation of the Newton-Raphson method function (the default) is generally faster than the R implementation. The R implementation has been included for didactic purposes.

`multiroot` makes use of function `stode`. Technically, it is just a wrapper around function `stode`. If the sparsity structure of the Jacobian is known, it may be more efficiently to call `stode`, `stodes`, `steady`, `steady.1D`, `steady.2D`, `steady.3D`.

It is NOT guaranteed that the method will converge to the root.

Author(s)

Karline Soetaert <k.soetaert@nioo.knaw.nl>

See Also

[stode](#), which uses a different function call.

[uniroot.all](#), to solve for all roots of one (nonlinear) equation

[steady](#), [steady.band](#), [steady.1D](#), [steady.2D](#), [steady.3D](#), steady-state solvers, which find the roots of ODEs or PDEs. The function call differs from `multiroot`.

[jacobian.full](#), [jacobian.band](#), estimates the Jacobian matrix assuming a full or banded structure.

[gradient](#), [hessian](#), estimates the gradient matrix or the Hessian.

Examples

```

# example 1
# 2 simultaneous equations
model <- function(x) c(F1=x[1]^2+ x[2]^2 -1,F2=x[1]^2- x[2]^2 +0.5)

(ss<-multiroot(f=model,start=c(1,1)))

# example 2
# 3 equations, two solutions
model <- function(x) c(F1= x[1] + x[2] + x[3]^2 - 12,
                      F2= x[1]^2 - x[2] + x[3] - 2,
                      F3= 2 * x[1] - x[2]^2 + x[3] - 1 )

# first solution
(ss<-multiroot(model,c(1,1,1),useFortran=FALSE))
(ss<-multiroot(f=model,start=c(1,1,1)))

# second solution; use different start values
(ss<-multiroot(model,c(0,0,0)))
model(ss$root)

# example 3: find a matrix
f2<-function(x)
{
  X<-matrix(nr=5,x)
  X %*% X %*% X -matrix(nr=5,data=1:25,byrow=TRUE)
}
x<-multiroot(f2, start= 1:25 )$root
X<-matrix(nr=5,x)

X%*%X%*%X

```

multiroot.1D

Solves for n roots of n (nonlinear) equations, created by discretizing ordinary differential equations.

Description

multiroot.1D finds the solution to boundary value problems of ordinary differential equations, which are approximated using the method-of-lines approach.

Assumes a banded Jacobian matrix, uses the Newton-Raphson method.

Usage

```

multiroot.1D(f, start, maxiter=100,
            rtol=1e-6, atol=1e-8, ctol=1e-8,
            nspec = NULL, dimens = NULL,
            verbose=FALSE,positive=FALSE, names=NULL, ...)

```

Arguments

<code>f</code>	function for which the root is sought; it must return a vector with as many values as the length of <code>start</code> .
<code>start</code>	vector containing initial guesses for the unknown <code>x</code> ; if <code>start</code> has a name attribute, the names will be used to label the output vector.
<code>maxiter</code>	maximal number of iterations allowed.
<code>rtol</code>	relative error tolerance, either a scalar or a vector, one value for each element in the unknown <code>x</code> .
<code>atol</code>	absolute error tolerance, either a scalar or a vector, one value for each element in <code>x</code> .
<code>ctol</code>	a scalar. If between two iterations, the maximal change in the variable values is less than this amount, then it is assumed that the root is found.
<code>nspec</code>	the number of <i>*species*</i> (components) in the model. If <code>NULL</code> , then <code>dimens</code> should be specified.
<code>dimens</code>	the number of <i>*boxes*</i> in the model. If <code>NULL</code> , then <code>nspec</code> should be specified.
<code>verbose</code>	if <code>TRUE</code> : full output to the screen, e.g. will output the steady-state settings.
<code>positive</code>	if <code>TRUE</code> , the unknowns <code>y</code> are forced to be non-negative numbers.
<code>names</code>	the names of the components; used to label the output, which will be written as a matrix.
<code>...</code>	additional arguments passed to function <code>f</code> .

Details

`multiroot.1D` is similar to `steady.1D`, except for the function specification which is simpler in `multiroot.1D`.

It is to be used to solve (simple) boundary value problems of differential equations.

The following differential equation:

$$0 = f(x, y, \frac{dy}{dx}, \frac{d^2y}{dx^2})$$

with boundary conditions

$y_{x=a} = y_a$, at the start and $y_{x=b} = y_b$ at the end of the integration interval `[a,b]` is approximated as follows:

1. First the integration interval `x` is discretized, for instance:

```
dx <- 0.01
```

```
x <- seq(a, b, by=dx)
```

where `dx` should be small enough to keep numerical errors small.

2. Then the first- and second-order derivatives are differenced on this numerical grid. R's `diff` function is very efficient in taking numerical differences, so it is used to approximate the first-, and second-order derivatives as follows.

A *first-order derivative* y' can be approximated either as:

$y' = \text{diff}(c(ya, y)) / dx$ if only the initial condition ya is prescribed,

$y' = \text{diff}(c(y, yb)) / dx$ if only the final condition, yb is prescribed,

$y' = 0.5 * (\text{diff}(c(ya, y)) / dx + \text{diff}(c(y, yb)) / dx)$ if initial, ya , and final condition, yb are prescribed.

The latter (centered differences) is to be preferred.

A *second-order derivative* y'' can be approximated by differencing twice.

$y'' = \text{diff}(\text{diff}(c(ya, y, yb)) / dx) / dx$

3. Finally, function `multiroot.1D` is used to locate the root.

See the examples

Value

a list containing:

<code>root</code>	the values of the root.
<code>f.root</code>	the value of the function evaluated at the <code>root</code> .
<code>iter</code>	the number of iterations used.
<code>estim.precis</code>	the estimated precision for <code>root</code> . It is defined as the mean of the absolute function values (<code>mean(abs(f.root))</code>).

Note

`multiroot.1D` makes use of function `steady.1D`.

It is NOT guaranteed that the method will converge to the root.

Author(s)

Karline Soetaert <k.soetaert@nioo.knaw.nl>

See Also

[stode](#), which uses a different function call.

[uniroot.all](#), to solve for all roots of one (nonlinear) equation

[steady](#), [steady.band](#), [steady.1D](#), [steady.2D](#), [steady.3D](#), steady-state solvers, which find the roots of ODEs or PDEs. The function call differs from `multiroot`.

[jacobian.full](#), [jacobian.band](#), estimates the Jacobian matrix assuming a full or banded structure.

[gradient](#), [hessian](#), estimates the gradient matrix or the Hessian.

Examples

```

=====
# Example 1: simple standard problem
# solve the BVP ODE:
#  $d^2y/dt^2 = -3py/(p+t^2)^2$ 
#  $y(t = -0.1) = -0.1/\sqrt{p+0.01}$ 
#  $y(t = 0.1) = 0.1/\sqrt{p+0.01}$ 
# where  $p = 1e-5$ 
#
# analytical solution  $y(t) = t/\sqrt{p + t^2}$ .
#
=====

bvp <- function(y) {
  dy2 <- diff(diff(c(ya,y,yb))/dx)/dx
  return(dy2+3*p*y/(p+x^2)^2)
}

dx<-0.0001
x<-seq(-0.1,0.1,by = dx)

p <- 1e-5
ya<- -0.1/sqrt(p+0.01)
yb<- 0.1/sqrt(p+0.01)

print(system.time(y<-multiroot.1D(start=runif(length(x)),f=bvp,nspec=1)))
plot(x,y$root, ylab="y", main="BVP test problem")

# add analytical solution
curve(x/sqrt(p+x*x),add=TRUE,type="l",col="red")

=====
# Example 2: bvp test problem 28
# solve:
#  $\xi y'' + y y' - y = 0$ 
# with boundary conditions:
#  $y_0 = 1$ 
#  $y_1 = 3/2$ 
#
=====

prob28 <-function(y,xi) {
  dy2 = diff(diff(c(ya,y,yb))/dx)/dx      # y''
  dy  = 0.5*(diff(c(ya,y)) +diff(c(y,yb)))/dx  # y' - centered differences

  xi*dy2 +dy*y-y
}

ya <- 1
yb <- 3/2
dx <- 0.001
x <- seq(0,1,by=dx)
print(system.time(

```

```

Y1 <- multiroot.1D(f=prob28,start=runif(length(x)),nspec=1, xi=0.1)
))
Y2<- multiroot.1D(f=prob28,start=runif(length(x)),nspec=1, xi=0.01)
Y3<- multiroot.1D(f=prob28,start=runif(length(x)),nspec=1, xi=0.001)

plot(x,Y3$root,type="l",col="green",main="bvp test problem 28")
lines(x,Y2$root,col="red")
lines(x,Y1$root,col="blue")

```

runsteady	<i>Dynamically runs a system of ordinary differential equations (ODE) to steady-state</i>
-----------	---

Description

Solves the steady-state condition of ordinary differential equations (ODE) in the form:

$$dy/dt = f(t, y)$$

by dynamically running till the summed absolute values of the derivatives become smaller than some predefined tolerance.

The R function `runsteady` makes use of the FORTRAN ODE solver DLSODE, written by Alan C. Hindmarsh and Andrew H. Sherman

The system of ODE's is written as an R function or defined in compiled code that has been dynamically loaded. The user has to specify whether or not the problem is stiff and choose the appropriate solution method (e.g. make choices about the type of the Jacobian).

Usage

```

runsteady(y, times=c(0,Inf), func, parms, stol=1e-8, rtol=1e-6, atol=1e-6,
  jacfunc=NULL, jactype="fullint", mf=NULL, verbose=FALSE, tcrit=NULL,
  hmin=0, hmax=NULL, hini=0, ynames=TRUE, maxord=NULL, bandup=NULL,
  banddown=NULL, maxsteps=100000, dllname=NULL, initfunc=dllname,
  initpar=parms, rpar=NULL, ipar=NULL, nout=0, outnames=NULL, ...)

```

Arguments

<code>y</code>	the initial (state) values for the ODE system. If <code>y</code> has a name attribute, the names will be used to label the output matrix.
<code>times</code>	The simulation time. This should be a 2-valued vector, consisting of the initial time and the end time. The last time value should be large enough to make sure that steady-state is effectively reached in this period. The simulation will stop either when <code>times[2]</code> has been reached or when <code>maxsteps</code> have been performed.

func	<p>either an R-function that computes the values of the derivatives in the ODE system (the <i>model definition</i>) at time <code>t</code>, or a character string giving the name of a compiled function in a dynamically loaded shared library.</p> <p>If <code>func</code> is an R-function, it must be defined as: <code>yprime = func(t, y, parms, ...)</code>. <code>t</code> is the current time point in the integration, <code>y</code> is the current estimate of the variables in the ODE system. If the initial values <code>y</code> has a names attribute, the names will be available inside <code>func</code>. <code>parms</code> is a vector or list of parameters; ... (optional) are any other arguments passed to the function.</p> <p>The return value of <code>func</code> should be a list, whose first element is a vector containing the derivatives of <code>y</code> with respect to time, and whose next elements are global values that are required at each point in <code>times</code>.</p> <p>The derivatives should be specified in the same order as the state variables <code>y</code>.</p>
parms	vector or list of parameters used in <code>func</code> or <code>jacfunc</code> .
stol	steady-state tolerance; it is assumed that steady-state is reached if the average of absolute values of the derivatives drops below this number.
rtol	relative error tolerance of integrator, either a scalar or an array as long as <code>y</code> . See details.
atol	absolute error tolerance of integrator, either a scalar or an array as long as <code>y</code> . See details.
jacfunc	<p>if not NULL, an R function that computes the jacobian of the system of differential equations $dy(i)/dy(j)$, or a string giving the name of a function or subroutine in 'dllname' that computes the jacobian (see Details below for more about this option). In some circumstances, supplying <code>jacfunc</code> can speed up the computations, if the system is stiff. The R calling sequence for <code>jacfunc</code> is identical to that of <code>func</code>.</p> <p>If the jacobian is a full matrix, <code>jacfunc</code> should return a matrix $dydot/dy$, where the ith row contains the derivative of dy_i/dt with respect to y_j, or a vector containing the matrix elements by columns (the way R and Fortran store matrices). If the jacobian is banded, <code>jacfunc</code> should return a matrix containing only the nonzero bands of the jacobian, rotated row-wise. See first example of <code>lsode</code>.</p>
jactype	the structure of the jacobian, one of "fullint", "fullusr", "bandusr" or "bandint" - either full or banded and estimated internally or by user; overruled if <code>mf</code> is not NULL.
mf	the "method flag" passed to function <code>lsode</code> - overrules <code>jactype</code> - provides more options than <code>jactype</code> - see details.
verbose	if TRUE: full output to the screen, e.g. will output the settings of vectors <code>*istate*</code> and <code>*rstate*</code> - see details.
tcrit	if not NULL, then <code>lsode</code> cannot integrate past <code>tcrit</code> . The Fortran routine <code>lsode</code> overshoots its targets (times points in the vector <code>times</code>), and interpolates values for the desired time points. If there is a time beyond which integration should not proceed (perhaps because of a singularity), that should be provided in <code>tcrit</code> .
hmin	an optional minimum value of the integration stepsize. In special situations this parameter may speed up computations with the cost of precision. Don't use <code>hmin</code> if you don't know why!

<code>hmax</code>	an optional maximum value of the integration stepsize. If not specified, <code>hmax</code> is set to the largest difference in <code>times</code> , to avoid that the simulation possibly ignores short-term events. If 0, no maximal size is specified.
<code>hini</code>	initial step size to be attempted; if 0, the initial step size is determined by the solver.
<code>ynames</code>	if FALSE: names of state variables are not passed to function <code>func</code> ; this may speed up the simulation.
<code>maxord</code>	the maximum order to be allowed. NULL uses the default, i.e. order 12 if implicit Adams method (<code>meth=1</code>), order 5 if BDF method (<code>meth=2</code>). Reduce <code>maxord</code> to save storage space.
<code>bandup</code>	number of non-zero bands above the diagonal, in case the jacobian is banded.
<code>banddown</code>	number of non-zero bands below the diagonal, in case the jacobian is banded.
<code>maxsteps</code>	maximal number of steps. The simulation will stop either when <code>maxsteps</code> have been performed or when <code>times[2]</code> has been reached.
<code>dllname</code>	a string giving the name of the shared library (without extension) that contains all the compiled function or subroutine definitions referred to in <code>func</code> and <code>jacfunc</code> . See package vignette.
<code>initfunc</code>	if not NULL, the name of the initialisation function (which initialises values of parameters), as provided in 'dllname'. See package vignette.
<code>initpar</code>	only when 'dllname' is specified and an initialisation function <code>initfunc</code> is in the dll: the parameters passed to the initialiser, to initialise the common blocks (fortran) or global variables (C, C++).
<code>rpar</code>	only when 'dllname' is specified: a vector with double precision values passed to the dll-functions whose names are specified by <code>func</code> and <code>jacfunc</code> .
<code>ipar</code>	only when 'dllname' is specified: a vector with integer values passed to the dll-functions whose names are specified by <code>func</code> and <code>jacfunc</code> .
<code>nout</code>	only used if <code>dllname</code> is specified and the model is defined in compiled code: the number of output variables calculated in the compiled function <code>func</code> , present in the shared library. Note: it is not automatically checked whether this is indeed the number of output variables calculated in the dll - you have to perform this check in the code - See package vignette of <code>deSolve</code> .
<code>outnames</code>	only used if 'dllname' is specified and <code>nout > 0</code> : the names of output variables calculated in the compiled function <code>func</code> , present in the shared library.
<code>...</code>	additional arguments passed to <code>func</code> and <code>jacfunc</code> allowing this to be a generic function.

Details

The work is done by the Fortran subroutine `dlssode`, whose documentation should be consulted for details (it is included as comments in the source file 'src/lssode.f'). The implementation is based on the November, 2003 version of `lsode`, from Netlib.

Before using `runsteady`, the user has to decide whether or not the problem is stiff.

If the problem is nonstiff, use method flag `mf = 10`, which selects a nonstiff (Adams) method, no Jacobian used..

If the problem is stiff, there are four standard choices which can be specified with `jactype` or `mf`.

The options for **jactype** are

- `jactype = "fullint"` : a full jacobian, calculated internally by `lsode`, corresponds to `mf=22`.
- `jactype = "fullusr"` : a full jacobian, specified by user function `jacfunc`, corresponds to `mf=21`.
- `jactype = "bandusr"` : a banded jacobian, specified by user function `jacfunc`; the size of the bands specified by `bandup` and `banddown`, corresponds to `mf=24`.
- `jactype = "bandint"` : a banded jacobian, calculated by `lsode`; the size of the bands specified by `bandup` and `banddown`, corresponds to `mf=25`.

More options are available when specifying **mf** directly.

The legal values of `mf` are 10, 11, 12, 13, 14, 15, 20, 21, 22, 23, 24, 25.

`mf` is a positive two-digit integer, $mf = (10 * METH + MITER)$, where

- **METH** indicates the basic linear multistep method: **METH = 1** means the implicit Adams method. **METH = 2** means the method based on backward differentiation formulas (BDF-s).
- **MITER** indicates the corrector iteration method: **MITER = 0** means functional iteration (no Jacobian matrix is involved). **MITER = 1** means chord iteration with a user-supplied full (NEQ by NEQ) Jacobian. **MITER = 2** means chord iteration with an internally generated (difference quotient) full Jacobian (using NEQ extra calls to `func` per `df/dy` value). **MITER = 3** means chord iteration with an internally generated diagonal Jacobian approximation (using 1 extra call to `func` per `df/dy` evaluation). **MITER = 4** means chord iteration with a user-supplied banded Jacobian. **MITER = 5** means chord iteration with an internally generated banded Jacobian (using `ML+MU+1` extra calls to `func` per `df/dy` evaluation).

If **MITER = 1** or **4**, the user must supply a subroutine `jacfunc`.

Inspection of the example below shows how to specify both a banded and full jacobian.

The input parameters `rtol`, and `atol` determine the **error control** performed by the solver.

See `stode` for details.

Models may be defined in compiled C or Fortran code, as well as in an R-function. See function `stode` for details.

The output will have the **attributes** `*istate*`, and `*rstate*`, two vectors with several useful elements.

if `verbose = TRUE`, the settings of `istate` and `rstate` will be written to the screen.

the following elements of **istate** are meaningful:

- `el 1` : gives the conditions under which the last call to the integrator returned. 2 if `lsode` was successful, -1 if excess work done, -2 means excess accuracy requested. (Tolerances too small), -3 means illegal input detected. (See printed message.), -4 means repeated error test failures. (Check all input), -5 means repeated convergence failures. (Perhaps bad Jacobian supplied or wrong choice of MF or tolerances.), -6 means error weight became zero during problem. (Solution component `i` vanished, and `atol` or `atol(i) = 0`.)
- `el 12` : The number of steps taken for the problem so far.
- `el 13` : The number of evaluations for the problem so far.,

- el 14 : The number of Jacobian evaluations and LU decompositions so far.,
- el 15 : The method order last used (successfully),.
- el 16 : The order to be attempted on the next step.,
- el 17 : if el 1 =-4,-5: the largest component in the error vector,

rstate contains the following:

- 1: The step size in t last used (successfully).
- 2: The step size to be attempted on the next step.
- 3: The current value of the independent variable which the solver has actually reached, i.e. the current internal mesh point in t.
- 4: A tolerance scale factor, greater than 1.0, computed when a request for too much accuracy was detected.

For more information, see the comments in the original code lsoode.f

Value

A list containing

- | | |
|------------------|--|
| <code>y</code> | a vector with the state variable values from the last iteration during estimation of steady-state condition of the system of equations. If <code>y</code> has a names attribute, it will be used to label the output values. |
| <code>...</code> | the number of "global" values returned. |

The output will have the attribute `steady`, which returns `TRUE`, if steady-state has been reached, the attribute `precis` with the precision attained at the last iteration estimated as the mean absolute rate of change ($\text{sum}(\text{abs}(\text{dy}))/n$), the attribute `time` with the simulation time reached and the attribute `steps` with the number of steps performed.

The output will also have the attributes `istate`, and `rstate`, two vectors with several useful elements of the dynamic simulation. See details. The first element of `istate` returns the conditions under which the last call to the integrator returned. Normal is `istate[1] = 2`. If `verbose = TRUE`, the settings of `istate` and `rstate` will be written to the screen.

Author(s)

Karline Soetaert <k.soetaert@nioo.knaw.nl>

References

Alan C. Hindmarsh, "ODEPACK, A Systematized Collection of ODE Solvers," in Scientific Computing, R. S. Stepleman, et al., Eds. (North-Holland, Amsterdam, 1983), pp. 55-64.

See Also

[steady](#), for a general interface to most of the steady-state solvers

[steady.band](#), to find the steady-state of ODE models with a banded Jacobian

[steady.1D](#), [steady.2D](#), [steady.3D](#) steady-state solvers for 1-D, 2-D and 3-D partial differential equations.

[stode](#), iterative steady-state solver for ODEs with full or banded Jacobian.

[stodes](#), iterative steady-state solver for ODEs with arbitrary sparse Jacobian.

Examples

```
# A simple sediment biogeochemical model

model<-function(t,y,pars)
{
  with (as.list(c(y,pars)),{

    Min      = r*OM
    oxicmin   = Min*(O2/(O2+ks))
    anoxicmin = Min*(1-O2/(O2+ks))* S04/(S04+ks2)

    dOM = Flux - oxicmin - anoxicmin
    dO2 = -oxicmin      -2*rox*HS*(O2/(O2+ks)) + D*(BO2-O2)
    dSO4 = -0.5*anoxicmin +rox*HS*(O2/(O2+ks)) + D*(BSO4-SO4)
    dHS  = 0.5*anoxicmin  -rox*HS*(O2/(O2+ks)) + D*(BHS-HS)

    list(c(dOM,dO2,dSO4,dHS),SumS=S04+HS)
  })
}

# parameter values
pars <- c(D=1,Flux=100,r=0.1,rox =1,
          ks=1,ks2=1,BO2=100,BSO4=10000,BHS = 0)
# initial conditions
y<-c(OM=1,O2=1,S04=1,HS=1)

# direct iteration
print( system.time(ST <- stode(y=y,func=model,parms=pars,pos=TRUE)))

print( system.time(
  ST2 <- runsteady(y=y,func=model,parms=pars,times=c(0,1000))) )

rbind("Newton Raphson"=ST$y, "Runsteady"=ST2$y)
```

steady *General steady-state solver for a set of ordinary differential equations.*

Description

Estimates the steady-state condition for a system of ordinary differential equations.

This is a wrapper around steady-state solvers `stode`, `stodes` and `runsteady`.

Usage

```
steady(y, time=0, func, parms=NULL, method="stode", ...)
```

Arguments

<code>y</code>	the initial guess of (state) values for the ODE system, a vector. If <code>y</code> has a <code>name</code> attribute, the names will be used to label the output matrix.
<code>time</code>	time for which steady-state is wanted; the default is <code>time=0</code> .
<code>func</code>	either an R-function that computes the values of the derivatives in the ode system (the model definition) at time <code>time</code> , or a character string giving the name of a compiled function in a dynamically loaded shared library. If <code>func</code> is an R-function, it must be defined as: <code>yprime = func(t, y, parms, ...)</code> . <code>t</code> is the current time point in the integration, <code>y</code> is the current estimate of the variables in the ODE system. If the initial values <code>y</code> has a <code>names</code> attribute, the names will be available inside <code>func</code> . <code>parms</code> is a vector or list of parameters; ... (optional) are any other arguments passed to the function. The return value of <code>func</code> should be a list, whose first element is a vector containing the derivatives of <code>y</code> with respect to <code>time</code> , and whose next elements are global values whose steady-state value is also required. The derivatives should be specified in the same order as the state variables <code>y</code> .
<code>parms</code>	parameters passed to <code>func</code> .
<code>method</code>	the solution method to use, one of <code>stode</code> , <code>stodes</code> or <code>runsteady</code> .
<code>...</code>	additional arguments passed to function <code>stode</code> , <code>stodes</code> or <code>runsteady</code> .

Details

This is simply a wrapper around the various steady-state solvers.

See package vignette for information about specifying the model in compiled code.

See the selected solver for the additional options.

Value

A list containing

<code>y</code>	a vector with the state variable values from the last iteration during estimation of steady-state condition of the system of equations. If <code>y</code> has a <code>names</code> attribute, it will be used to label the output values.
----------------	---

... the number of "global" values returned.

The output will have the attribute `steady`, which returns `TRUE`, if steady-state has been reached and the attribute `precis` with the precision attained during each iteration.

Author(s)

Karline Soetaert <k.soetaert@nioo.knaw.nl>

See Also

[steady.band](#), to find the steady-state of ODE models with a banded Jacobian

[steady.1D](#), [steady.2D](#), [steady.3D](#), steady-state solvers for 1-D, 2-D and 3-D partial differential equations.

[stode](#), iterative steady-state solver for ODEs with full or banded Jacobian.

[stodes](#), iterative steady-state solver for ODEs with arbitrary sparse Jacobian.

[runsteady](#), steady-state solver by dynamically running to steady-state

Examples

```
#####
### Bacteria growing on a substrate
#####

# Bacteria (Bac) are growing on a substrate (Sub)
model <- function(t, state, pars)
{
  with (as.list(c(state, pars)), {
    #      substrate uptake          death  respiration
    dBact = gmax*eff*Sub/(Sub+ks)*Bact - dB*Bact - rB*Bact
    dSub  =-gmax  *Sub/(Sub+ks)*Bact + dB*Bact          +input

    return(list(c(dBact, dSub)))
  })
}

pars <- list(gmax =0.5, eff = 0.5,
            ks =0.5, rB =0.01, dB =0.01, input=0.1)
# Newton-Raphson
steady(y=c(Bact=0.1, Sub=0), time=0,
      func=model, parms=pars, pos=TRUE)

# Dynamic run to steady-state
as.data.frame(steady(y=c(Bact=0.1, Sub=0), time=c(0, 1e5),
                    func=model, parms=pars, method="runsteady"))
```

steady.1D	<i>Steady-state solver for multicomponent 1-D ordinary differential equations</i>
-----------	---

Description

Estimates the steady-state condition for a system of ordinary differential equations that result from 1-Dimensional partial differential equation models that have been converted to ODEs by numerical differencing.

It is assumed that exchange occurs only between adjacent layers.

Usage

```
steady.1D(y, time=0, func, parms=NULL, nspec=NULL, dims=NULL,
          names=NULL, method = "stode", cyclicBnd = NULL, ...)
```

Arguments

y	the initial guess of (state) values for the ODE system, a vector.
time	time for which steady-state is wanted; the default is time=0.
func	either an R-function that computes the values of the derivatives in the ode system (the model definition) at time <code>time</code> , or a character string giving the name of a compiled function in a dynamically loaded shared library. If <code>func</code> is an R-function, it must be defined as: <code>yprime = func(t, y, parms, ...)</code> . <code>t</code> is the current time point in the integration, <code>y</code> is the current estimate of the variables in the ODE system. If the initial values <code>y</code> has a <code>names</code> attribute, the names will be available inside <code>func</code> . <code>parms</code> is a vector or list of parameters; ... (optional) are any other arguments passed to the function. The return value of <code>func</code> should be a list, whose first element is a vector containing the derivatives of <code>y</code> with respect to <code>time</code> , and whose next elements are global values whose steady-state value is also required. The derivatives should be specified in the same order as the state variables <code>y</code> .
parms	parameters passed to <code>func</code> .
nspec	the number of <i>*species*</i> (components) in the model. If <code>NULL</code> , then <code>dims</code> should be specified.
dims	the number of <i>*boxes*</i> in the model. If <code>NULL</code> , then <code>nspec</code> should be specified.
names	the names of the components; used to label the output, which will be written as a matrix.
method	the solution method, one of "stode", "stodes" or "runsteady".
cyclicBnd	if a cyclic boundary exists, a value of 1 else <code>NULL</code> ; see details.
...	additional arguments passed to the solver function as defined by <code>method</code> .

Details

This is the method of choice for multi-species 1-dimensional models, that are only subjected to transport between adjacent layers

More specifically, this method is to be used if the state variables are arranged per species:

A[1],A[2],A[3],....B[1],B[2],B[3],.... (for species A, B))

Two methods are implemented.

- The default method rearranges the state variables as A[1],B[1],...A[2],B[2],...A[3],B[3],.... This reformulation leads to a banded Jacobian with (upper and lower) half bandwidth = number of species. Then function `stode` solves the banded problem.
- The second method uses function `stodes`. Based on the dimension of the problem, the method first calculates the sparsity pattern of the Jacobian, under the assumption that transport is only occurring between adjacent layers. Then `stodes` is called to solve the problem. As `stodes` is used to estimate steady-state, it may be necessary to specify the length of the real work array, `lrw`. Although a reasonable guess of `lrw` is made, it is possible that this will be too low. In this case, `steady.1D` will return with an error message telling the size of the work array actually needed. In the second try then, set `lrw` equal to this number.

For single-species 1-D models, use `steady.band`.

If state variables are arranged as (e.g. A[1],B[1],A[2],B[2],A[3],B[3],... then the model should be solved with `steady.band`

In some cases, a cyclic boundary condition exists. This is when the first box interacts with the last box and vice versa. In this case, there will be extra non-zero fringes in the Jacobian which need to be taken into account. The occurrence of cyclic boundaries can be toggled on by specifying argument `cyclicBnd=1`. If this is the case, then the steady-state will be estimated using `stodes`. The default is no cyclic boundaries.

Value

A list containing

<code>y</code>	if <code>names</code> is not given: a vector with the state variable values from the last iteration during estimation of steady-state condition of the system of equations. if <code>names</code> is given, a matrix with one column for every steady-state *component*.
<code>...</code>	the number of "global" values returned.

The output will have the attribute `steady`, which returns TRUE, if steady-state has been reached and the attribute `precis` with the precision attained during each iteration.

Note

It is advisable though not mandatory to specify BOTH `nspec` and `dimens`. In this case, the solver can check whether the input makes sense (i.e. if `nspec*dimens = length(y)`)

Author(s)

Karline Soetaert <k.soetaert@nioo.knaw.nl>

See Also

[steady](#), for a general interface to most of the steady-state solvers
[steady.band](#), to find the steady-state of ODE models with a banded Jacobian
[steady.2D](#), [steady.3D](#), steady-state solvers for 2-D and 3-D partial differential equations.
[stode](#), iterative steady-state solver for ODEs with full or banded Jacobian.
[stodes](#), iterative steady-state solver for ODEs with arbitrary sparse Jacobian.
[runsteady](#), steady-state solver by dynamically running to steady-state

Examples

```
#####
#####  EXAMPLE 1: BOD + O2  #####
#####
# Biochemical Oxygen Demand (BOD) and oxygen (O2) dynamics
# in a river

#####
# Model equations #
#####
O2BOD <- function(t,state,pars)

{
  BOD <- state[1:N]
  O2  <- state[(N+1):(2*N)]

# BOD dynamics
  FluxBOD <- v*c(BOD_0,BOD) # fluxes due to water transport
  FluxO2  <- v*c(O2_0,O2)

  BODrate <- r*BOD*O2/(O2+10) # 1-st order consumption, Monod in oxygen

#rate of change = flux gradient - consumption + reaeration (O2)
  dBOD <- -diff(FluxBOD)/dx - BODrate
  dO2  <- -diff(FluxO2)/dx - BODrate + p*(O2sat-O2)

  return(list(c(dBOD=dBOD,dO2=dO2),BODrate=BODrate))
} # END O2BOD

#####
# Model application#
#####
# parameters
dx <- 100 # grid size, meters
v <- 1e2 # velocity, m/day
x <- seq(dx/2,10000,by=dx) # m, distance from river
N <- length(x)
r <- 0.1 # /day, first-order decay of BOD
p <- 0.1 # /day, air-sea exchange rate
```

```

O2sat <- 300      # mmol/m3 saturated oxygen conc
O2_0  <- 50      # mmol/m3 riverine oxygen conc
BOD_0  <- 1500   # mmol/m3 riverine BOD concentration

# initial guess:
state <- c(rep(200,N),rep(200,N))

# running the model
print(system.time(
  out <- steady.1D (y=state,func=O2BOD,parms=NULL,
                  nspec=2,pos=TRUE,names=c("BOD","O2"))))

#####
# Plotting output #
#####
mf <- par(mfrow=c(2,2))
plot(x,out$y[,"O2"],xlab="Distance from river",
     ylab="mmol/m3",main="Oxygen",type="l")

plot(x,out$y[,"BOD"],xlab="Distance from river",
     ylab="mmol/m3",main="BOD",type="l")

plot(x,out$BODrate,xlab="Distance from river",
     ylab="mmol/m3/d",main="BOD decay rate",type="l")
par(mfrow=mf)

# same, but now running dynamically to steady-state
print(system.time(
  out2 <- steady.1D (y=state,func=O2BOD,parms=NULL, nspec=2,
                  time=c(0,1000),method="runsteady"))))

#####
##### EXAMPLE 2: Silicate diagenesis #####
#####
# Example from the book:
# Soetaert and Herman (2009).
# a practical guide to ecological modelling -
# using R as a simulation platform.
# Springer

#####
# Model equations #
#####

SiDIAModel <- function (time=0,      # time, not used here
                       Conc,        # concentrations: BSi, DSi
                       parms=NULL) # parameter values; not used
{
  BSi<- Conc[1:N]
  DSi<- Conc[(N+1):(2*N)]

# transport
# diffusive fluxes at upper interface of each layer

```

```

# upper concentration imposed (bwDSi), lower: zero gradient
DSiFlux <- -SedDisp * IntPor *diff(c(bwDSi ,DSi,DSi[N]))/thick
BSiFlux <- -Db * (1-IntPor)*diff(c(BSi[1],BSi,BSi[N]))/thick

BSiFlux[1] <- BSidepo # upper boundary flux is imposed

# BSi dissolution
Dissolution <- rDissSi * BSi*(1.- DSi/EquilSi )^pow
Dissolution <- pmax(0,Dissolution)

# Rate of change= Flux gradient, corrected for porosity + dissolution
dDSi <- -diff(DSiFlux)/thick/Porosity + # transport
      Dissolution * (1-Porosity)/Porosity # biogeochemistry

dBSi <- -diff(BSiFlux)/thick/(1-Porosity) - Dissolution

return(list(c(dBSi=dBSi,dDSi=dDSi), # Rates of changes
            Dissolution=Dissolution, # Profile of dissolution rates
            DSiSurfFlux =DSiFlux[1], # DSi sediment-water exchange rate
            DSiDeepFlux =DSiFlux[N+1], # DSi deep-water (burial) flux
            BSiDeepFlux =BSiFlux[N+1])) # BSi deep-water (burial) flux
}

#####
# Model run #
#####
# sediment parameters
thick <- 0.1 # thickness of sediment layers (cm)
Intdepth <- seq(0,10,by=thick) # depth at upper interface of layers
Nint <- length(Intdepth) # number of interfaces
Depth <- 0.5*(Intdepth[-Nint] +Intdepth[-1]) # depth at middle of layers
N <- length(Depth) # number of layers

por0 <- 0.9 # surface porosity (-)
pordeep <- 0.7 # deep porosity (-)
porcoef <- 2 # porosity decay coefficient (/cm)
# porosity profile, middle of layers
Porosity <- pordeep + (por0-pordeep)*exp(-Depth*porcoef)
# porosity profile, upper interface
IntPor <- pordeep + (por0-pordeep)*exp(-Intdepth*porcoef)

dB0 <- 1/365 # cm2/day - bioturbation coefficient
dBcoeff <- 2
mixdepth <- 5 # cm
Db <- pmin(dB0,dB0*exp(-(Intdepth-mixdepth)*dBcoeff))

# biogeochemical parameters
SedDisp <- 0.4 # diffusion coefficient, cm2/d
rDissSi <- 0.005 # dissolution rate, /day
EquilSi <- 800 # equilibrium concentration
pow <- 1
BSidepo <- 0.2*100 # nmol/cm2/day

```

```

bwDSi    <- 150                # mmol/m3

# initial guess of state variables-just random numbers between 0,1
Conc     <- runif(2*N)

# three runs with different deposition rates
BSidepo <- 0.2*100            # nmol/cm2/day
sol     <- steady.1D (Conc, func=SiDIAModel, parms=NULL, nspec=2)
CONC    <- sol$y

BSidepo <- 2*100              # nmol/cm2/day
sol2    <- steady.1D (Conc, func=SiDIAModel, parms=NULL, nspec=2)
CONC    <- cbind(CONC,sol2$y)

BSidepo <- 3*100              # nmol/cm2/day
sol3    <- steady.1D (Conc, func=SiDIAModel, parms=NULL, nspec=2)
CONC    <- cbind(CONC,sol3$y)

DSi     <- CONC[(N+1):(2*N),]
BSi     <- CONC[1:N,]

#####
# plotting output      #
#####
par(mfrow=c(2,2))

matplot(DSi,Depth,ylim=c(10,0),xlab="mmolSi/m3 Liquid",
        main="DSi",type="l",lwd=c(1,2,1),col="black")
matplot(BSi,Depth,ylim=c(10,0),xlab="mmolSi/m3 Solid" ,
        main="BSi",type="l",lwd=c(1,2,1),col="black")
legend("right",c("0.2","2","3"),title="mmol/m2/d",
      lwd=c(1,2,1),lty=1:3)
plot(Porosity,Depth,ylim=c(10,0),xlab="-" ,
     main="Porosity",   type="l",lwd=2)
plot(Db,Intdepth,ylim=c(10,0),xlab="cm2/d",
     main="Bioturbation",type="l",lwd=2)
mtext(outer=TRUE,side=3,line=-2,cex=1.5,"SiDIAModel")

```

steady.2D

Steady-state solver for 2-Dimensional ordinary differential equations

Description

Estimates the steady-state condition for a system of ordinary differential equations that result from 2-Dimensional partial differential equation models that have been converted to ODEs by numerical differencing.

It is assumed that exchange occurs only between adjacent layers.

Usage

```
steady.2D(y, time=0, func, parms=NULL, nspec=NULL, dimens,
         cyclicBnd = NULL, ...)
```

Arguments

<code>y</code>	the initial guess of (state) values for the ODE system, a vector.
<code>time</code>	time for which steady-state is wanted; the default is <code>time=0</code> .
<code>func</code>	either an R-function that computes the values of the derivatives in the ode system (the model definition) at time <code>time</code> , or a character string giving the name of a compiled function in a dynamically loaded shared library. If <code>func</code> is an R-function, it must be defined as: <code>yprime = func(t, y, parms, ...)</code> . <code>t</code> is the current time point in the integration, <code>y</code> is the current estimate of the variables in the ODE system. If the initial values <code>y</code> has a <code>names</code> attribute, the names will be available inside <code>func</code> . <code>parms</code> is a vector or list of parameters; ... (optional) are any other arguments passed to the function. The return value of <code>func</code> should be a list, whose first element is a vector containing the derivatives of <code>y</code> with respect to <code>time</code> , and whose next elements are global values whose steady-state value is also required. The derivatives should be specified in the same order as the state variables <code>y</code> .
<code>parms</code>	parameters passed to <code>func</code> .
<code>nspec</code>	the number of *species* (components) in the model.
<code>dimens</code>	a 2-valued vector with the dimensionality of the model, i.e. the number of *boxes* in x- and y-direction.
<code>cyclicBnd</code>	if not <code>NULL</code> then a number or a 2-valued vector with the dimensions where a cyclic boundary is used - 1: x-dimension, 2: y-dimension; see details.
<code>...</code>	additional arguments passed to function <code>stodes</code> .

Details

This is the method of choice for 2-dimensional models, that are only subjected to transport between adjacent layers.

Based on the dimension of the problem, the method first calculates the sparsity pattern of the Jacobian, under the assumption that transport is only occurring between adjacent layers. Then `stodes` is called to find the steady-state.

As `stodes` is used, it will probably be necessary to specify the length of the real work array, `lrw`. Although a reasonable guess of `lrw` is made, it may occur that this will be too low. In this case, `steady.2D` will return with an error message telling the size of the work array actually needed. In the second try then, set `lrw` equal to this number.

In some cases, a cyclic boundary condition exists. This is when the first boxes in x-or y-direction interact with the last boxes. In this case, there will be extra non-zero fringes in the Jacobian which need to be taken into account. The occurrence of cyclic boundaries can be toggled on by specifying argument `cyclicBnd`. For instance, `cyclicBnd = 1` indicates that a cyclic boundary is required only for the x-direction, whereas `cyclicBnd = c(1,2)` imposes a cyclic boundary for both x- and y-direction. The default is no cyclic boundaries.

See `stodes` for the additional options.

Value

A list containing

`y` a vector with the state variable values from the last iteration during estimation of steady-state condition of the system of equations.
 ... the number of "global" values returned.

The output will have the attribute `steady`, which returns `TRUE`, if steady-state has been reached and the attribute `precis` with the precision attained during each iteration.

Note

It is advisable though not mandatory to specify BOTH `nspec` and `dimens`. In this case, the solver can check whether the input makes sense (as `nspec*dimens[1]*dimens[2] = length(y)`)
 do NOT use this method for problems that are not 2D.

Author(s)

Karline Soetaert <k.soetaert@nioo.knaw.nl>

See Also

[steady](#), for a general interface to most of the steady-state solvers
[steady.band](#), to find the steady-state of ODE models with a banded Jacobian
[steady.1D](#), [steady.3D](#), steady-state solvers for 1-D and 3-D partial differential equations.
[stode](#), iterative steady-state solver for ODEs with full or banded Jacobian.
[stodes](#), iterative steady-state solver for ODEs with arbitrary sparse Jacobian.
[runsteady](#), steady-state solver by dynamically running to steady-state

Examples

```
#####
# Diffusion in 2-D; imposed boundary conditions
#####
diffusion2D <- function(t,Y,par)
{
  y <- matrix(nr=n,nc=n,data=Y) # vector to 2-D matrix
  dY <- -r*y # consumption
  BND <- rep(1,n) # boundary concentration

  #diffusion in X-direction; boundaries=imposed concentration
  Flux <- -Dx * rbind(y[,1]-BND, (y[,2:n]-y[,1:(n-1)]), BND-y[,n])/dx
  dY <- dY - (Flux[,2:(n+1)]-Flux[,1:n])/dx

  #diffusion in Y-direction
  Flux <- -Dy * cbind(y[,1]-BND, (y[,2:n]-y[,1:(n-1)]), BND-y[,n])/dy
  dY <- dY - (Flux[,2:(n+1)]-Flux[,1:n])/dy

  return(list(as.vector(dY)))
}
```

```

}

# parameters
dy  <- dx <- 1  # grid size
Dy  <- Dx <- 1  # diffusion coeff, X- and Y-direction
r   <- 0.025    # consumption rate

n   <- 100
y   <- matrix(nr=n,nc=n,10.)

ST3 <- steady.2D(y,func=diffusion2D,parms=NULL,pos=TRUE,dimens=c(n,n),
                 lrw=1000000,atol=1e-10,rtol=1e-10,ctol=1e-10)
y   <- matrix(nr=n,nc=n,data=ST3$y)
     filled.contour(y,color.palette=terrain.colors)

#####
# Diffusion in 2-D; extra flux on 2 boundaries, cyclic in y
#####

diffusion2Db <- function(t,Y,par)
{
  y   <- matrix(nr=nx,nc=ny,data=Y) # vector to 2-D matrix
  dY  <- -r*y                       # consumption

  BNDx <- rep(1,nx)  # boundary concentration
  BNDy <- rep(1,ny)  # boundary concentration

  #diffusion in X-direction; boundaries=imposed concentration
  Flux <- -Dx * rbind(y[1,]-BNDy, (y[2:nx,]-y[1:(nx-1),]), BNDy-y[nx,])/dx
  dY   <- dY - (Flux[2:(nx+1),]-Flux[1:nx,])/dx

  #diffusion in Y-direction
  Flux <- -Dy * cbind(y[,1]-BNDx, (y[,2:ny]-y[,1:(ny-1)]), BNDx-y[,ny])/dy
  dY   <- dY - (Flux[,2:(ny+1)]-Flux[,1:ny])/dy

  # extra flux on two sides
  dY[,1] <- dY[,1]+ 10
  dY[1,] <- dY[1,]+ 10

  # and exchange between sides on y-direction
  dY[,ny] <- dY[,ny]+ (y[,1]-y[,ny])*10

  return(list(as.vector(dY)))
}

# parameters
dy  <- dx <- 1  # grid size
Dy  <- Dx <- 1  # diffusion coeff, X- and Y-direction
r   <- 0.025    # consumption rate

nx  <- 50
ny  <- 100

```

```

y <- matrix(nr=nx,nc=ny,10.)
print(system.time(
ST3 <- steady.2D(y,func=diffusion2Db, parms=NULL, pos=TRUE,
                dims=c(nx,ny),verbose=TRUE,
                lrw=283800, atol=1e-10, rtol=1e-10, ctol=1e-10,
                cyclicBnd=2)          # y-direction: cyclic boundary
))
y <- matrix(nr=nx,nc=ny,data=ST3$y)
filled.contour(y,color.palette=terrain.colors)

```

steady.3D

Steady-state solver for 3-Dimensional ordinary differential equations

Description

Estimates the steady-state condition for a system of ordinary differential equations that result from 3-Dimensional partial differential equation models that have been converted to ODEs by numerical differencing.

It is assumed that exchange occurs only between adjacent layers.

Usage

```

steady.3D(y, time=0, func, parms=NULL, nspec=NULL, dims,
          cyclicBnd = NULL, ...)

```

Arguments

y	the initial guess of (state) values for the ODE system, a vector.
time	time for which steady-state is wanted; the default is time=0.
func	either an R-function that computes the values of the derivatives in the ode system (the model definition) at time <code>time</code> , or a character string giving the name of a compiled function in a dynamically loaded shared library. If <code>func</code> is an R-function, it must be defined as: <code>yprime = func(t, y, parms, ...)</code> . <code>t</code> is the current time point in the integration, <code>y</code> is the current estimate of the variables in the ODE system. If the initial values <code>y</code> has a <code>names</code> attribute, the names will be available inside <code>func</code> . <code>parms</code> is a vector or list of parameters; ... (optional) are any other arguments passed to the function. The return value of <code>func</code> should be a list, whose first element is a vector containing the derivatives of <code>y</code> with respect to <code>time</code> , and whose next elements are global values whose steady-state value is also required. The derivatives should be specified in the same order as the state variables <code>y</code> .
parms	parameters passed to <code>func</code> .
nspec	the number of <i>*species*</i> (components) in the model.
dims	a 3-valued vector with the dimensionality of the model, i.e. the number of <i>*boxes*</i> in x-, y- and z- direction.

`cyclicBnd` if not `NULL` then a number or a 3-valued vector with the dimensions where a cyclic boundary is used - 1: x-dimension, 2: y-dimension; 3: z-dimension; see details.

`...` additional arguments passed to function `stodes`.

Details

This is the method of choice for 3-dimensional models, that are only subjected to transport between adjacent layers.

Based on the dimension of the problem, the method first calculates the sparsity pattern of the Jacobian, under the assumption that transport is only occurring between adjacent layers. Then `stodes` is called to find the steady-state.

As `stodes` is used, it will probably be necessary to specify the length of the real work array, `lrw`.

Although a reasonable guess of `lrw` is made, it may occur that this will be too low. In this case, `steady.3D` will return with an error message telling the size of the work array actually needed. In the second try then, set `lrw` equal to this number.

In some cases, a cyclic boundary condition exists. This is when the first boxes in x-, y-, or z-direction interact with the last boxes. In this case, there will be extra non-zero fringes in the Jacobian which need to be taken into account. The occurrence of cyclic boundaries can be toggled on by specifying argument `cyclicBnd`. For instance, `cyclicBnd = 1` indicates that a cyclic boundary is required only for the x-direction, whereas `cyclicBnd = c(1, 2)` imposes a cyclic boundary for both x- and y-direction. The default is no cyclic boundaries.

See `stodes` for the additional options.

Value

A list containing

`y` a vector with the state variable values from the last iteration during estimation of steady-state condition of the system of equations.

`...` the number of "global" values returned.

The output will have the attribute `steady`, which returns `TRUE`, if steady-state has been reached and the attribute `precis` with the precision attained during each iteration.

Note

It is advisable though not mandatory to specify BOTH `nspec` and `dimens`. In this case, the solver can check whether the input makes sense (as `nspec*dimens[1]*dimens[2]*dimens[3] = length(y)`) do NOT use this method for problems that are not 3D.

Author(s)

Karline Soetaert <k.soetaert@nioo.knaw.nl>

See Also

[steady](#), for a general interface to most of the steady-state solvers
[steady.band](#), to find the steady-state of ODE models with a banded Jacobian
[steady.1D](#), [steady.2D](#), steady-state solvers for 1-D and 2-D partial differential equations.
[stode](#), iterative steady-state solver for ODEs with full or banded Jacobian.
[stodes](#), iterative steady-state solver for ODEs with arbitrary sparse Jacobian.
[runsteady](#), steady-state solver by dynamically running to steady-state

Examples

```
#####
# Diffusion in 3-D; imposed boundary conditions
#####
diffusion3D <- function(t,Y,par)
{
  yy    <- array(dim=c(n,n,n),data=Y) # vector to 3-D array
  dY    <- -r*yy # consumption
  BND   <- rep(1,n) # boundary concentration
  for (i in 1:n) {
    y <- yy[i,,]
    #diffusion in X-direction; boundaries=imposed concentration
    Flux <- -Dy * rbind(y[1,]-BND, (y[2:n,]-y[1:(n-1),]), BND-y[,n])/dy
    dY[i,,] <- dY[i,,] - (Flux[2:(n+1),]-Flux[1:n,])/dy

    #diffusion in Y-direction
    Flux <- -Dz * cbind(y[,1]-BND, (y[,2:n]-y[,1:(n-1)]), BND-y[,n])/dz
    dY[i,,] <- dY[i,,] - (Flux[,2:(n+1)]-Flux[,1:n])/dz
  }
  for (j in 1:n) {
    y <- yy[,j,]
    #diffusion in X-direction; boundaries=imposed concentration
    Flux <- -Dx * rbind(y[1,]-BND, (y[2:n,]-y[1:(n-1),]), BND-y[,n])/dx
    dY[,j,] <- dY[,j,] - (Flux[2:(n+1),]-Flux[1:n,])/dx

    #diffusion in Y-direction
    Flux <- -Dz * cbind(y[,1]-BND, (y[,2:n]-y[,1:(n-1)]), BND-y[,n])/dz
    dY[,j,] <- dY[,j,] - (Flux[,2:(n+1)]-Flux[,1:n])/dz
  }
  for (k in 1:n) {
    y <- yy[, ,k]
    #diffusion in X-direction; boundaries=imposed concentration
    Flux <- -Dx * rbind(y[1,]-BND, (y[2:n,]-y[1:(n-1),]), BND-y[,n])/dx
    dY[, ,k] <- dY[, ,k] - (Flux[2:(n+1),]-Flux[1:n,])/dx

    #diffusion in Y-direction
    Flux <- -Dy * cbind(y[,1]-BND, (y[,2:n]-y[,1:(n-1)]), BND-y[,n])/dy
    dY[, ,k] <- dY[, ,k] - (Flux[,2:(n+1)]-Flux[,1:n])/dy
  }
  return(list(as.vector(dY)))
}

```

```

# parameters
dy   <- dx <- dz <-1   # grid size
Dy   <- Dx <- Dz <-1   # diffusion coeff, X- and Y-direction
r    <- 0.025          # consumption rate

n    <- 10
y    <- array(dim=c(n,n,n),data=10.)

print(system.time(
  ST3 <- steady.3D(y, func=diffusion3D, parms=NULL, pos=TRUE,
                  dims=c(n,n,n), lrw=100000,
                  atol=1e-10, rtol=1e-10, ctol=1e-10, verbose=TRUE)
))
y <- array(dim=c(n,n,n),data=ST3$y)
filled.contour(y[, , n/2], color.palette=terrain.colors)

```

steady.band	<i>Steady-state solver for ordinary differential equations; assumes a banded jacobian</i>
-------------	---

Description

Estimates the steady-state condition for a system of ordinary differential equations.
Assumes a banded jacobian matrix.

Usage

```
steady.band(y, time=0, func, parms=NULL,
            nspec=NULL, bandup=nspec, banddown=nspec, ...)
```

Arguments

y	the initial guess of (state) values for the ODE system, a vector. If y has a name attribute, the names will be used to label the output matrix.
time	time for which steady-state is wanted; the default is time=0.
func	either an R-function that computes the values of the derivatives in the ode system (the model definition) at time time, or a character string giving the name of a compiled function in a dynamically loaded shared library. If func is an R-function, it must be defined as: <code>yprime = func(t, y, parms, ...)</code> . t is the current time point in the integration, y is the current estimate of the variables in the ODE system. If the initial values y has a names attribute, the names will be available inside func. parms is a vector or list of parameters; ... (optional) are any other arguments passed to the function.

The return value of `func` should be a list, whose first element is a vector containing the derivatives of `y` with respect to `time`, and whose next elements are global values whose steady-state value is also required.

The derivatives should be specified in the same order as the state variables `y`.

<code>parms</code>	parameters passed to <code>func</code> .
<code>nspec</code>	the number of *species* (components) in the model.
<code>bandup</code>	the number of nonzero bands above the Jacobian diagonal.
<code>banddown</code>	the number of nonzero bands below the Jacobian diagonal.
<code>...</code>	additional arguments passed to function <code>stode</code> .

Details

This is the method of choice for single-species 1-D models.

For multi-species 1-D models, this method can only be used if the state variables are arranged per box, per species (e.g. `A[1],B[1],A[2],B[2],A[3],B[3],...` for species A, B).

Usually a 1-D *model* function will have the species arranged as `A[1],A[2],A[3],...B[1],B[2],B[3],...` in this case, use `steady.1D`

Value

A list containing

<code>y</code>	a vector with the state variable values from the last iteration during estimation of steady-state condition of the system of equations. If <code>y</code> has a <code>names</code> attribute, it will be used to label the output values.
<code>...</code>	the number of "global" values returned.

The output will have the attribute `steady`, which returns `TRUE`, if steady-state has been reached and the attribute `precis` with the precision attained during each iteration.

Author(s)

Karline Soetaert <k.soetaert@nioo.knaw.nl>

See Also

[steady](#), for a general interface to most of the steady-state solvers

[steady.1D](#), [steady.2D](#), [steady.3D](#), steady-state solvers for 1-D, 2-D and 3-D partial differential equations.

[stode](#), iterative steady-state solver for ODEs with full or banded Jacobian.

[stodes](#), iterative steady-state solver for ODEs with arbitrary sparse Jacobian.

[runsteady](#), steady-state solver by dynamically running to steady-state

Examples

```
#####
# 1000 simultaneous equations, solved 6 times for different
# values of parameter "decay"
#####
model <- function (time,OC,parms,decay)
{
  # model of particles (OC) that sink out of the water and decay
  # exponentially declining sinking rate, maximal 100 m/day
  sink <- 100*exp(-0.01*dist)

  # boundary flux; upper boundary=imposed concentration (100)
  Flux <- sink * c(100 ,OC)

  # Rate of change= Flux gradient and first-order consumption
  dOC <- -diff(Flux)/dx - decay*OC
  list(dOC,maxC=max(OC))
}
dx <- 1 # thickness of boxes
dist <- seq(0,1000,by=dx) # water depth at each modeled box interface

ss <- NULL
for (decay in seq(from=0.1,to=1.1,by=0.2))
  ss <- cbind(ss,steady.band(runif(1000),func=model,
    parms=NULL,nspec=1,decay=decay)$y)

matplot(ss,1:1000,type="l",lwd=2,main="steady.band", ylim=c(1000,0),
  ylab="water depth, m", xlab="concentration of sinking particles")
legend("bottomright",legend=seq(from=0.1,to=1.1,by=0.2),lty=1:10,
  title="decay rate",col=1:10,lwd=2)

#####
# 5001 simultaneous equations: solve
#  $dy/dt = 0 = d^2y/dx^2 + 1/x*dy/dx + (1-1/(4x^2))y - \sqrt{x} \cos(x)$ ,
# over the interval [1,6]
# with boundary conditions:  $y(1)=1$ ,  $y(6)=-0.5$ 
#####

derivs <- function(t,y,parms, x,dx,N,y1,y6)
{
  # Numerical approximation of derivates:
  #  $d^2y/dx^2 = (y_{i+1}-2y_i+y_{i-1})/dx^2$ 
  d2y <- (c(y[-1],y6) - 2*y + c(y1,y[-N])) /dx/dx

  #  $dy/dx = (y_{i+1}-y_{i-1})/(2dx)$ 
  dy <- (c(y[-1],y6) - c(y1,y[-N])) /2/dx

  res <- d2y+dy/x+(1-1/(4*x*x))*y-sqrt(x)*cos(x)
  return(list(res))
}
```

```

dx      <- 0.001
x       <- seq(1, 6, by=dx)
N       <- length(x)
y      <- steady.band(y=rep(1, N), time=0, func=derivs, x=x, dx=dx,
                    N=N, y1=1, y6=-0.5, nspec=1) $y
plot(x, y, type="l", main="5001 nonlinear equations - banded Jacobian")

# add the analytic solution for comparison:
xx      <- seq(1, 6, by=0.1)
ana     <- 0.0588713*cos(xx)/sqrt(xx)+1/4*sqrt(xx)*cos(xx)+
         0.740071*sin(xx)/sqrt(xx)+1/4*xx^(3/2)*sin(xx)
points(xx, ana)
legend("topright", pch=c(NA, 1), lty=c(1, NA), c("numeric", "analytic"))

```

stode	<i>Iterative steady-state solver for ordinary differential equations (ODE) and a full or banded Jacobian.</i>
-------	---

Description

Estimates the steady-state condition for a system of ordinary differential equations (ODE) written in the form:

$$dy/dt = f(t, y)$$

i.e. finds the values of y for which $f(t, y) = 0$.

Uses a newton-raphson method, implemented in Fortran 77.

The system of ODE's is written as an R function or defined in compiled code that has been dynamically loaded.

Usage

```

stode(y, time=0, func, parms=NULL,
      rtol=1e-6, atol=1e-8, ctol=1e-8, jacfunc=NULL,
      jactype="fullint", verbose=FALSE, bandup=1, banddown=1,
      positive=FALSE, maxiter=100, ynames=TRUE,
      dllname=NULL, initfunc=dllname, initpar=parms,
      rpar=NULL, ipar=NULL, nout=0, outnames = NULL, ...)

```

Arguments

<code>y</code>	the initial guess of (state) values for the ode system, a vector. If <code>y</code> has a name attribute, the names will be used to label the output matrix.
<code>time</code>	time for which steady-state is wanted; the default is <code>time=0</code> .

<code>func</code>	<p>either a user-supplied function that computes the values of the derivatives in the ode system (the <i>model definition</i>) at time <code>time</code>, or a character string giving the name of a compiled function in a dynamically loaded shared library.</p> <p>If <code>func</code> is a user-supplied function, it must be called as: <code>yprime = func(t, y, parms, ...)</code>. <code>t</code> is the time point at which the steady-state is wanted, <code>y</code> is the current estimate of the variables in the ode system. If the initial values <code>y</code> has a <code>names</code> attribute, the <code>names</code> will be available inside <code>func</code>. <code>parms</code> is a vector of parameters (which may have a <code>names</code> attribute).</p> <p>The return value of <code>func</code> should be a list, whose first element is a vector containing the derivatives of <code>y</code> with respect to <code>time</code>, and whose next elements (possibly with a <code>names</code> attribute) are global values that are required as output. The derivatives should be specified in the same order as the state variables <code>y</code>.</p> <p>If <code>func</code> is a string, then <code>dllname</code> must give the name of the shared library (without extension) which must be loaded before <code>stode()</code> is called. see Details for more information.</p>
<code>parms</code>	other parameters passed to <code>func</code> and <code>jacfunc</code> .
<code>rtol</code>	relative error tolerance, either a scalar or a vector, one value for each <code>y</code> .
<code>atol</code>	absolute error tolerance, either a scalar or a vector, one value for each <code>y</code> .
<code>ctol</code>	if between two iterations, the maximal change in <code>y</code> is less than this amount, steady-state is assumed to be reached.
<code>jacfunc</code>	<p>if not <code>NULL</code>, either a user-supplied R function that estimates the Jacobian of the system of differential equations $dy_{dot}(i)/dy(j)$, or a character string giving the name of a compiled function in a dynamically loaded shared library as provided in <code>dllname</code>. In some circumstances, supplying <code>jacfunc</code> can speed up the computations. The R calling sequence for <code>jacfunc</code> is identical to that of <code>func</code>.</p> <p>If the Jacobian is a full matrix, <code>jacfunc</code> should return a matrix <code>dydot/dy</code>, where the <code>i</code>th row contains the derivative of dy_i/dt with respect to y_j, or a vector containing the matrix elements by columns (the way R and Fortran store matrices). If the Jacobian is banded, <code>jacfunc</code> should return a matrix containing only the nonzero bands of the jacobian, (<code>dydot/dy</code>), rotated row-wise.</p>
<code>jactype</code>	the structure of the Jacobian, one of "fullint", "fullusr", "bandusr", or "bandint" - either full or banded and estimated internally or by the user.
<code>verbose</code>	if <code>TRUE</code> : full output to the screen, e.g. will output the steady-state settings.
<code>bandup</code>	number of non-zero bands above the diagonal, in case the Jacobian is banded.
<code>banddown</code>	number of non-zero bands below the diagonal, in case the jacobian is banded.
<code>positive</code>	either a logical or a vector with indices of the state variables that have to be non-negative; if <code>TRUE</code> , all state variables <code>y</code> are forced to be non-negative numbers.
<code>maxiter</code>	maximal number of iterations during one call to the solver.
<code>ynames</code>	if <code>FALSE</code> : names of state variables are not passed to function <code>func</code> ; this may speed up the simulation especially for multi-D models.
<code>dllname</code>	a string giving the name of the shared library (without extension) that contains all the compiled function or subroutine definitions referred to in <code>func</code> and <code>jacfunc</code> .

<code>initfunc</code>	if not NULL, the name of the initialisation function (which initialises values of parameters), as provided in 'dllname'. See details.
<code>initpar</code>	only when 'dllname' is specified and an initialisation function <code>initfunc</code> is in the dll: the parameters passed to the initialiser, to initialise the common blocks (FORTRAN) or global variables (C, C++).
<code>rpar</code>	only when 'dllname' is specified: a vector with double precision values passed to the dll-functions whose names are specified by <code>func</code> and <code>jacfunc</code> .
<code>ipar</code>	only when 'dllname' is specified: a vector with integer values passed to the dll-functions whose names are specified by <code>func</code> and <code>jacfunc</code> .
<code>nout</code>	only used if 'dllname' is specified and the model is defined in compiled code: the number of output variables calculated in the compiled function <code>func</code> , present in the shared library. Note: it is not automatically checked whether this is indeed the number of output variables calculated in the dll - you have to perform this check in the code - see package vignette.
<code>outnames</code>	only used if 'dllname' is specified and <code>nout > 0</code> : the names of output variables calculated in the compiled function <code>func</code> , present in the shared library.
<code>...</code>	additional arguments passed to <code>func</code> and <code>jacfunc</code> allowing this to be a generic function.

Details

The work is done by a Fortran 77 routine that implements the Newton-Raphson method. It uses code from LINPACK.

The form of the **Jacobian** can be specified by `jactype` which can take the following values:

- `jactype = "fullint"` : a full jacobian, calculated internally by the solver, the default.
- `jactype = "fullusr"` : a full jacobian, specified by user function `jacfunc`.
- `jactype = "bandusr"` : a banded jacobian, specified by user function `jacfunc`; the size of the bands specified by `bandup` and `banddown`.
- `jactype = "bandint"` : a banded jacobian, calculated by the solver; the size of the bands specified by `bandup` and `banddown`.

if `jactype = "fullusr"` or `"bandusr"` then the user must supply a subroutine `jacfunc`.

The input parameters `rtol`, `atol` and `ctol` determine the **error control** performed by the solver.

The solver will control the vector **e** of estimated local errors in **y**, according to an inequality of the form $\max\text{-norm of } (\mathbf{e}/\mathbf{ewt}) \leq 1$, where **ewt** is a vector of positive error weights. The values of `rtol` and `atol` should all be non-negative. The form of **ewt** is:

$$\mathbf{rtol} \times \mathbf{abs}(\mathbf{y}) + \mathbf{atol}$$

where multiplication of two vectors is element-by-element.

In addition, the solver will stop if between two iterations, the maximal change in the values of **y** is less than `ctol`.

Models may be defined in compiled C or Fortran code, as well as in R.

If `func` or `jacfunc` are a string, then they are assumed to be compiled code.

In this case, `dllname` must give the name of the shared library (without extension) which must be loaded before `stode()` is called.

See `vignette("rooSolve")` for how a model has to be specified in compiled code. Also, `vignette("compiledCode")` from package **deSolve** contains examples of how to do this.

If `func` is a user-supplied **R-function**, it must be called as: `yprime = func(t, y, parms,...)`. `t` is the time at which the steady-state should be estimated, `y` is the current estimate of the variables in the ode system. The return value of `func` should be a list, whose first element is a vector containing the derivatives of `y` with respect to `time`, and whose next elements contains output variables whose values at steady-state are also required.

An example is given below:

```
model<-function(t,y,parms)
{
  with (as.list(c(y,parms)),{
    Min = r*OM
    oxicmin = Min*(O2/(O2+ks))
    anoxicmin = Min*(1-O2/(O2+ks))*SO4/(SO4+ks2)
    dOM = Flux - oxicmin - anoxicmin
    dO2 = -oxicmin -2*rox*HS*(O2/(O2+ks)) + D*(BO2-O2)
    dSO4 = -0.5*anoxicmin +rox*HS*(O2/(O2+ks)) + D*(BSO4-SO4)
    dHS = 0.5*anoxicmin -rox*HS*(O2/(O2+ks)) + D*(BHS-HS)

    list(c(dOM,dO2,dSO4,dHS),SumS=SO4+HS)
  })
}
```

This model can be solved as follows:

```
parms <- c(D=1,Flux=100,r=0.1,rox =1,
ks=1,ks2=1,BO2=100,BSO4=10000,BHS = 0)

y<-c(OM=1,O2=1,SO4=1,HS=1)
ST <- stode(y=y,func=model,parms=parms,pos=TRUE)
```

Value

A list containing

- `y` a vector with the state variable values from the last iteration during estimation of steady-state condition of the system of equations. If `y` has a `names` attribute, it will be used to label the output values.
- `...` the number of "global" values returned.

The output will have the attribute `steady`, which returns `TRUE`, if steady-state has been reached and the attribute `precis` with an estimate of the precision attained during each iteration, the mean absolute rate of change (`sum(abs(dy))/n`).

Note

The implementation of `stode` and substantial parts of the help file is similar to the implementation of the integration routines (e.g. `lsode`) from package `deSolve`.

Author(s)

Karline Soetaert <k.soetaert@nioo.knaw.nl>

References

For a description of the Newton-Raphson method, e.g.

Press, WH, Teukolsky, SA, Vetterling, WT, Flannery, BP, 1996. Numerical Recipes in FORTRAN. The Art of Scientific computing. 2nd edition. Cambridge University Press.

The algorithm uses LINPACK code:

Dongarra, J.J., J.R. Bunch, C.B. Moler and G.W. Stewart, 1979. LINPACK user's guide, SIAM, Philadelphia.

See Also

[steady](#), for a general interface to most of the steady-state solvers

[steady.band](#), to find the steady-state of ODE models with a banded Jacobian

[steady.1D](#), [steady.2D](#), [steady.3D](#) steady-state solvers for 1-D, 2-D and 3-D partial differential equations.

[stodes](#), iterative steady-state solver for ODEs with arbitrary sparse Jacobian.

[runsteady](#), steady-state solver by dynamically running to steady-state

Examples

```
#####
# Example 1. A simple sediment biogeochemical model
#####

model<-function(t,y,pars)
{
  with (as.list(c(y,pars)),{

    Min          = r*OM
    oxicmin      = Min*(O2/(O2+ks))
    anoxicmin    = Min*(1-O2/(O2+ks))* S04/(S04+ks2)

    dOM  = Flux - oxicmin - anoxicmin
    dO2  = -oxicmin      -2*rox*HS*(O2/(O2+ks)) + D*(BO2-O2)
    dSO4 = -0.5*anoxicmin +rox*HS*(O2/(O2+ks)) + D*(BSO4-SO4)
    dHS  = 0.5*anoxicmin -rox*HS*(O2/(O2+ks)) + D*(BHS-HS)

    list(c(dOM,dO2,dSO4,dHS),SumS=SO4+HS)
  })
}
```

```

}

# parameter values
pars <- c(D=1,Flux=100,r=0.1,rox =1,
          ks=1,ks2=1,BO2=100,BSO4=10000,BHS = 0)
# initial conditions
y<-c(OM=1,O2=1,S04=1,HS=1)

# direct iteration - enforces positivity..
ST <- stode(y=y,func=model,parms=pars,pos=TRUE)

ST

#####
# Example 2. 1000 simultaneous equations
#####
model <- function (time,OC,parms,decay,ing)
{
  # model describing organic Carbon (C) in a sediment,
  # Upper boundary = imposed flux, lower boundary = zero-gradient
  Flux <- v * c(OC[1],OC) + # advection
           -Kz*diff(c(OC[1],OC,OC[N]))/dx # diffusion;
  Flux[1]<- flux # imposed flux

  # Rate of change= Flux gradient and first-order consumption
  dOC <- -diff(Flux)/dx - decay*OC

  # Fraction of OC in first 5 layers is translocated to mean depth
  dOC[1:5] <- dOC[1:5] - ing*OC[1:5]
  dOC[N/2] <- dOC[N/2] + ing*sum(OC[1:5])
  list(dOC)
}
v <- 0.1 # cm/yr
flux <- 10
dx <- 0.01
N <- 1000
dist <- seq(dx/2,by=dx,len=N)
Kz <- 1 #bioturbation (diffusion), cm2/yr
print( system.time(
ss <- stode(runif(N),func=model,parms=NULL,positive=TRUE, decay=5,ing=20))

plot(ss$y[1:N],dist,ylim=rev(range(dist)),type="l",lwd=2,
xlab="Nonlocal exchange",ylab="sediment depth",main="stode, full jacobian")

#####
# Example 3. Solving a system of linear equations
#####

# this example is included to demonstrate how to use the "jactype" option.
# (and that stode is quite efficient).

A <- matrix(nr=500,nc=500,runif(500*500))

```

```

B <- 1:500

# this is how one would solve this in R
print(system.time(X1<-solve(A,B)))

# to use stode:
# 1. create a function that receives the current estimate of x
# and that returns the difference A%*%x-b, as a list:

fun <- function (t,x,p) # t and p are dummies here...
  list(A%*%x-B)

# 2. jfun returns the Jacobian: here this equals "A"
jfun <- function (t,x,p) # all input parameters are dummies
  A

# 3. solve with jactype="fullusr" (a full Jacobian, specified by user)
print (system.time(
  X <- stode(y=1:500,func=fun, jactype="fullusr", jacfunc=jfun)
))

# the results are the same (within precision)
sum((X1-X$y)^2)

```

stodes

Steady-state solver for ordinary differential equations (ODE) with a sparse jacobian.

Description

Estimates the steady-state condition for a system of ordinary differential equations (ODE) in the form:

$$dy/dt = f(t,y)$$

and where the jacobian matrix df/dy has an arbitrary sparse structure.

Uses a newton-raphson method, implemented in Fortran.

The system of ODE's is written as an R function or defined in compiled code that has been dynamically loaded.

Usage

```

stodes(y, time=0, func, parms=NULL, rtol=1e-6, atol=1e-8,
  ctol=1e-8, sparsetype="sparseint", verbose=FALSE,
  nnz=NULL, inz=NULL, lrw=NULL, ngp=NULL, positive=FALSE, maxiter=100,
  ynames=TRUE, dllname=NULL, initfunc=dllname, initpar=parms,
  rpar=NULL, ipar=NULL, nout=0, outnames = NULL, ...)

```

Arguments

<code>y</code>	the initial guess of (state) values for the ode system, a vector. If <code>y</code> has a <code>name</code> attribute, the names will be used to label the output matrix.
<code>time</code>	time for which steady-state is wanted; the default is <code>time=0</code> .
<code>func</code>	either a user-supplied function that computes the values of the derivatives in the ode system (the <i>model definition</i>) at time <code>time</code> , or a character string giving the name of a compiled function in a dynamically loaded shared library. If <code>func</code> is a user-supplied function, it must be called as: <code>yprime = func(t, y, parms)</code> . <code>t</code> is the time point at which the steady-state is wanted, <code>y</code> is the current estimate of the variables in the ode system. If the initial values <code>y</code> has a <code>names</code> attribute, the names will be available inside <code>func</code> . <code>parms</code> is a vector of parameters (which may have a <code>names</code> attribute). The return value of <code>func</code> should be a list, whose first element is a vector containing the derivatives of <code>y</code> with respect to <code>time</code> , and whose next elements (possibly with a <code>names</code> attribute) are global values that are required as output. The derivatives should be specified in the same order as the state variables <code>y</code> . If <code>func</code> is a string, then <code>dllname</code> must give the name of the shared library (without extension) which must be loaded before <code>stodes()</code> is called. see Details for more information.
<code>parms</code>	other parameters passed to <code>func</code> .
<code>rtol</code>	relative error tolerance, either a scalar or a vector, one value for each <code>y</code> .
<code>atol</code>	absolute error tolerance, either a scalar or a vector, one value for each <code>y</code> .
<code>ctol</code>	if between two iterations, the maximal change in <code>y</code> is less than this amount, steady-state is assumed to be reached.
<code>sparsetype</code>	the sparsity pattern, to date only "sparseint", sparse jacobian, estimated internally by <code>stodes</code> .
<code>verbose</code>	if TRUE: full output to the screen, e.g. will output the steady-state settings.
<code>nnz</code>	the number of nonzero elements in the sparse Jacobian (if this is unknown, use an estimate); If NULL, a guess will be made, and if not sufficient, <code>stodes</code> will return with a message indicating the size actually required. If a solution is found, the minimal value of <code>nnz</code> actually required is returned by the solver (1st element of attribute <code>dims</code>).
<code>inz</code>	(row,column) indices to the nonzero elements in the sparse Jacobian. If this is NULL, the sparsity will be determined by <code>stodes</code> .
<code>lrw</code>	the length of the work array of solver; due to the sparsity, this cannot be readily predicted. If NULL, a guess will be made, and if not sufficient, <code>stodes</code> will return with a message indicating the size actually required. Therefore, some experimentation may be necessary to estimate the value of <code>lrw</code> If a solution is found, the minimal value of <code>lrw</code> actually required is returned by the solver (3rd element of attribute <code>dims</code>).
<code>ngp</code>	number of groups of independent state variables. Due to the sparsity, this cannot be readily predicted. If NULL, a guess will be made, and if not sufficient, <code>stodes</code> will return with a message indicating the size actually required. Therefore, some experimentation may be necessary to estimate the value of <code>ngp</code>

	If a solution is found, the minimal value of <code>ngp</code> actually required is returned by the solver (2nd element of attribute <code>dims</code>).
<code>positive</code>	either a logical or a vector with indices of the state variables that have to be non-negative; if <code>TRUE</code> , the state variables are forced to be non-negative numbers.
<code>maxiter</code>	maximal number of iterations during one call to the solver.
<code>yname</code>	if <code>FALSE</code> : names of state variables are not passed to function <code>func</code> ; this may speed up the simulation especially for multi-D models.
<code>dllname</code>	a string giving the name of the shared library (without extension) that contains all the compiled function or subroutine definitions referred to in <code>func</code> .
<code>initfunc</code>	if not <code>NULL</code> , the name of the initialisation function (which initialises values of parameters), as provided in <code>'dllname'</code> . See details.
<code>initpar</code>	only when <code>'dllname'</code> is specified and an initialisation function <code>initfunc</code> is in the dll: the parameters passed to the initialiser, to initialise the common blocks (FORTRAN) or global variables (C, C++).
<code>rpar</code>	only when <code>'dllname'</code> is specified: a vector with double precision values passed to the dll-functions whose names are specified by <code>func</code> .
<code>ipar</code>	only when <code>'dllname'</code> is specified: a vector with integer values passed to the dll-functions whose names are specified by <code>func</code> .
<code>nout</code>	only used if <code>'dllname'</code> is specified: the number of output variables calculated in the compiled function <code>func</code> , present in the shared library.
<code>outnames</code>	only used if <code>'dllname'</code> is specified and <code>nout > 0</code> : the names of output variables calculated in the compiled function <code>func</code> , present in the shared library.
<code>...</code>	additional arguments passed to <code>func</code> allowing this to be a generic function.

Details

The work is done by a Fortran 77 routine that implements the Newton-Raphson method.

`stodes` is to be used for problems, where the Jacobian has a sparse structure.

There are two choices for the sparsity specification, depending on whether `inz` is present.

- If matrix `inz` is present, the sparsity is determined by the user. `inz` should contain indices (row, column) to the nonzero elements in the Jacobian matrix. In this case, `nnz` will be set equal to the number of rows in `inz`.
- If matrix `inz` is NOT present, the sparsity is estimated by the solver, based on numerical differences. In this case, it is advisable to provide an estimate of the number of non-zero elements in the Jacobian (`nnz`). This value can be approximate; upon return the number of nonzero elements actually required will be known (1st element of attribute `dims`).

Either way, the Jacobian itself is always generated by the solver (i.e. there is no provision to provide an analytic Jacobian).

This is done by perturbing simultaneously a combination of state variables that do not affect each other.

This significantly reduces computing time. The number of groups with independent state variables can be given by `ngp`

The input parameters `rtol`, `atol` and `ctol` determine the **error control** performed by the solver. See help for `stode` for details.

Models may be defined in compiled C or Fortran code, as well as in R. See package vignette for details on how to write models in compiled code.

Value

A list containing

`y` a vector with the state variable values from the last iteration during estimation of steady-state condition of the system of equations. If `y` has a `names` attribute, it will be used to label the output values.

... the number of "global" values returned.

The output will have the attribute `steady`, which returns `TRUE`, if steady-state has been reached and the attribute `precis` with an estimate of the precision attained during each iteration, the mean absolute rate of change ($\text{sum}(\text{abs}(\text{dy}))/n$).

Author(s)

Karline Soetaert <k.soetaert@nioo.knaw.nl>

References

For a description of the Newton-Raphson method, e.g.

Press, WH, Teukolsky, SA, Vetterling, WT, Flannery, BP, 1996. Numerical Recipes in FORTRAN. The Art of Scientific computing. 2nd edition. Cambridge University Press.

The algorithm uses linear algebra routines from the Yale sparse matrix package:

Eisenstat, S.C., Gursky, M.C., Schultz, M.H., Sherman, A.H., 1982. Yale Sparse Matrix Package. i. The symmetric codes. Int. J. Num. meth. Eng. 18, 1145-1151.

See Also

[steady](#), for a general interface to most of the steady-state solvers

[steady.band](#), to find the steady-state of ODE models with a banded Jacobian

[steady.1D](#), [steady.2D](#), [steady.3D](#), steady-state solvers for 1-D, 2-D and 3-D partial differential equations.

[stode](#), iterative steady-state solver for ODEs with full or banded Jacobian.

[runsteady](#), steady-state solver by dynamically running to steady-state

Examples

```
# 1000 simultaneous equations
model <- function (time,OC,parms,decay,ing)
{
  # model describing C in a sediment,
  # Upper boundary = imposed flux, lower boundary = zero-gradient
  Flux <- v * c(OC[1] ,OC) +           # advection
```

```

      -Kz*diff(c(OC[1],OC,OC[N]))/dx # diffusion;
Flux[1]<- flux      # imposed flux

# Rate of change= Flux gradient and first-order consumption
dOC  <- -diff(Flux)/dx - decay*OC

# Fraction of OC in first 5 layers is translocated to mean depth
# (layer N/2)
dOC[1:5] <- dOC[1:5] - ing*OC[1:5]
dOC[N/2] <- dOC[N/2] + ing*sum(OC[1:5])
list(dOC)
}
v      <- 0.1      # cm/yr
flux <- 10
dx     <- 0.01
N      <- 1000
dist  <- seq(dx/2,by=dx,len=N)
Kz    <- 1 #bioturbation (diffusion), cm2/yr
ss    <- stodes(runif(N),func=model,parms=NULL,
               positive=TRUE, decay=5,ing=20,verbose=TRUE)

plot(ss$y[1:N],dist,ylim=rev(range(dist)),type="l",lwd=2,
     xlab="Nonlocal exchange",ylab="sediment depth",
     main="stodes, sparse jacobian")

```

uniroot.all

Finds many (all) roots of one equation within an interval

Description

The function `uniroot.all` searches the interval from lower to upper for several roots (i.e., zero's) of a function `f` with respect to its first argument.

Usage

```
uniroot.all(f, interval, lower=min(interval), upper=max(interval),
           tol=.Machine$double.eps^0.2, maxiter=1000, n=100, ...)
```

Arguments

<code>f</code>	the function for which the root is sought.
<code>interval</code>	a vector containing the end-points of the interval to be searched for the root.
<code>lower</code>	the lower end point of the interval to be searched.
<code>upper</code>	the upper end point of the interval to be searched.
<code>tol</code>	the desired accuracy (convergence tolerance).
<code>maxiter</code>	the maximum number of iterations.
<code>n</code>	number of subintervals in which the root is sought.
<code>...</code>	additional named or unnamed arguments to be passed to <code>f</code> (but beware of partial matching to other arguments).

Details

`f` will be called as `f(x, ...)` for a numeric value of `x`.

Run `demo(Jacobandroots)` for an example of the use of `uniroot.all` for steady-state analysis.

See also second example of [gradient](#). This example is discussed in the book by Soetaert and Herman (2009).

Value

a vector with the roots found in the interval

Note

The function calls `uniroot`, the basic R-function.

It is not guaranteed that all roots will be recovered.

This will depend on `n`, the number of subintervals in which the interval is divided.

If the function "touches" the X-axis (i.e. the root is a saddle point), then this root will generally not be retrieved. (but chances of this are pretty small).

Author(s)

Karline Soetaert <k.soetaert@nioo.knaw.nl>

See Also

[uniroot](#) for more information about input.

Examples

```
#####
## Mathematical examples ##
#####

# a well-behaved case...
fun <- function (x) cos(2*x)^3
curve(fun(x), 0, 10, main="uniroot.all")
All <- uniroot.all(fun, c(0, 10))
points(All, y=rep(0, length(All)), pch=16, cex=2)

# a pathetic case...
f <- function (x) 1/cos(1+x^2)
AA <- uniroot.all(f, c(-5, 5))
curve(f(x), -5, 5, n=500, main="uniroot.all")
points(AA, rep(0, length(AA)), col="red", pch=16)
f(AA) # !!!

#####
## Ecological modelling example ##
#####
```

```
# Example from the book of Soetaert and Herman(2009)
# A practical guide to ecological modelling -
# using R as a simulation platform. Springer

r  <- 0.05
K  <- 10
bet <- 0.1
alf <- 1

# the model : density-dependent growth and sigmoid-type mortality rate
rate <- function(x,r=0.05) r*x*(1-x/K)-bet*x^2/(x^2+alf^2)

# find all roots within the interval [0,10]
Eq  <- uniroot.all(rate,c(0,10))

# jacobian evaluated at all roots:
# This is just one value - and therefore jacobian = eigenvalue
# the sign of eigenvalue: stability of the root: neg=stable, 0=saddle, pos=unstable

eig <- vector()
for (i in 1:length(Eq)) eig[i] <- sign (gradient(rate,Eq[i]))

curve(rate(x),ylab="dx/dt",from=0,to=10,
main="Budworm model, roots",sub= "Example from Soetaert and Herman, 2009")
abline(h=0)
points(x=Eq,y=rep(0,length(Eq)),pch=21,cex=2,bg=c("grey","black","white")[eig+2] )
legend("topleft",pch=22,pt.cex=2,c("stable","saddle","unstable"),
col=c("grey","black","white"),pt.bg=c("grey","black","white"))
```

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