Package ‘cOde’

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Type Package

Title Automated C Code Generation for 'deSolve', 'bvpSolve'

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NeedsCompilation no

Depends R (>= 3.0)

Suggests deSolve, bvpSolve, testthat

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Description Generates all necessary C functions allowing the user to work with
the compiled-code interface of ode() and bvptwp(). The implementation supports
``forcings'' and ``events''. Also provides functions to symbolically compute
Jacobians, sensitivity equations and adjoint sensitivities being the basis for
sensitivity analysis.

License GPL (>= 2)

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adjointSymb

Compute adjoint equations of a function symbolically

Description
Compute adjoint equations of a function symbolically

Usage
adjointSymb(f, states = names(f), parameters = NULL, inputs = NULL)

Arguments
f Named vector of type character, the functions
states Character vector of the ODE states for which observations are available
parameters Character vector of the parameters
inputs Character vector of the "variable" input states, i.e. time-dependent parameters (in contrast to the forcings).

Details
The adjoint equations are computed with respect to the functional

$$(x, u) \mapsto \int_0^T \|x(t) - x^D(t)\|^2 + \|u(t) - u^D(t)\|^2 dt,$$

where $x$ are the states being constrained by the ODE, $u$ are the inputs and $x^D$ and $u^D$ indicate the trajectories to be best possibly approached. When the ODE is linear with respect to $u$, the attribute inputs of the returned equations can be used to replace all occurrences of $u$ by the corresponding character in the attribute. This guarantees that the input course is optimal with respect to the above function.

Value
Named vector of type character with the adjoint equations. The vector has attributes "chi" (integrand of the chisquare functional), "grad" (integrand of the gradient of the chisquare functional), "forcings" (character vector of the forcings necessary for integration of the adjoint equations) and "inputs" (the input expressed as a function of the adjoint variables).
Examples

## Not run:

```
# Solve an optimal control problem:
library(bvpsolve)

# 02 + 0 <-> 03
# 03 is removed by a variable rate u(t)

f <- c(
  03 = " build_03 * 02 * 0 - decay_03 * 03 - u * 03",
  02 = "-build_03 * 02 * 0 + decay_03 * 03",
  0 = "-build_03 * 02 * 0 + decay_03 * 03"
)

# Compute adjoints equations and replace u by optimal input

f_a <- adjointSymb(f, states = c("03"), inputs = "u")
inputs <- attr(f_a, "inputs")
f_tot <- replaceSymbols("u", inputs, c(f, f_a))
forcings <- attr(f_a, "forcings")

# Initialize times, states, parameters

times <- seq(0, 15, by = .1)
boundary <- data.frame(
  name = c("03", "02", "0", "adj03", "adj02", "adj0"),
  yini = c(0.1, 1, 2, 2.5, NA, NA, NA),
  yend = c(NA, NA, NA, 0, 0, 0))

pars <- c(build_03 = 0.2, decay_03 = 0.1, eps = 1)

# Generate ODE function
func <- func(f = f_tot, forcings = forcings,
  jacobian = "full", boundary = boundary,
  modelname = "example5")

# Initialize forcings (the objective)
forcData <- data.frame(time = times,
  name = rep(forcings, each=length(times)),
  value = rep(c(0, 0.5, 1, 1), each=length(times)))
forc <- setForcings(func, forcData)

# Solve BVP
out <- bvptwpC(x = times, func = func, parms = pars, forcings = forc)

# Plot solution
par(mfcol=c(1,2))
t <- out[,1]
M1 <- out[,2:4]
M2 <- with(list(uD = 0, 03 = out[,2],
adj03 = out[,5], eps = 1, weightU = 1),
eval(parse(text=inputs))

matplot(t, M1, type="l", lty=1, col=1:3,
  xlab="time", ylab="value", main="states")
  abline(h = .5, lty=2)
legend("topright", legend = names(f), lty=1, col=1:3)
matplot(t, M2, type="l", lty=1, col=1,
  xlab="time", ylab="value", main="input u")
  abline(h = 0, lty=2)

## End(Not run)

---

**bvptwpC**

**Interface to bvptwp()**

**Description**

Interface to bvptwp()

**Usage**

```
bvptwpC(yini = NULL, x, func, yend = NULL, parms, xguess = NULL,
  yguess = NULL, ...)
```

**Arguments**

- `yini` named vector of type numeric. Initial values to be overwritten.
- `x` vector of type numeric. Integration times
- `func` return value from funC() with a boundary argument.
- `yend` named vector of type numeric. End values to be overwritten.
- `parms` named vector of type numeric. The dynamic parameters.
- `xguess` vector of type numeric, the x values
- `yguess` matrix with as many rows as variables and columns as x values
- `...` further arguments going to bvptwp()

**Details**

See bvpSolve-package for a full description of possible arguments

**Value**

matrix with times and states
Examples

```r
## Not run:

########################################################################
## Boundary value problem: Ozon formation with fixed ozon/oxygen ratio
## at final time point
########################################################################

library(bvpSolve)

# 02 + O <-> O3
# diff = 02 - 03
# build_03 = const.

f <- c(
  03 = " build_03 * 02 * 0 - decay_03 * 03",
  02 = "-build_03 * 02 * 0 + decay_03 * 03",
  O = "-build_03 * 02 * 0 + decay_03 * 03",
  diff = "-2 * build_03 * 02 * 0 + 2 * decay_03 * 03",
  build_03 = "0"
)

bound <- data.frame(
  name = names(f),
  yini = c(0, 3, 2, 3, NA),
  yend = c(NA, NA, NA, 0, NA)
)

# Generate ODE function
func <- funC(f, jacobian="full", boundary = bound, modelname = "example4")

# Initialize times, states, parameters and forcings

times <- seq(0, 15, by = .1)
pars <- c(decay_03 = .1)
xguess <- times
yguess <- matrix(c(1, 1, 1, 1, 1), ncol=length(times),
  nrow = length(f))

# Solve BVP
out <- bvptwpC(x = times, func = func, pars = pars,
  xguess = xguess, yguess = yguess)

# Solve BVP for different ini values, end values and parameters

yini <- c(03 = 2)
yend <- c(diff = 0.2)
pars <- c(decay_03 = .01)
out <- bvptwpC(yini = yini, yend = yend, x = times, func = func,
  pars = pars, xguess = xguess, yguess = yguess)

# Plot solution
par(mfcol=c(1,2))
t <- out[,1]
M1 <- out[,2:5]
```
M2 <- cbind(out[,6], pars)

matplot(t, M1, type="l", lty=1, col=1:4,
       xlab="time", ylab="value", main="states")
legend("topright", legend = c("03", "02", "0", "02 - 03"),
       lty=1, col=1:4)

matplot(t, M2, type="l", lty=1, col=1:2,
       xlab="time", ylab="value", main="parameters")
legend("right", legend = c("build_03", "decay_03"), lty=1, col=1:2)

## End(Not run)

---

**compileAndLoad**

*Compile and load shared object implementing the ODE system.*

**Description**

Compile and load shared object implementing the ODE system.

**Usage**

```r
compileAndLoad(filename, dllname, fcontrol, verbose)
```

**Arguments**

- `filename`: Full file name of the source file.
- `dllname`: Base name for source and dll file.
- `fcontrol`: Interpolation method for forcings.
- `verbose`: Print compiler output or not.

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**forcData**

*Forcings data.frame*

**Description**

Forcings data.frame
funC

Generate C code for a function and compile it

Description

Generate C code for a function and compile it

Usage

funC(f, forcings = NULL, events = NULL, fixed = NULL, outputs = NULL, jacobian = c("none", "full", "inz.lsodes", "jacvec.lsodes"), rootfunc = NULL, boundary = NULL, compile = TRUE, fcontrol = c("nospline", "einspline"), nGridpoints = -1, includeTimeZero = TRUE, precision = 1e-05, modelname = NULL, verbose = FALSE, solver = c("deSolve", "Sundials"))

Arguments

f
Named character vector containing the right-hand sides of the ODE. You may use the key word time in your equations for non-autonomous ODEs.

forcings
Character vector with the names of the forcings

events
data.frame of events with columns "var" (character, the name of the state to be affected), "time" (numeric or character, time point), "value" (numeric or character, value), "method" (character, either "replace" or "add"). See events. If "var" and "time" are characters, their values need to be specified in the parameter vector when calling odeC. An event function is generated and compiled with the ODE.

fixed
character vector with the names of parameters (initial values and dynamic) for which no sensitivities are required (will speed up the integration).

outputs
Named character vector for additional output variables, see arguments nout and outnames of lsode

jacobian
Character, either "none" (no jacobian is computed), "full" (full jacobian is computed and written as a function into the C file) or "inz.lsodes" (only the non-zero elements of the jacobian are determined, see lsodes)

rootfunc
Named character vector. The root function (see lsoda). Besides the variable names (names(f)) also other symbols are allowed that are treated like new parameters.

boundary
data.frame with columns name, yini, yend specifying the boundary condition set-up. NULL if not a boundary value problem

compile
Logical. If FALSE, only the C file is written

fcontrol
Character, either "nospline" (default, forcings are handled by deSolve) or "einspline" (forcings are handled as splines within the C code based on the einspline library).
ngridpoints  
Integer, defining for which time points the ODE is evaluated or the solution is returned: Set $-1$ to return only the explicitly requested time points (default). If additional time points are introduced through events, they will not be returned. Set $\geq 0$ to introduce additional time points between $t_{\text{min}}$ and $t_{\text{max}}$ where the ODE is evaluated in any case. Additional time points that might be introduced by events will be returned. If splines are used with fcontrol = "einspline", ngridpoints also indicates the number of spline nodes.

includeTimeZero  
Logical. Include $t = 0$ in the integration time points if TRUE (default). Consequently, integration starts at $t = 0$ if only positive time points are provided by the user and at $t_{\text{min}}$, if also negative time points are provided.

precision  
Numeric. Only used when fcontrol = "einspline".

modelname  
Character. The C file is generated in the working directory and is named <modelname>.c. If NULL, a random name starting with ".f" is chosen, i.e. the file is hidden on a UNIX system.

verbose  
Print compiler output to R command line.

solver  
Select the solver suite as either desolve or Sundials (not available any more). Defaults to desolve.

Details  
The function replaces variables by arrays $y[i]$, etc. and replaces "^" by pow() in order to have the correct C syntax. The file name of the C-File is derived from f. I.e. funC(abc, ...) will generate a file abc.c in the current directory. Currently, only explicit ODE specification is supported, i.e. you need to have the right-hand sides of the ODE.

Value  
the name of the generated shared object file together with a number of attributes

Examples  

```R
## Not run:
# Exponential decay plus constant supply
f <- c(x = "-k*x + supply")
func <- funC(f, forcings = "supply")

# Example 2: root function
f <- c(A = "-k1*A + k2*B", B = "k1*A - k2*B")
rootfunc <- c(steadystate = "-k1*A + k2*B - tol")
func <- funC(f, rootfunc = rootfunc, modelname = "test")

yini <- c(A = 1, B = 2)
parms <- c(k1 = 1, k2 = 5, tol = 0.1)
times <- seq(0, 10, len = 100)
odeC(yini, times, func, parms)
## End(Not run)
```
**getSymbols**

*Get symbols from a character*

**Description**

Get symbols from a character

**Usage**

```r
getSymbols(char, exclude = NULL)
```

**Arguments**

- `char`: Character vector (e.g. equation)
- `exclude`: Character vector, the symbols to be excluded from the return value

**Value**

character vector with the symbols

**Examples**

```r
getSymbols(c("A*AB+B^2"))
```

---

**jacobianSymb**

*Compute Jacobian of a function symbolically*

**Description**

Compute Jacobian of a function symbolically

**Usage**

```r
jacobianSymb(f, variables = NULL)
```

**Arguments**

- `f`: named vector of type character, the functions
- `variables`: other variables, e.g. parameters, f depends on. If variables is given, f is derived with respect to variables instead of `names(f)`

**Value**

named vector of type character with the symbolic derivatives
odeC

Interface to ode()

Description
Interface to ode()

Usage
odeC(y, times, func, parms, ...)

Arguments
y named vector of type numeric. Initial values for the integration

vector of type numeric. Integration times. If includeTimeZero is TRUE (see
funC), the times vector is augmented by t = 0. If nGridpoints (see funC) was
set >= 0, uniformly distributed time points between the first and last time point
are introduced and the solution is returned for these time points, too. Any addi-
tional time points that are introduced during integration (e.g. event time points)
are returned unless nGridpoints = -1 (the default).

func return value from funC()

parms named vector of type numeric.

... further arguments going to ode()

Details
See deSolve-package for a full description of possible arguments

Value
matrix with times and states

Examples
## Not run:

#########################################################################
## Ozone formation and decay, modified by external forcings
#########################################################################

library(deSolve)
data(forcData)
forcData$value <- forcData$value + 1

Examples
jacobianSymb(c(A="A+B", B="A+B"))
jacobianSymb(c(x="A*B", y="A+B"), c("A", "B"))
odeC

# 02 + O <-> 03
f <- c(
  03 = " (build_03 + u_build) * 02 * 0 - (decay_03 + u_degrade) * 03",
  02 = "-(build_03 + u_build) * 02 * 0 + (decay_03 + u_degrade) * 03",
  0 = "-(build_03 + u_build) * 02 * 0 + (decay_03 + u_degrade) * 03"
)

# Generate ODE function
forcings <- c("u_build", "u_degrade")
func <- function(f, forcings = forcings, modelname = "test",
  fcontrol = "nospline", nGridpoints = 10)

# Initialize times, states, parameters and forcings
times <- seq(0, 8, by = .1)
yini <- c(03 = 0, 02 = 3, 0 = 2)
pars <- c(build_03 = 1/6, decay_03 = 1)

forc <- setForcings(func, forcData)

# Solve ODE
out <- odeC(y = yini, times = times, func = func, pars = pars,
  forcings = forc)

# Plot solution
par(mfcol=c(1,2))
t1 <- unique(forcData[,2])
M1 <- matrix(forcData[,3], ncol=2)
t2 <- out[,1]
M2 <- out[,2:4]
M3 <- out[,5:6]

matplot(t1, M1, type="l", lty=1, col=1:2, xlab="time", ylab="value",
  main="forcings", ylim=c(0,4))
matplot(t2, M3, type="l", lty=2, col=1:2, xlab="time", ylab="value",
  main="forcings", add=TRUE)

legend("topleft", legend = c("u_build", "u_degrade"), lty=1, col=1:2)
matplot(t2, M2, type="l", lty=1, col=1:3, xlab="time", ylab="value",
  main="response")
legend("topright", legend = c("03", "02", "0"), lty=1, col=1:3)

#########################################################################
## Ozone formation and decay, modified by events
#########################################################################

f <- c(
  03 = " (build_03 + u_build) * 02 * 0 - (decay_03 + u_degrade) * 03",

```
oxygenData

```r
O2 = "-(build_03 + u_build) * O2 * O + (decay_03 + u_degrade) * O3",
O = "-(build_03 + u_build) * O2 * O + (decay_03 + u_degrade) * O3",

u_build = "0",  # piecewise constant
u_degrade = "0"  # piecewise constant
```

# Define parametric events
events.pars <- data.frame(
  var = c("u_degrade", "u_degrade", "u_build"),
  time = c("t_on", "t_off", "2"),
  value = c("plus", "minus", "2"),
  method = "replace"
)

# Declare parametric events when generating func object
func <- funCf, forcings = NULL, events = events.pars, modelname = "test",
  fcontrol = "nospline", nGridpoints = -1)

# Set Parameters
yini <- c(O3 = 0, O2 = 3, O = 2, u_build = 1, u_degrade = 1)
times <- seq(0, 8, by = .1)
pars <- c(build_03 = 1/6, decay_03 = 1, t_on = exp(rnorm(1, 0)), t_off = 6, plus = 3, minus = 1)

# Solve ODE with additional fixed-value events
out <- odeC(y = yini, times = times, func = func, pars = pars)

# Plot solution
par(mfcol=c(1,2))
t2 <- out[,1]
M2 <- out[,2:4]
M3 <- out[,5:6]

matplot(t2, M3, type="l", lty=2, col=1:2, xlab="time", ylab="value",
main="events")
legend("topleft", legend = c("u_build", "u_degrade"), lty=1, col=1:2)
matplot(t2, M2, type="l", lty=1, col=1:3, xlab="time", ylab="value",
main="response")
legend("topright", legend = c("O3", "O2", "O"), lty=1, col=1:3)

## End(Not run)
```

oxygenData

Time-course data of O, O2 and O3
prodSymb

Description
Forcings data.frame

prodSymb Compute matrix product symbolically

Description
Compute matrix product symbolically

Usage
prodSymb(M, N)

Arguments
M matrix of type character
N matrix of type character

Value
Matrix of type character, the matrix product of M and N

reduceSensitivities

Description
reduceSensitivities

Usage
reduceSensitivities(sens, vanishing)

Arguments
sens Named character, the sensitivity equations
vanishing Character, names of the vanishing sensitivities

Details
Given the set vanishing of vanishing sensitivities, the algorithm determines sensitivities that vanish as a consequence of the first set.

Value
Named character, the sensitivity equations with zero entries for vanishing sensitivities.
replaceNumbers

Replace integer number in a character vector by other double

Description
Replace integer number in a character vector by other double

Usage
replaceNumbers(x)

Arguments
x vector of type character, the object where the replacement should take place

Value
vector of type character, conserves the names of x.

replaceOperation

Replace a binary operator in a string by a function

Description
Replace a binary operator in a string by a function

Usage
replaceOperation(what, by, x)

Arguments
what character, the operator symbol, e.g. "^"
by character, the function string, e.g. "pow"
x vector of type character, the object where the replacement should take place

Value
vector of type character

Examples
replaceOperation("^", "pow", "(x^2 + y^2)^.5")
replaceSymbols

Replace symbols in a character vector by other symbols

Description

Replace symbols in a character vector by other symbols

Usage

replaceSymbols(what, by, x)

Arguments

what vector of type character, the symbols to be replaced, e.g. c("A", "B")
by vector of type character, the replacement, e.g. c("x[0]", "x[1]")
x vector of type character, the object where the replacement should take place

Value

vector of type character, conserves the names of x.

Examples

replaceSymbols(c("A", "B"), c("x[0]", "x[1]"), c("A*B", "A+B+C"))

sensitivitiesSymb

Compute sensitivity equations of a function symbolically

Description

Compute sensitivity equations of a function symbolically

Usage

sensitivitiesSymb(f, states = names(f), parameters = NULL, inputs = NULL, events = NULL, reduce = FALSE)
Arguments

- **f**: named vector of type character, the functions
- **states**: Character vector. Sensitivities are computed with respect to initial values of these states
- **parameters**: Character vector. Sensitivities are computed with respect to initial values of these parameters
- **inputs**: Character vector. Input functions or forcings. They are excluded from the computation of sensitivities.
- **events**: data.frame of events with columns "var" (character, the name of the state to be affected), "time" (numeric or character, time point), "value" (numeric or character, value), "method" (character, either "replace" or "add"). See events. Within `sensitivitiesSymb()` a data.frame of additional events is generated to reset the sensitivities appropriately, depending on the event method.
- **reduce**: Logical. Attempts to determine vanishing sensitivities, removes their equations and replaces their right-hand side occurrences by 0.

Details

The sensitivity equations are ODEs that are derived from the original ODE f. They describe the sensitivity of the solution curve with respect to parameters like initial values and other parameters contained in f. These equations are also useful for parameter estimation by the maximum-likelihood method. For consistency with the time-continuous setting provided by `adjointSymb`, the returned equations contain attributes for the chisquare functional and its gradient.

Value

Named vector of type character with the sensitivity equations. Furthermore, attributes "chi" (the integrand of the chisquare functional), "grad" (the integrand of the gradient of the chisquare functional), "forcings" (Character vector of the additional forcings being necessary to compute chi and grad) and "yini" (The initial values of the sensitivity equations) are returned.

Examples

```r
## Not run:

##############################################
# Sensitivity analysis of ozone formation
##############################################

library(deSolve)

# 02 + 0 <-> 03
f <- c(
  03 = " build_03 * 02 * 0 - decay_03 * 03",
  02 = " -build_03 * 02 * 0 + decay_03 * 03",
  0 = " -build_03 * 02 * 0 + decay_03 * 03"
)
```
# Compute sensitivity equations
f_s <- sensitivitiesSymb(f)

# Generate ODE function
func <- funC(c(f, f_s))

# Initialize times, states, parameters and forcings
times <- seq(0, 15, by = .1)
yini <- c(03 = 0, 02 = 3, 0 = 2, attr(f_s, "yini"))
pars <- c(build_03 = .1, decay_03 = .01)

# Solve ODE
out <- odeC(y = yini, times = times, func = func, pars = pars)

# Plot solution
par(mfcol=c(2,3))
t <- out[,1]
M1 <- out[,2:4]
M2 <- out[,5:7]
M3 <- out[,8:10]
M4 <- out[,11:13]
M5 <- out[,14:16]
M6 <- out[,17:19]

matplot(t, M1, type="l", lty=1, col=1:3,
        xlab="time", ylab="value", main="solution")
legend("topright", legend = c("03", "02", "0"), lty=1, col=1:3)
matplot(t, M2, type="l", lty=1, col=1:3,
        xlab="time", ylab="value", main="d/(d 03)" )
matplot(t, M3, type="l", lty=1, col=1:3,
        xlab="time", ylab="value", main="d/(d 02)" )
matplot(t, M4, type="l", lty=1, col=1:3,
        xlab="time", ylab="value", main="d/(d 0)" )
matplot(t, M5, type="l", lty=1, col=1:3,
        xlab="time", ylab="value", main="d/(d build_03)" )
matplot(t, M6, type="l", lty=1, col=1:3,
        xlab="time", ylab="value", main="d/(d decay_03)" )

## End(Not run)
## Not run:

# Estimate parameter values from experimental data
library(deSolve)

# 02 + 0 <-> 03
# diff = 02 - 03
# build_03 = const.
f <- c(
    03 = " build_03 * 02 * 0 - decay_03 * 03",
)
02 = "-build_03 * O2 * 0 + decay_03 * O3",
0 = "-build_03 * O2 * 0 + decay_03 * O3"
)

# Compute sensitivity equations and get attributes
f_s <- sensitivitiesSymb(f)
chi <- attr(f_s, "chi")
grad <- attr(f_s, "grad")
forcings <- attr(f_s, "forcings")

# Generate ODE function
func <- function(f = c(f, f_s, chi, grad), forcings = forcings,
                 fcontrol = "nospline", modelname = "example3")

# Initialize times, states, parameters
times <- seq(0, 15, by = .1)
yini <- c(O3 = 0, O2 = 2, O = 2.5)
yini_s <- attr(f_s, "yini")
yini_ch <- c(chi = 0)
yini_grad <- rep(0, length(grad)); names(yini_grad) <- names(grad)
pars <- c(build_03 = .2, decay_03 = .1)

# Initialize forcings (the data)
data(oxygenData)
forcData <- data.frame(time = oxygenData[,1],
                       name = rep(
                         colnames(oxygenData[,1]),
                         each=dim(oxygenData)[1]),
                       value = as.vector(oxygenData[,1]))
forc <- setforcings(func, forcData)

# Solve ODE
out <- ode(y = c(yini, yini_s, yini_ch, yini_grad),
           times = times, func = func, pars = pars, forcings = forc,
           method = "lsodes")

# Plot solution
par(mfcol=c(1,2))
t <- out[,1]
M1 <- out[,2:4]
M2 <- out[,names(grad)]
tD <- oxygenData[,1]
M1D <- oxygenData[,2:4]

matplot(t, M1, type="l", lty=1, col=1:3,
        xlab="time", ylab="value", main="states")
matplot(tD, M1D, type="b", lty=2, col=1:3, pch=4, add=TRUE)
legend("topright", legend = names(f), lty=1, col=1:3)
matplot(t, M2, type="l", lty=1, col=1:5,
        xlab="time", ylab="value", main="gradient")
legend("topleft", legend = names(grad), lty=1, col=1:5)

# Define objective function
setForcings

Generate interpolation spline for the forcings and write into list of matrices

```r
obj <- function(p) {
  out <- odeC(y = c(p[names(f)], yini_s, yini_chi, yini_grad),
              times = times, func = func, parms = p[names(pars)],
              forcings = forc, method = "lsodes")

  value <- as.vector(tail(out, 1)[,"chi"])
  gradient <- as.vector(tail(out, 1)[,paste("chi", names(p), sep="."))]
  hessian <- gradient * gradient

  return(list(value = value, gradient = gradient, hessian = hessian))
}

# Fit the data
myfit <- optim(par = c(yini, pars),
               fn = function(p) obj(p)$value,
               gr = function(p) obj(p)$gradient,
               method = "L-BFGS-B",
               lower=0,
               upper=5)

# Model prediction for fit parameters
prediction <- odeC(y = c(myfit$par[1:3], yini_s, yini_chi, yini_grad),
                   times = times, func = func, parms = myfit$par[4:5],
                   forcings = forc, method = "lsodes")

# Plot solution
par(mfcol=c(1,2))
t <- prediction[,1]
M1 <- prediction[,2:4]
M2 <- prediction[,names(grad)]
tD <- oxygenData[,1]
M1D <- oxygenData[,2:4]

matplot(t, M1, type="l", lty=1, col=1:3,
        xlab="time", ylab="value", main="states")
matplot(tD, M1D, type="b", lty=2, col=1:3, pch=4, add=TRUE)
legend("topleft", legend = names(f), lty=1, col=1:3)
matplot(t, M2, type="l", lty=1, col=1:5,
        xlab="time", ylab="value", main="gradient")
legend("topleft", legend = names(grad), lty=1, col=1:5)

## End(Not run)
```
Description
Generate interpolation spline for the forcings and write into list of matrices

Usage
setForcings(func, forcings)

Arguments
func result from funC()
forcings data.frame with columns name (factor), time (numeric) and value (numeric)

Details
Splines are generated for each name in forcings and both, function value and first derivative are evaluated at the time points of the data frame.

Value
list of matrices with time points and values assigned to the forcings interface of deSolve

Examples
f <- c(x = "-k*x + a - b")
func <- funC(f, forcings = c("a", "b"))
forData <- rbind(
  data.frame(name = "a", time = c(0, 1, 10), value = c(0, 5, 2)),
  data.frame(name = "b", time = c(0, 5, 10), value = c(1, 3, 6))
forc <- setForcings(func, forData)

sumSymb

Description
Compute matrix sumSymbolically

Usage
sumSymb(M, N)

Arguments
M matrix of type character
N matrix of type character

Value
Matrix of type character, the matrix sum of M and N
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