Package ‘rODE’

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Type Package

Title Ordinary Differential Equation (ODE) Solvers Written in R Using S4 Classes

Version 0.99.6

Description Show physics, math and engineering students how an ODE solver is made and how effective R classes can be for the construction of the equations that describe natural phenomena. Inspiration for this work comes from the book on ``Computer Simulations in Physics'' by Harvey Gould, Jan Tobochnik, and Wolfgang Christian. Book link: <http://www.compadre.org/osp/items/detail.cfm?ID=7375>.

Depends R (>= 3.3.0)

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VignetteBuilder knitr

URL https://github.com/f0nzie/rODE

NeedsCompilation no

Author Alfonso R. Reyes [aut, cre]

Maintainer Alfonso R. Reyes <alfonso.reyes@oilgainsanalytics.com>

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Contents

`rODE-package` *Ordinary Differential Equations*

Description

Ordinary Differential Equations rODE.

`AbstractODESolver-class` *AbstractODESolver class*

Description

Defines the basic methods for all the ODE solvers.

AbstractODESolver generic

AbstractODESolver constructor missing

AbstractODESolver constructor ODE. Uses this constructor when ODE object is passed

Usage

```
AbstractODESolver(ode, ...)

## S4 method for signature 'AbstractODESolver'
step(object, ...)

## S4 method for signature 'AbstractODESolver'
getODE(object, ...)

## S4 method for signature 'AbstractODESolver'
setStepSize(object, stepSize, ...)

## S4 method for signature 'AbstractODESolver'
init(object, stepSize, ...)

## S4 replacement method for signature 'AbstractODESolver'
init(object, ...) <- value

## S4 method for signature 'AbstractODESolver'
getStepSize(object, ...)

## S4 method for signature 'missing'
AbstractODESolver(ode, ...)

## S4 method for signature 'ODE'
AbstractODESolver(ode, ...)
```

Arguments

`ode`	an ODE object
`...`	additional parameters
`object`	a class object
`stepSize`	the size of the step
`value`	the step size value

Details

Inherits from: ODESolver class

Examples

```
# This is how we start defining a new ODE solver: Euler
.Euler <- setClass("Euler",             # Euler solver very simple; no slots
     contains = c("AbstractODESolver"))



# Here we define the ODE solver Verlet
.Verlet <- setClass("Verlet", slots = c(
    rate1 = "numeric",                         # Verlet calculates two rates
    rate2 = "numeric",
    rateCounter = "numeric"),
contains = c("AbstractODESolver"))



# This is the definition of the ODE solver Runge-Kutta 4
.RK4 <- setClass("RK4", slots = c(       # On the other hand RK4 uses 4 rates
   rate1 = "numeric",
   rate2 = "numeric",
   rate3 = "numeric",
   rate4 = "numeric",
   estimated_state = "numeric"),        # and estimates another state
contains = c("AbstractODESolver"))
```

DormandPrince45-class *DormandPrince45 ODE solver class*

Description

DormandPrince45 ODE solver class

DormandPrince45 generic

DormandPrince45 constructor ODE

Usage

```
DormandPrince45(ode, ...)

## S4 method for signature 'DormandPrince45'
init(object, stepSize, ...)

## S4 replacement method for signature 'DormandPrince45'
init(object, ...) <- value
```

```
## S4 method for signature 'DormandPrince45'
step(object, ...)

## S4 method for signature 'DormandPrince45'
enableRuntimeExceptions(object, enable)

## S4 method for signature 'DormandPrince45'
setStepSize(object, stepSize, ...)

## S4 method for signature 'DormandPrince45'
getStepSize(object, ...)

## S4 method for signature 'DormandPrince45'
setTolerance(object, tol)

## S4 replacement method for signature 'DormandPrince45'
setTolerance(object, ...) <- value

## S4 method for signature 'DormandPrince45'
getTolerance(object)

## S4 method for signature 'DormandPrince45'
getErrorCode(object)

## S4 method for signature 'ODE'
DormandPrince45(ode, ...)
```

Arguments

ode	ODE object
...	additional parameters
object	a class object
stepSize	size of the step
value	step size to set
enable	a logical flag
tol	tolerance

Examples

```
# ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~  base class: KeplerVerlet.R

setClass("KeplerDormandPrince45", slots = c(
    GM = "numeric",
    odeSolver = "DormandPrince45",
    counter = "numeric"
    ),
    contains = c("ODE")
```

```
)

setMethod("initialize", "KeplerDormandPrince45", function(.Object, ...) {
    .Object@GM <- 4 * pi * pi         # gravitation constant times combined mass
    .Object@state <- vector("numeric", 5)  # x, vx, y, vy, t
    .Object@odeSolver <- DormandPrince45(.Object)
    .Object@counter <- 0
    return(.Object)
})

setMethod("doStep", "KeplerDormandPrince45", function(object, ...) {
    object@odeSolver <- step(object@odeSolver)
    object@state <- object@odeSolver@ode@state
    object
})

setMethod("getTime", "KeplerDormandPrince45", function(object, ...) {
    return(object@state[5])
})

setMethod("getEnergy", "KeplerDormandPrince45", function(object, ...) {
    ke <- 0.5 * (object@state[2] * object@state[2] +
                 object@state[4] * object@state[4])
    pe <- -object@GM / sqrt(object@state[1] * object@state[1] +
                            object@state[3] * object@state[3])
    return(pe+ke)
})

setMethod("init", "KeplerDormandPrince45", function(object, initState, ...) {
    object@state <- initState
    # call init in AbstractODESolver
    object@odeSolver <- init(object@odeSolver, getStepSize(object@odeSolver))
    object@counter <- 0
    object
})

setReplaceMethod("init", "KeplerDormandPrince45", function(object, ..., value) {
    object@state <- value
    # call init in AbstractODESolver
    object@odeSolver <- init(object@odeSolver, getStepSize(object@odeSolver))
    object@counter <- 0
    object
})

setMethod("getRate", "KeplerDormandPrince45", function(object, state, ...) {
    # Computes the rate using the given state.
    r2 <- state[1] * state[1] + state[3] * state[3]  # distance squared
    r3 <- r2 * sqrt(r2)   # distance cubed
    object@rate[1] <- state[2]
    object@rate[2] <- (- object@GM * state[1]) / r3
    object@rate[3] <- state[4]
    object@rate[4] <- (- object@GM * state[3]) / r3
    object@rate[5] <- 1   # time derivative
```

```
    object@counter <- object@counter + 1
    object@rate
})

setMethod("getState", "KeplerDormandPrince45", function(object, ...) {
    # Gets the state variables.
    return(object@state)
})

setReplaceMethod("setSolver", "KeplerDormandPrince45", function(object, value) {
    object@odeSolver <- value
    object
})

# constructor
KeplerDormandPrince45 <- function() {
    kepler <- new("KeplerDormandPrince45")
    return(kepler)
}
# +++++++++++++++++++++++++++++++++++++++++ Example:      ComparisonRK45ODEApp.R
# Updates the ODE state instead of using the internal state in the ODE solver
# Also plots the solver solution versus the analytical solution at a
# tolerance of 1e-6
# Example file: ComparisonRK45ODEApp.R
# ODE Solver:   Runge-Kutta 45
# ODE class :   RK45
# Base class:   ODETest

library(ggplot2)
library(dplyr)
library(tidyr)

importFromExamples("ODETest.R")

ComparisonRK45ODEApp <- function(verbose = FALSE) {
    ode <- new("ODETest")                         # new ODE instance
    ode_solver <- RK45(ode)                       # select ODE solver
    ode_solver <- setStepSize(ode_solver, 1)      # set the step

    # two ways to set tolerance
      # ode_solver <- setTolerance(ode_solver, 1e-6)
    setTolerance(ode_solver) <-  1e-6

    time <-  0
    rowVector <- vector("list")                   # row vector
    i <- 1    # counter
    while (time < 50) {
        # add solution objects to a row vector
        rowVector[[i]] <- list(t     = getState(ode)[2],
                               ODE   = getState(ode)[1],
                               s2    = getState(ode)[2],
                               exact = getExactSolution(ode, time),
```

```
                               rate.counts = getRateCounts(ode),
                               time = time )
        ode_solver <- step(ode_solver)            # advance solver one step
        stepSize <-  getStepSize(ode_solver)      # get the current step size
        time  <- time + stepSize
        ode   <- getODE(ode_solver)               # get updated ODE object
        state <- getState(ode)                    # get the `state` vector
        i <- i + 1                                # add a row vector
    }
    DT <- data.table::rbindlist(rowVector)        # create data table
    return(DT)
}

solution <- ComparisonRK45ODEApp()
plot(solution)


# aditional plot for analytics solution vs. RK45 solver
solution.multi <- solution %>%
    select(t, ODE, exact)
plot(solution.multi)             # 3x3 plot

# plot comparative curves analytical vs ODE solver
solution.2x1 <- solution.multi %>%
    gather(key, value, -t)         # make a table of 3 variables. key: ODE/exact

g <- ggplot(solution.2x1, mapping = aes(x = t, y = value, color = key))
g <-  g + geom_line(size = 1) +
    labs(title = "ODE vs Exact solution",
         subtitle = "tolerance = 1E-6")
print(g)
```

---

doStep *doStep*

Description

Perform a step

Usage

```
doStep(object, ...)
```

Arguments

object	a class object
...	additional parameters

Examples

```
# +++++++++++++++++++++++++++++++++++++++++++++++++++++++++  example: PlanetApp.R
# Simulation of Earth orbiting around the SUn using the Euler ODE solver

importFromExamples("Planet.R")      # source the class

PlanetApp <- function(verbose = FALSE) {
    # x =  1, AU or Astronomical Units. Length of semimajor axis or the orbit
    # of the Earth around the Sun.
    x <- 1; vx <- 0; y <- 0; vy <- 6.28; t <- 0
    state <- c(x, vx, y, vy, t)
    dt <-  0.01
    planet <- Planet()
    planet@odeSolver <- setStepSize(planet@odeSolver, dt)
    planet <- init(planet, initState = state)
    rowvec <- vector("list")
    i <- 1
    # run infinite loop. stop with ESCAPE.
    while (getState(planet)[5] <= 90) {     # Earth orbit is 365 days around the sun
        rowvec[[i]] <- list(t  = getState(planet)[5],     # just doing 3 months
                            x  = getState(planet)[1],     # to speed up for CRAN
                            vx = getState(planet)[2],
                            y  = getState(planet)[3],
                            vy = getState(planet)[4])
        for (j in 1:5) {                 # advances time
            planet <- doStep(planet)
        }
        i <- i + 1
    }
    DT <- data.table::rbindlist(rowvec)
    return(DT)
}
# run the application
solution <- PlanetApp()
select_rows <- seq(1, nrow(solution), 10)      # do not overplot
solution <- solution[select_rows,]
plot(solution)

# ++++++++++++++++++++++++++++++++++++++++++++++++++++   application:  Logistic.R
# Simulates the logistic equation
importFromExamples("Logistic.R")

# Run the application
LogisticApp <- function(verbose = FALSE) {
    x  <- 0.1
    vx <- 0
    r  <- 2        # Malthusian parameter (rate of maximum population growth)
    K  <- 10.0     # carrying capacity of the environment
    dt   <- 0.01; tol  <- 1e-3; tmax <- 10

    population <- Logistic()                # create a Logistic ODE object
```

```
    # Two ways of initializing the object
      # population <- init(population, c(x, vx, 0), r, K)
    init(population) <-  list(initState = c(x, vx, 0),
                              r = r,
                              K = K)

    odeSolver <- Verlet(population)        # select the solver

    # Two ways of initializing the solver
      # odeSolver <- init(odeSolver, dt)
    init(odeSolver) <-  dt

    population@odeSolver <- odeSolver
    # setSolver(population) <-  odeSolver

    rowVector <- vector("list")
    i <- 1
    while (getTime(population) <= tmax) {
        rowVector[[i]] <- list(t = getTime(population),
                               s1 = getState(population)[1],
                               s2 = getState(population)[2])
        population <- doStep(population)
        i <- i + 1
    }
    DT <- data.table::rbindlist(rowVector)
    return(DT)
}
# show solution
solution <- LogisticApp()
plot(solution)
```

`enableRuntimeExceptions` *enableRuntimeExceptions*

Description

Enable Runtime Exceptions

Usage

```
enableRuntimeExceptions(object, enable, ...)
```

Arguments

`object`	a class object
`enable`	a boolean to enable exceptions
`...`	additional parameters

Examples

```
setMethod("enableRuntimeExceptions", "DormandPrince45", function(object, enable) {
    object@enableExceptions <- enable
})
```

`Euler-class` *Euler ODE solver class*

Description

Euler ODE solver class

Euler generic

Euler constructor when ‘ODE‘ passed

Euler constructor ‘missing‘ is passed

Usage

```
Euler(ode, ...)

## S4 method for signature 'Euler'
init(object, stepSize, ...)

## S4 method for signature 'Euler'
step(object, ...)

## S4 method for signature 'Euler'
setStepSize(object, stepSize, ...)

## S4 method for signature 'Euler'
getStepSize(object, ...)

## S4 method for signature 'ODE'
Euler(ode, ...)

## S4 method for signature 'missing'
Euler(ode, ...)
```

Arguments

`ode`	an ODE object
`...`	additional parameters
`object`	an internal object of the class
`stepSize`	the size of the step

Examples

```
# +++++++++++++++++++++++++++++++++++++++++++++++ application: RigidBodyNXFApp.R
# example of a nonstiff system is the system of equations describing
# the motion of a rigid body without external forces.

importFromExamples("RigidBody.R")

# run the application
RigidBodyNXFApp <- function(verbose = FALSE) {
    # load the R class that sets up the solver for this application
    y1 <- 0   # initial y1 value
    y2 <- 1    # initial y2 value
    y3 <- 1    # initial y3 value
    dt       <- 0.01 # delta time for step

    body   <- RigidBodyNXF(y1, y2, y3)
    solver <- Euler(body)
    solver <- setStepSize(solver, dt)
    rowVector <- vector("list")
    i <- 1
    # stop loop when the body hits the ground
    while (getState(body)[4] <= 12) {
        rowVector[[i]] <- list(t  = getState(body)[4],
                               y1 = getState(body)[1],
                               y2 = getState(body)[2],
                               y3 = getState(body)[3])
        solver <- step(solver)
        body   <- getODE(solver)
        i <- i + 1
    }
    DT <- data.table::rbindlist(rowVector)
    return(DT)
}

# get the data table from the app
solution <- RigidBodyNXFApp()
plot(solution)

# +++++++++++++++++++++++++++++++++++++++++++++++  example: FallingParticleApp.R
# Application that simulates the free fall of a ball using Euler ODE solver

importFromExamples("FallingParticleODE.R")      # source the class

FallingParticleODEApp <- function(verbose = FALSE) {
    # initial values
    initial_y <- 10
    initial_v <- 0
    dt <- 0.01
    ball   <- FallingParticleODE(initial_y, initial_v)
    solver <- Euler(ball)                        # set the ODE solver
    solver <- setStepSize(solver, dt)            # set the step
    rowVector <- vector("list")
```

```
    i <- 1
    # stop loop when the ball hits the ground, state[1] is the vertical position
    while (getState(ball)[1] > 0) {
        rowVector[[i]] <- list(t  = getState(ball)[3],
                               y  = getState(ball)[1],
                               vy = getState(ball)[2])
        solver <- step(solver)                   # move one step at a time
        ball   <- getODE(solver)                       # update the ball state
        i <- i + 1
    }
    DT <- data.table::rbindlist(rowVector)
    return(DT)
}
# show solution
solution <- FallingParticleODEApp()
plot(solution)
# KeplerVerlet.R



setClass("Kepler", slots = c(
    GM = "numeric",
    odeSolver = "Euler",
    counter = "numeric"
    ),
    contains = c("ODE")
)

setMethod("initialize", "Kepler", function(.Object, ...) {
    .Object@GM <- 4 * pi * pi                # gravitation constant times combined mass
    .Object@state <- vector("numeric", 5)  # x, vx, y, vy, t
    .Object@odeSolver <- Euler(.Object)
    .Object@counter <- 0
    return(.Object)
})

setMethod("doStep", "Kepler", function(object, ...) {
    # cat("state@doStep=", object@state, "\n")
    object@odeSolver <- step(object@odeSolver)

    object@state <- object@odeSolver@ode@state

    # object@rate <- object@odeSolver@ode@rate
    # cat("\t", object@odeSolver@ode@state)
    object
})

setMethod("getTime", "Kepler", function(object, ...) {
    return(object@state[5])
})

setMethod("getEnergy", "Kepler", function(object, ...) {
    ke <- 0.5 * (object@state[2] * object@state[2] +
```

```
                     object@state[4] * object@state[4])
    pe <- -object@GM / sqrt(object@state[1] * object@state[1] +
                                object@state[3] * object@state[3])
    return(pe+ke)
})

setMethod("init", "Kepler", function(object, initState, ...) {
    object@state <- initState
    object@odeSolver <- init(object@odeSolver, getStepSize(object@odeSolver))
    object@counter <- 0
    object
})

setReplaceMethod("init", "Kepler", function(object, ..., value) {
    object@state <- value
    object@odeSolver <- init(object@odeSolver, getStepSize(object@odeSolver))
    object@counter <- 0
    object
})


setMethod("getRate", "Kepler", function(object, state, ...) {
    # Computes the rate using the given state.
    r2 <- state[1] * state[1] + state[3] * state[3]  # distance squared
    r3 <- r2 * sqrt(r2)   # distance cubed
    object@rate[1] <- state[2]
    object@rate[2] <- (- object@GM * state[1]) / r3
    object@rate[3] <- state[4]
    object@rate[4] <- (- object@GM * state[3]) / r3
    object@rate[5] <- 1   # time derivative

    # object@state <- object@odeSolver@ode@state <- state
    # object@state <- state
    object@counter <- object@counter + 1
    object@rate

})

setMethod("getState", "Kepler", function(object, ...) {
    # Gets the state variables.
    return(object@state)
})

# constructor
Kepler <- function() {
    kepler <- new("Kepler")
    return(kepler)
}
# ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++  example: PlanetApp.R
# Simulation of Earth orbiting around the SUn using the Euler ODE solver

importFromExamples("Planet.R")      # source the class
```

```
PlanetApp <- function(verbose = FALSE) {
    # x =  1, AU or Astronomical Units. Length of semimajor axis or the orbit
    # of the Earth around the Sun.
    x <- 1; vx <- 0; y <- 0; vy <- 6.28; t <- 0
    state <- c(x, vx, y, vy, t)
    dt <-  0.01
    planet <- Planet()
    planet@odeSolver <- setStepSize(planet@odeSolver, dt)
    planet <- init(planet, initState = state)
    rowvec <- vector("list")
    i <- 1
    # run infinite loop. stop with ESCAPE.
    while (getState(planet)[5] <= 90) {     # Earth orbit is 365 days around the sun
        rowvec[[i]] <- list(t  = getState(planet)[5],     # just doing 3 months
                            x  = getState(planet)[1],     # to speed up for CRAN
                            vx = getState(planet)[2],
                            y  = getState(planet)[3],
                            vy = getState(planet)[4])
        for (j in 1:5) {                 # advances time
            planet <- doStep(planet)
        }
        i <- i + 1
    }
    DT <- data.table::rbindlist(rowvec)
    return(DT)
}
# run the application
solution <- PlanetApp()
select_rows <- seq(1, nrow(solution), 10)      # do not overplot
solution <- solution[select_rows,]
plot(solution)

# +++++++++++++++++++++++++++++++++++++++++++++++++ application: RigidBodyNXFApp.R
# example of a nonstiff system is the system of equations describing
# the motion of a rigid body without external forces.

importFromExamples("RigidBody.R")

# run the application
RigidBodyNXFApp <- function(verbose = FALSE) {
    # load the R class that sets up the solver for this application
    y1 <- 0   # initial y1 value
    y2 <- 1    # initial y2 value
    y3 <- 1    # initial y3 value
    dt       <- 0.01 # delta time for step

    body   <- RigidBodyNXF(y1, y2, y3)
    solver <- Euler(body)
    solver <- setStepSize(solver, dt)
    rowVector <- vector("list")
    i <- 1
    # stop loop when the body hits the ground
    while (getState(body)[4] <= 12) {
```

```
        rowVector[[i]] <- list(t  = getState(body)[4],
                               y1 = getState(body)[1],
                               y2 = getState(body)[2],
                               y3 = getState(body)[3])
        solver <- step(solver)
        body   <- getODE(solver)
        i <- i + 1
    }
    DT <- data.table::rbindlist(rowVector)
    return(DT)
}

# get the data table from the app
solution <- RigidBodyNXFApp()
plot(solution)
```

`EulerRichardson-class` *EulerRichardson ODE solver class*

Description

EulerRichardson ODE solver class

EulerRichardson generic

EulerRichardson constructor ODE

Usage

```
EulerRichardson(ode, ...)

## S4 method for signature 'EulerRichardson'
init(object, stepSize, ...)

## S4 method for signature 'EulerRichardson'
step(object, ...)

## S4 method for signature 'ODE'
EulerRichardson(ode, ...)
```

Arguments

`ode`	an ODE object
`...`	additional parameters
`object`	internal passing object
`stepSize`	the size of the step

Examples

```
# +++++++++++++++++++++++++++++++++++++++++++++++++++      example: PendulumApp.R
# Simulation of a pendulum using the EulerRichardson ODE solver

suppressPackageStartupMessages(library(ggplot2))

importFromExamples("Pendulum.R")      # source the class

PendulumApp <- function(verbose = FALSE) {
    # initial values
    theta <- 0.2
    thetaDot <- 0
    dt <- 0.1
    pendulum <- Pendulum()
    # pendulum@state[3] <- 0      # set time to zero, t = 0
    pendulum <- setState(pendulum, theta, thetaDot)
    pendulum <- setStepSize(pendulum, dt = dt) # using stepSize in RK4
    pendulum@odeSolver <- setStepSize(pendulum@odeSolver, dt) # set new step size
    rowvec <- vector("list")
    i <- 1
    while (getState(pendulum)[3] <= 40)    {
        rowvec[[i]] <- list(t        = getState(pendulum)[3],    # time
                            theta    = getState(pendulum)[1], # angle
                            thetadot = getState(pendulum)[2]) # derivative of angle
        pendulum <- step(pendulum)
        i <- i + 1
    }
    DT <- data.table::rbindlist(rowvec)
    return(DT)
}
# show solution
solution <- PendulumApp()
plot(solution)
```

---

getEnergy *getEnergy*

Description

Get the calculated energy level

Usage

```
getEnergy(object, ...)
```

Arguments

object	a class object
...	additional parameters

Examples

```
# KeplerEnergy.R
#

setClass("KeplerEnergy", slots = c(
    GM        = "numeric",
    odeSolver = "Verlet",
    counter   = "numeric"
    ),
    contains = c("ODE")
)

setMethod("initialize", "KeplerEnergy", function(.Object, ...) {
    .Object@GM <- 4 * pi * pi         # gravitation constant times combined mass
    .Object@state <- vector("numeric", 5)  # x, vx, y, vy, t
    # .Object@odeSolver <- Verlet(ode = .Object)
    .Object@odeSolver <- Verlet(.Object)
    .Object@counter <- 0
    return(.Object)
})

setMethod("doStep", "KeplerEnergy", function(object, ...) {
    object@odeSolver <- step(object@odeSolver)
    object@state <- object@odeSolver@ode@state
    object
})

setMethod("getTime", "KeplerEnergy", function(object, ...) {
    return(object@state[5])
})

setMethod("getEnergy", "KeplerEnergy", function(object, ...) {
    ke <- 0.5 * (object@state[2] * object@state[2] +
                     object@state[4] * object@state[4])
    pe <- -object@GM / sqrt(object@state[1] * object@state[1] +
                                object@state[3] * object@state[3])
    return(pe+ke)
})


setMethod("init", "KeplerEnergy", function(object, initState, ...) {
    object@state <- initState
    object@odeSolver <- init(object@odeSolver, getStepSize(object@odeSolver))
    object@counter <- 0
    object
})


setReplaceMethod("init", "KeplerEnergy", function(object, ..., value) {
    initState <- value
    object@state <- initState
    object@odeSolver <- init(object@odeSolver, getStepSize(object@odeSolver))
```

```
    object@counter <- 0
    object
})

setMethod("getRate", "KeplerEnergy", function(object, state, ...) {
    # Computes the rate using the given state.
    r2 <- state[1] * state[1] + state[3] * state[3]  # distance squared
    r3 <- r2 * sqrt(r2)   # distance cubed
    object@rate[1] <- state[2]
    object@rate[2] <- (- object@GM * state[1]) / r3
    object@rate[3] <- state[4]
    object@rate[4] <- (- object@GM * state[3]) / r3
    object@rate[5] <- 1   # time derivative

    object@counter <- object@counter + 1
    object@rate

})


setMethod("getState", "KeplerEnergy", function(object, ...) {
    # Gets the state variables.
    return(object@state)
})

# constructor
KeplerEnergy <- function() {
    kepler <- new("KeplerEnergy")
    return(kepler)
}
```

`getErrorCode` *getErrorCode*

Description

Get an error code

Usage

```
getErrorCode(object, tol, ...)
```

Arguments

`object`	a class object
`tol`	tolerance
`...`	additional parameters

Examples

```
setMethod("getErrorCode", "DormandPrince45", function(object) {
return(object@error_code)
})
```

---

getExactSolution *getExactSolution*

Description

Compare analytical and calculated solutions

Usage

```
getExactSolution(object, t, ...)
```

Arguments

object	a class object
t	time ath what we are performing the evaluation
...	additional parameters

Examples

```
# ++++++++++++++++++++++++++++++++++++++++++++++++  example: ComparisonRK45App.R
# Compares the solution by the RK45 ODE solver versus the analytical solution
# Example file: ComparisonRK45App.R
# ODE Solver:   Runge-Kutta 45
# ODE class :   RK45
# Base class:   ODETest

importFromExamples("ODETest.R")

 ComparisonRK45App <- function(verbose = FALSE) {
     ode <- new("ODETest")                     # create an `ODETest` object
     ode_solver <- RK45(ode)                   # select the ODE solver
     ode_solver <- setStepSize(ode_solver, 1)      # set the step

     # Two ways of setting the tolerance
       # ode_solver <- setTolerance(ode_solver, 1e-8)  # set the tolerance
     setTolerance(ode_solver) <-  1e-8

     time <-  0
     rowVector <- vector("list")
     i <- 1
     while (time < 50) {
         rowVector[[i]] <- list(t  = getState(ode)[2],
                                s1 = getState(ode)[1],
```

```
                                s2 = getState(ode)[2],
                                xs = getExactSolution(ode, time),
                                counts = getRateCounts(ode),
                                time   = time
                                )
         ode_solver <- step(ode_solver)           # advance one step
         stepSize   <- getStepSize(ode_solver)
         time <- time + stepSize
         ode  <- getODE(ode_solver)                     # get updated ODE object
         i <- i + 1
     }
     return(data.table::rbindlist(rowVector))    # a data table with the results
 }
# show solution
solution <- ComparisonRK45App()                          # run the example
plot(solution)
# ODETest.R
# Called as base class for examples:
#                         ComparisonRK45App.R
#                         ComparisonRK45ODEApp.R

#' ODETest as an example of ODE class inheritance
#'
#' ODETest is a base class for examples ComparisonRK45App.R and
#' ComparisonRK45ODEApp.R. ODETest also uses an environment variable to store
#' the rate counts.
#'
#' @rdname ODE-class-example
#' @include ODE.R
setClass("ODETest", slots = c(
    n     = "numeric",           # counts the number of getRate evaluations
    stack = "environment"        # environnment object to accumulate rate counts
    ),
    contains = c("ODE")
    )

setMethod("initialize", "ODETest", function(.Object, ...) {
    .Object@stack$rateCounts <-  0              # counter for rate calculations
    .Object@state <- c(5.0, 0.0)
    return(.Object)
})

#' @rdname getExactSolution-method
setMethod("getExactSolution", "ODETest", function(object, t, ...) {
    return(5.0 * exp(-t))
})

#' @rdname getState-method
setMethod("getState", "ODETest", function(object, ...) {
    object@state
})

#' @rdname getRate-method
```

```
setMethod("getRate", "ODETest", function(object, state, ...) {
    object@rate[1] <- - state[1]
    object@rate[2] <-  1            # rate of change of time, dt/dt
    # accumulate how many times the rate has been called to calculate
    object@stack$rateCounts <- object@stack$rateCounts + 1
    object@state <- state
    object@rate
})


#' @rdname getRateCounts-method
setMethod("getRateCounts", "ODETest", function(object, ...) {
    # use environment stack to accumulate rate counts
    object@stack$rateCounts
})

# constructor
ODETest <- function() {
    odetest <- new("ODETest")
    odetest
}
```

`getODE` *getODE*

Description

Get the ODE status from the solver

Usage

```
getODE(object, ...)
```

Arguments

`object`	a class object
`...`	additional parameters

`getRate` *getRate*

Description

Get a new rate given a state

Usage

```
getRate(object, state, ...)
```

Arguments

object	a class object
state	current state
...	additional parameters

Examples

```
#  Kepler models Keplerian orbits of a mass moving under the influence of an
#  inverse square force by implementing the ODE interface.
#  Kepler.R
#

setClass("Kepler", slots = c(
    GM = "numeric"
    ),
    contains = c("ODE")
)

setMethod("initialize", "Kepler", function(.Object, ...) {
    .Object@GM <- 1.0                 # gravitation constant times combined mass
    .Object@state <- vector("numeric", 5)  # x, vx, y, vy, t
    return(.Object)
})

setMethod("getState", "Kepler", function(object, ...) {
    # Gets the state variables.
    return(object@state)
})

setMethod("getRate", "Kepler", function(object, state, ...) {
    # Computes the rate using the given state.
    r2 <- state[1] * state[1] + state[3] * state[3]  # distance squared
    r3 <- r2 * sqrt(r2)   # distance cubed
    object@rate[1] <- state[2]
    object@rate[2] <- (- object@GM * state[1]) / r3
    object@rate[3] <- state[4]
    object@rate[4] <- (- object@GM * state[3]) / r3
    object@rate[5] <- 1   # time derivative

    object@rate

})

# constructor
Kepler <- function(r, v) {
    kepler <- new("Kepler")
    kepler@state[1] = r[1]
    kepler@state[2] = v[1]
    kepler@state[3] = r[2]
    kepler@state[4] = v[2]
    kepler@state[5] = 0
```

```
    return(kepler)
}
```

getRateCounter *getRateCounter*

Description

Get the rate counter

Usage

```
getRateCounter(object, ...)
```

Arguments

`object`	a class object
`...`	additional parameters

Details

How many times the rate has changed with a step

Examples

```
# ++++++++++++++++++++++++++++++++++++++++++++++++  example: ComparisonRK45App.R
# Compares the solution by the RK45 ODE solver versus the analytical solution
# Example file: ComparisonRK45App.R
# ODE Solver:   Runge-Kutta 45
# ODE class :   RK45
# Base class:   ODETest

importFromExamples("ODETest.R")

 ComparisonRK45App <- function(verbose = FALSE) {
     ode <- new("ODETest")                     # create an `ODETest` object
     ode_solver <- RK45(ode)                   # select the ODE solver
     ode_solver <- setStepSize(ode_solver, 1)      # set the step

     # Two ways of setting the tolerance
       # ode_solver <- setTolerance(ode_solver, 1e-8)  # set the tolerance
     setTolerance(ode_solver) <-  1e-8

     time <-  0
     rowVector <- vector("list")
     i <- 1
     while (time < 50) {
         rowVector[[i]] <- list(t  = getState(ode)[2],
                                s1 = getState(ode)[1],
```

```
                                s2 = getState(ode)[2],
                                xs = getExactSolution(ode, time),
                                counts = getRateCounts(ode),
                                time   = time
                                )
          ode_solver <- step(ode_solver)           # advance one step
          stepSize   <- getStepSize(ode_solver)
          time <- time + stepSize
          ode  <- getODE(ode_solver)                     # get updated ODE object
          i <- i + 1
      }
      return(data.table::rbindlist(rowVector))    # a data table with the results
 }
# show solution
solution <- ComparisonRK45App()                          # run the example
plot(solution)
```

---

getRateCounts *getRateCounts*

Description

Get the number of times that the rate has been calculated

Usage

```
getRateCounts(object, ...)
```

Arguments

`object`	a class object
`...`	additional parameters

---

getState *getState*

Description

Get current state of the system

Usage

```
getState(object, ...)
```

Arguments

`object`	a class object
`...`	additional parameters

Examples

```
# ++++++++++++++++++++++++++++++++++++++++++++++++   application: VanderPolApp.R
# Solution of the Van der Pol equation
#
importFromExamples("VanderPol.R")

# run the application
VanderpolApp <- function(verbose = FALSE) {
    # set the orbit into a predefined state.
    y1 <- 2; y2 <- 0; dt <- 0.1;
    rigid_body <- VanderPol(y1, y2)
    solver <- RK45(rigid_body)
    rowVector <- vector("list")
    i <- 1
    while (getState(rigid_body)[3] <= 20) {
        rowVector[[i]] <- list(t  = getState(rigid_body)[3],
                               y1 = getState(rigid_body)[1],
                               y2 = getState(rigid_body)[2])
        solver     <- step(solver)
        rigid_body <- getODE(solver)
        i <-  i + 1
    }
    DT <- data.table::rbindlist(rowVector)
    return(DT)

}
# show solution
solution <- VanderpolApp()
plot(solution)

# ++++++++++++++++++++++++++++++++++++++++++++++++++application:  SpringRK4App.R
# Simulation of a spring considering no friction

importFromExamples("SpringRK4.R")


# run application
SpringRK4App <- function(verbose = FALSE) {
    theta    <- 0
    thetaDot <- -0.2
    tmax     <- 22; dt <- 0.1
    spring <- SpringRK4()
    spring@state[3] <- 0      # set time to zero, t = 0
    spring <- setState(spring, theta, thetaDot)
    #  spring <- setStepSize(spring, dt = dt) # using stepSize in RK4
    spring@odeSolver <- setStepSize(spring@odeSolver, dt) # set new step size
    rowvec <- vector("list")
    i <- 1
    while (getState(spring)[3] <= tmax)    {
        rowvec[[i]] <- list(t  = getState(spring)[3],      # angle
                            y1 = getState(spring)[1],      # derivative of the angle
                            y2 = getState(spring)[2])      # time
```

```
        i <- i + 1
        spring <- step(spring)
    }
    DT <- data.table::rbindlist(rowvec)
    return(DT)
}

# show solution
solution <- SpringRK4App()
plot(solution)
```

`getStepSize` *getStepSize*

Description

Get the current value of the step size

Usage

```
getStepSize(object, ...)
```

Arguments

`object`	a class object
`...`	additional parameters

Examples

```
# +++++++++++++++++++++++++++++++++++++++++++ Example:      ComparisonRK45ODEApp.R
# Updates the ODE state instead of using the internal state in the ODE solver
# Also plots the solver solution versus the analytical solution at a
# tolerance of 1e-6
# Example file: ComparisonRK45ODEApp.R
# ODE Solver:   Runge-Kutta 45
# ODE class :   RK45
# Base class:   ODETest

library(ggplot2)
library(dplyr)
library(tidyr)

importFromExamples("ODETest.R")

ComparisonRK45ODEApp <- function(verbose = FALSE) {
    ode <- new("ODETest")                         # new ODE instance
    ode_solver <- RK45(ode)                       # select ODE solver
    ode_solver <- setStepSize(ode_solver, 1)      # set the step

    # two ways to set tolerance
```

```
      # ode_solver <- setTolerance(ode_solver, 1e-6)
    setTolerance(ode_solver) <-  1e-6

    time <-  0
    rowVector <- vector("list")                  # row vector
    i <- 1    # counter
    while (time < 50) {
        # add solution objects to a row vector
        rowVector[[i]] <- list(t     = getState(ode)[2],
                               ODE   = getState(ode)[1],
                               s2    = getState(ode)[2],
                               exact = getExactSolution(ode, time),
                               rate.counts = getRateCounts(ode),
                               time = time )
        ode_solver <- step(ode_solver)            # advance solver one step
        stepSize <-  getStepSize(ode_solver)      # get the current step size
        time  <- time + stepSize
        ode   <- getODE(ode_solver)               # get updated ODE object
        state <- getState(ode)                    # get the `state` vector
        i <- i + 1                                # add a row vector
    }
    DT <- data.table::rbindlist(rowVector)        # create data table
    return(DT)
}

solution <- ComparisonRK45ODEApp()
plot(solution)


# aditional plot for analytics solution vs. RK45 solver
solution.multi <- solution %>%
    select(t, ODE, exact)
plot(solution.multi)             # 3x3 plot

# plot comparative curves analytical vs ODE solver
solution.2x1 <- solution.multi %>%
    gather(key, value, -t)         # make a table of 3 variables. key: ODE/exact

g <- ggplot(solution.2x1, mapping = aes(x = t, y = value, color = key))
g <-  g + geom_line(size = 1) +
    labs(title = "ODE vs Exact solution",
         subtitle = "tolerance = 1E-6")
print(g)
```

getTime *getTime*

Description

Get the elapsed time

Usage

```
getTime(object, ...)
```

Arguments

object	a class object
...	additional parameters

Examples

```
# ++++++++++++++++++++++++++++++++++++++++++++++++++++   application:  Logistic.R
# Simulates the logistic equation
importFromExamples("Logistic.R")

# Run the application
LogisticApp <- function(verbose = FALSE) {
    x  <- 0.1
    vx <- 0
    r  <- 2        # Malthusian parameter (rate of maximum population growth)
    K  <- 10.0     # carrying capacity of the environment
    dt   <- 0.01; tol  <- 1e-3; tmax <- 10

    population <- Logistic()                # create a Logistic ODE object

    # Two ways of initializing the object
      # population <- init(population, c(x, vx, 0), r, K)
    init(population) <-  list(initState = c(x, vx, 0),
                              r = r,
                              K = K)

    odeSolver <- Verlet(population)        # select the solver

    # Two ways of initializing the solver
      # odeSolver <- init(odeSolver, dt)
    init(odeSolver) <-  dt

    population@odeSolver <- odeSolver
    # setSolver(population) <-  odeSolver

    rowVector <- vector("list")
    i <- 1
    while (getTime(population) <= tmax) {
        rowVector[[i]] <- list(t = getTime(population),
                               s1 = getState(population)[1],
                               s2 = getState(population)[2])
        population <- doStep(population)
        i <- i + 1
```

```
    }
    DT <- data.table::rbindlist(rowVector)
    return(DT)
}
# show solution
solution <- LogisticApp()
plot(solution)
# KeplerEnergy.R
#

setClass("KeplerEnergy", slots = c(
    GM        = "numeric",
    odeSolver = "Verlet",
    counter   = "numeric"
    ),
    contains = c("ODE")
)

setMethod("initialize", "KeplerEnergy", function(.Object, ...) {
    .Object@GM <- 4 * pi * pi         # gravitation constant times combined mass
    .Object@state <- vector("numeric", 5)  # x, vx, y, vy, t
    # .Object@odeSolver <- Verlet(ode = .Object)
    .Object@odeSolver <- Verlet(.Object)
    .Object@counter <- 0
    return(.Object)
})

setMethod("doStep", "KeplerEnergy", function(object, ...) {
    object@odeSolver <- step(object@odeSolver)
    object@state <- object@odeSolver@ode@state
    object
})

setMethod("getTime", "KeplerEnergy", function(object, ...) {
    return(object@state[5])
})

setMethod("getEnergy", "KeplerEnergy", function(object, ...) {
    ke <- 0.5 * (object@state[2] * object@state[2] +
                     object@state[4] * object@state[4])
    pe <- -object@GM / sqrt(object@state[1] * object@state[1] +
                                object@state[3] * object@state[3])
    return(pe+ke)
})


setMethod("init", "KeplerEnergy", function(object, initState, ...) {
    object@state <- initState
    object@odeSolver <- init(object@odeSolver, getStepSize(object@odeSolver))
    object@counter <- 0
    object
})
```

```
setReplaceMethod("init", "KeplerEnergy", function(object, ..., value) {
    initState <- value
    object@state <- initState
    object@odeSolver <- init(object@odeSolver, getStepSize(object@odeSolver))
    object@counter <- 0
    object
})

setMethod("getRate", "KeplerEnergy", function(object, state, ...) {
    # Computes the rate using the given state.
    r2 <- state[1] * state[1] + state[3] * state[3]  # distance squared
    r3 <- r2 * sqrt(r2)   # distance cubed
    object@rate[1] <- state[2]
    object@rate[2] <- (- object@GM * state[1]) / r3
    object@rate[3] <- state[4]
    object@rate[4] <- (- object@GM * state[3]) / r3
    object@rate[5] <- 1   # time derivative

    object@counter <- object@counter + 1
    object@rate

})


setMethod("getState", "KeplerEnergy", function(object, ...) {
    # Gets the state variables.
    return(object@state)
})

# constructor
KeplerEnergy <- function() {
    kepler <- new("KeplerEnergy")
    return(kepler)
}
```

---

getTolerance *getTolerance*

Description

Get the tolerance for the solver

Usage

```
getTolerance(object, ...)
```

Arguments

object	a class object
...	additional parameters

`importFromExamples` *importFromExamples*

Description

Source the R script

Usage

```
importFromExamples(aClassFile, aFolder = "examples")
```

Arguments

`aClassFile`	a file containing one or more classes
`aFolder`	a folder where examples are located

`init` *init*

Description

Set initial values before starting the ODE solver

Set initial values before starting the ODE solver

Usage

```
init(object, ...)

init(object, ...) <- value
```

Arguments

`object`	a class object
`...`	additional parameters
`value`	a value to set

Details

Sets the tolerance like this: solver <- init(solver, dt) Not all super classes require an init method.

Sets the tolerance like this: init(solver) <- dt

Examples

```
# init method in Kepler.R
setMethod("init", "Kepler", function(object, initState, ...) {
    object@state <- initState
    object@odeSolver <- init(object@odeSolver, getStepSize(object@odeSolver))
    object@counter <- 0
    object
})

# init method in LogisticApp.R
setMethod("init", "Logistic", function(object, initState, r, K, ...) {
    object@r <- r
    object@K <- K
    object@state <- initState
    object@odeSolver <- init(object@odeSolver, getStepSize(object@odeSolver))
    object@counter <- 0
    object
})

# init method in Planet.R
setMethod("init", "Planet", function(object, initState, ...) {
    object@state <- object@odeSolver@ode@state <- initState
    # initialize providing the step size
    object@odeSolver <- init(object@odeSolver, getStepSize(object@odeSolver))
    object@rate <- object@odeSolver@ode@rate
    object@state <- object@odeSolver@ode@state
    object
})
```

`ODE-class` *ODE class*

Description

Defines an ODE object for any solver

ODE constructor

Usage

```
ODE()

## S4 method for signature 'ODE'
getState(object, ...)

## S4 method for signature 'ODE'
getRate(object, state, ...)
```

Arguments

object	a class object
...	additional parameters
state	current state

Examples

```
# ++++++++++++++++++++++++++++++++++++++++++++++++++      example: PendulumApp.R
# Simulation of a pendulum using the EulerRichardson ODE solver

suppressPackageStartupMessages(library(ggplot2))

importFromExamples("Pendulum.R")      # source the class

PendulumApp <- function(verbose = FALSE) {
    # initial values
    theta <- 0.2
    thetaDot <- 0
    dt <- 0.1
    pendulum <- Pendulum()
    # pendulum@state[3] <- 0      # set time to zero, t = 0
    pendulum <- setState(pendulum, theta, thetaDot)
    pendulum <- setStepSize(pendulum, dt = dt) # using stepSize in RK4
    pendulum@odeSolver <- setStepSize(pendulum@odeSolver, dt) # set new step size
    rowvec <- vector("list")
    i <- 1
    while (getState(pendulum)[3] <= 40)    {
        rowvec[[i]] <- list(t        = getState(pendulum)[3],    # time
                            theta    = getState(pendulum)[1], # angle
                            thetadot = getState(pendulum)[2]) # derivative of angle
        pendulum <- step(pendulum)
        i <- i + 1
    }
    DT <- data.table::rbindlist(rowvec)
    return(DT)
}
# show solution
solution <- PendulumApp()
plot(solution)
# ++++++++++++++++++++++++++++++++++++++++++++++++++  example: PendulumEulerApp.R
# Pendulum simulation with the Euler ODE solver
# Notice how Euler is not applicable in this case as it diverges very quickly
# even when it is using a very small `delta t``?ODE

importFromExamples("PendulumEuler.R")      # source the class

PendulumEulerApp <- function(verbose = FALSE) {
    # initial values
    theta <- 0.2
    thetaDot <- 0
    dt <- 0.01
```

```
    pendulum <- PendulumEuler()
    pendulum@state[3] <- 0      # set time to zero, t = 0
    pendulum <- setState(pendulum, theta, thetaDot)
    stepSize <- dt
    pendulum <- setStepSize(pendulum, stepSize)
    pendulum@odeSolver <- setStepSize(pendulum@odeSolver, dt) # set new step size
    rowvec <- vector("list")
    i <- 1
    while (getState(pendulum)[3] <= 50)    {
        rowvec[[i]] <- list(t        = getState(pendulum)[3],
                            theta    = getState(pendulum)[1],
                            thetaDot = getState(pendulum)[2])
        pendulum <- step(pendulum)
        i <- i + 1
    }
    DT <- data.table::rbindlist(rowvec)
    return(DT)
}

solution <- PendulumEulerApp()
plot(solution)
#  +++++++++++++++++++++++++++++++++++++++++++++++++++++++++ example KeplerApp.R
#  KeplerApp solves an inverse-square law model (Kepler model) using an adaptive
#  stepsize algorithm.
#  Application showing two planet orbiting
#  File in examples: KeplerApp.R

importFromExamples("Kepler.R") # source the class Kepler

KeplerApp <- function(verbose = FALSE) {

    # set the orbit into a predefined state.
    r <- c(2, 0)                                # orbit radius
    v <- c(0, 0.25)                             # velocity
    dt <- 0.1
    planet <- Kepler(r, v)                      # make up an ODE object
    solver <- RK45(planet)
    rowVector <- vector("list")
    i <- 1
    while (getState(planet)[5] <= 10) {
        rowVector[[i]] <- list(t  = planet@state[5],
                               planet1.r = getState(planet)[1],
                               p1anet1.v = getState(planet)[2],
                               planet2.r = getState(planet)[3],
                               p1anet2.v = getState(planet)[4])
        solver <- step(solver)
        planet <- getODE(solver)
        i <-  i + 1
    }
    DT <- data.table::rbindlist(rowVector)

    return(DT)
}
```

```
solution <- KeplerApp()
plot(solution)


# ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~ base class: FallingParticleODE.R
# Class definition for application FallingParticleODEApp.R

setClass("FallingParticleODE", slots = c(
        g = "numeric"
        ),
        prototype = prototype(
            g = 9.8
        ),
        contains = c("ODE")
        )


setMethod("initialize", "FallingParticleODE", function(.Object, ...) {
    .Object@state <- vector("numeric", 3)
    return(.Object)
})

setMethod("getState", "FallingParticleODE", function(object, ...) {
    # Gets the state variables.
    return(object@state)
})

setMethod("getRate", "FallingParticleODE", function(object, state, ...) {
    # Gets the rate of change using the argument's state variables.
    object@rate[1] <- state[2]
    object@rate[2] <- - object@g
    object@rate[3] <- 1

    object@rate
})

# constructor
FallingParticleODE <- function(y, v) {
    .FallingParticleODE <- new("FallingParticleODE")
    .FallingParticleODE@state[1] <- y
    .FallingParticleODE@state[2] <- v
    .FallingParticleODE@state[3] <- 0
    .FallingParticleODE
}
```

ODEAdaptiveSolver-class

ODEAdaptiveSolver class

Description

Base class to be inherited by adaptive solvers such as RK45

ODEAdaptiveSolver generic

ODEAdaptiveSolver constructor

Usage

```
ODEAdaptiveSolver(...)

## S4 method for signature 'ODEAdaptiveSolver'
setTolerance(object, tol)

## S4 replacement method for signature 'ODEAdaptiveSolver'
setTolerance(object, ...) <- value

## S4 method for signature 'ODEAdaptiveSolver'
getTolerance(object)

## S4 method for signature 'ODEAdaptiveSolver'
getErrorCode(object)

## S4 method for signature 'ANY'
ODEAdaptiveSolver(...)
```

Arguments

...	additional parameters
object	a class object
tol	tolerance
value	the value for the tolerance

ODESolver-class *ODESolver virtual class*

Description

A virtual class inherited by AbstractODESolver

ODESolver constructor

Set initial values and get ready to start the solver

Set the size of the step

Usage

```
ODESolver(object, stepSize, ...)

## S4 method for signature 'ODESolver'
init(object, stepSize, ...)

## S4 method for signature 'ODESolver'
step(object, ...)

## S4 method for signature 'ODESolver'
getODE(object, ...)

## S4 method for signature 'ODESolver'
setStepSize(object, stepSize, ...)

## S4 method for signature 'ODESolver'
getStepSize(object, ...)
```

Arguments

`object`	a class object
`stepSize`	size of the step
`...`	additional parameters

See Also

Other ODESolver helpers: `ODESolverFactory-class`

ODESolverFactory-class *ODESolverFactory*

Description

ODESolverFactory helps to create a solver given only the name as string

ODESolverFactory generic

This is a factory method that creates an ODESolver using a name.

ODESolverFactory constructor

Usage

```
ODESolverFactory(...)

createODESolver(object, ...)
```

```
## S4 method for signature 'ODESolverFactory'
createODESolver(object, ode, solverName, ...)

## S4 method for signature 'ANY'
ODESolverFactory(...)
```

Arguments

`...`	additional parameters
`object`	an solver object
`ode`	an ODE object
`solverName`	the desired solver as a string

See Also

Other ODESolver helpers: `ODESolver-class`

Other ODESolver helpers: `ODESolver-class`

Examples

```
# This example uses ODESolverFactory

importFromExamples("SHO.R")

# SHOApp.R
SHOApp <- function(...) {
    x <- 1.0; v <- 0; k <- 1.0; dt <- 0.01; tolerance <- 1e-3
    sho    <- SHO(x, v, k)

    # Use ODESolverFactory
    solver_factory <- ODESolverFactory()
    solver <- createODESolver(solver_factory, sho, "DormandPrince45")
    # solver <- DormandPrince45(sho)                    # this can also be used

    # Two ways of setting the tolerance
    # solver <- setTolerance(solver, tolerance)          # or this below
    setTolerance(solver) <-  tolerance

    # Two ways of initializing the solver
      # solver <- init(solver, dt)
    init(solver) <- dt

    i <- 1; rowVector <- vector("list")
    while (getState(sho)[3] <= 500) {
        rowVector[[i]] <- list(x = getState(sho)[1],
                               v = getState(sho)[2],
                               t = getState(sho)[3])
        solver <- step(solver)
        sho    <- getODE(solver)
        i <- i + 1
```

```
    }
    return(data.table::rbindlist(rowVector))
}

solution <- SHOApp()
plot(solution)


# This example uses ODESolverFactory

importFromExamples("SHO.R")

# SHOApp.R
SHOApp <- function(...) {
    x <- 1.0; v <- 0; k <- 1.0; dt <- 0.01; tolerance <- 1e-3
    sho    <- SHO(x, v, k)

    # Use ODESolverFactory
    solver_factory <- ODESolverFactory()
    solver <- createODESolver(solver_factory, sho, "DormandPrince45")
    # solver <- DormandPrince45(sho)                    # this can also be used

    # Two ways of setting the tolerance
    # solver <- setTolerance(solver, tolerance)           # or this below
    setTolerance(solver) <-  tolerance

    # Two ways of initializing the solver
      # solver <- init(solver, dt)
    init(solver) <- dt

    i <- 1; rowVector <- vector("list")
    while (getState(sho)[3] <= 500) {
        rowVector[[i]] <- list(x = getState(sho)[1],
                               v = getState(sho)[2],
                               t = getState(sho)[3])
        solver <- step(solver)
        sho    <- getODE(solver)
        i <- i + 1
    }
    return(data.table::rbindlist(rowVector))
}

solution <- SHOApp()
plot(solution)
```

RK4-class *RK4 class*

Description

RK4 class

RK4 generic

RK4 class constructor

Usage

```
RK4(ode, ...)

## S4 method for signature 'RK4'
init(object, stepSize, ...)

## S4 replacement method for signature 'RK4'
init(object, ...) <- value

## S4 method for signature 'RK4'
step(object, ...)

## S4 method for signature 'ODE'
RK4(ode, ...)
```

Arguments

ode	an ODE object
...	additional parameters
object	internal passing object
stepSize	the size of the step
value	value for the step

Examples

```
# ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~  base class: Projectile.R
# Projectile class to be solved with Euler method


setClass("Projectile", slots = c(
    g = "numeric",
    odeSolver = "RK4"
    ),
    prototype = prototype(
        g = 9.8
    ),
    contains = c("ODE")
    )

setMethod("initialize", "Projectile", function(.Object) {
    .Object@odeSolver <- RK4(.Object)
    return(.Object)
```

```
})

setMethod("setStepSize", "Projectile", function(object, stepSize, ...) {
    # use explicit parameter declaration
    # setStepSize generic has two step parameters: stepSize and dt
    object@odeSolver <- setStepSize(object@odeSolver, stepSize)
    object
})


setMethod("step", "Projectile", function(object) {
    object@odeSolver <- step(object@odeSolver)
    object@rate  <- object@odeSolver@ode@rate
    object@state <- object@odeSolver@ode@state
    object
})


setMethod("setState", signature("Projectile"), function(object, x, vx, y, vy, ...) {
    object@state[1] <- x
    object@state[2] <- vx
    object@state[3] <- y
    object@state[4] <- vy
    object@state[5] <- 0     # t + dt
    object@odeSolver@ode@state <- object@state
    object
})


setMethod("getState", "Projectile", function(object) {
    object@state
})


setMethod("getRate", "Projectile", function(object, state, ...) {
    object@rate[1] <- state[2]     # rate of change of x
    object@rate[2] <- 0            # rate of change of vx
    object@rate[3] <- state[4]     # rate of change of y
    object@rate[4] <- - object@g   # rate of change of vy
    object@rate[5] <- 1            # dt/dt = 1

    object@rate
})


# constructor
Projectile <- function()  new("Projectile")
# ++++++++++++++++++++++++++++++++++++++++++++++++++++      example: PendulumApp.R
# Simulation of a pendulum using the EulerRichardson ODE solver

suppressPackageStartupMessages(library(ggplot2))

importFromExamples("Pendulum.R")      # source the class
```

```
PendulumApp <- function(verbose = FALSE) {
    # initial values
    theta <- 0.2
    thetaDot <- 0
    dt <- 0.1
    pendulum <- Pendulum()
    # pendulum@state[3] <- 0      # set time to zero, t = 0
    pendulum <- setState(pendulum, theta, thetaDot)
    pendulum <- setStepSize(pendulum, dt = dt) # using stepSize in RK4
    pendulum@odeSolver <- setStepSize(pendulum@odeSolver, dt) # set new step size
    rowvec <- vector("list")
    i <- 1
    while (getState(pendulum)[3] <= 40)    {
        rowvec[[i]] <- list(t        = getState(pendulum)[3],    # time
                            theta    = getState(pendulum)[1], # angle
                            thetadot = getState(pendulum)[2]) # derivative of angle
        pendulum <- step(pendulum)
        i <- i + 1
    }
    DT <- data.table::rbindlist(rowvec)
    return(DT)
}
# show solution
solution <- PendulumApp()
plot(solution)
# +++++++++++++++++++++++++++++++++++++++++++++++++++++ application: ReactionApp.R
# ReactionApp solves an autocatalytic oscillating chemical
# reaction (Brusselator model) using
# a fourth-order Runge-Kutta algorithm.

importFromExamples("Reaction.R")      # source the class

ReactionApp <- function(verbose = FALSE) {
    X <- 1; Y <- 5;
    dt <- 0.1

    reaction <- Reaction(c(X, Y, 0))
    solver <- RK4(reaction)
    rowvec <- vector("list")
    i <- 1
    while (getState(reaction)[3] < 100) {             # stop at t = 100
        rowvec[[i]] <- list(t = getState(reaction)[3],
                            X = getState(reaction)[1],
                            Y = getState(reaction)[2])
        solver   <- step(solver)
        reaction <- getODE(solver)
        i <-  i + 1
    }
    DT <- data.table::rbindlist(rowvec)
    return(DT)
}
```

```
solution <- ReactionApp()
plot(solution)
```

RK45-class *RK45 ODE solver class*

Description

RK45 ODE solver class

RK45 class constructor

Usage

```
RK45(ode)
```

Arguments

ode	and ODE object

Examples

```
# +++++++++++++++++++++++++++++++++++++++++++++++++  example: ComparisonRK45App.R
# Compares the solution by the RK45 ODE solver versus the analytical solution
# Example file: ComparisonRK45App.R
# ODE Solver:   Runge-Kutta 45
# ODE class :   RK45
# Base class:   ODETest

importFromExamples("ODETest.R")

 ComparisonRK45App <- function(verbose = FALSE) {
     ode <- new("ODETest")                     # create an `ODETest` object
     ode_solver <- RK45(ode)                   # select the ODE solver
     ode_solver <- setStepSize(ode_solver, 1)      # set the step

     # Two ways of setting the tolerance
       # ode_solver <- setTolerance(ode_solver, 1e-8)  # set the tolerance
     setTolerance(ode_solver) <-  1e-8

     time <-  0
     rowVector <- vector("list")
     i <- 1
     while (time < 50) {
         rowVector[[i]] <- list(t  = getState(ode)[2],
                                s1 = getState(ode)[1],
                                s2 = getState(ode)[2],
                                xs = getExactSolution(ode, time),
```

```
                                counts = getRateCounts(ode),
                                time   = time
                                )
         ode_solver <- step(ode_solver)           # advance one step
         stepSize   <- getStepSize(ode_solver)
         time <- time + stepSize
         ode  <- getODE(ode_solver)                     # get updated ODE object
         i <- i + 1
     }
     return(data.table::rbindlist(rowVector))    # a data table with the results
 }
# show solution
solution <- ComparisonRK45App()                          # run the example
plot(solution)
#  ++++++++++++++++++++++++++++++++++++++++++++++++++++++++ example KeplerApp.R
#  KeplerApp solves an inverse-square law model (Kepler model) using an adaptive
#  stepsize algorithm.
#  Application showing two planet orbiting
#  File in examples: KeplerApp.R

importFromExamples("Kepler.R") # source the class Kepler

KeplerApp <- function(verbose = FALSE) {

    # set the orbit into a predefined state.
    r <- c(2, 0)                                     # orbit radius
    v <- c(0, 0.25)                                  # velocity
    dt <- 0.1
    planet <- Kepler(r, v)                           # make up an ODE object
    solver <- RK45(planet)
    rowVector <- vector("list")
    i <- 1
    while (getState(planet)[5] <= 10) {
        rowVector[[i]] <- list(t  = planet@state[5],
                               planet1.r = getState(planet)[1],
                               p1anet1.v = getState(planet)[2],
                               planet2.r = getState(planet)[3],
                               p1anet2.v = getState(planet)[4])
        solver <- step(solver)
        planet <- getODE(solver)
        i <-  i + 1
    }
    DT <- data.table::rbindlist(rowVector)

    return(DT)
}

solution <- KeplerApp()
plot(solution)
```

`run_test_applications` *run_test_applications*

Description

Run test all the examples

Usage

```
run_test_applications()
```

`setSolver<-` *setSolver*

Description

Set a solver over an ODE object

Usage

```
setSolver(object) <- value
```

Arguments

`object`	a class object
`value`	value to be set

`setState` *setState*

Description

New setState that should work with different methods "theta", "thetaDot": used in PendulumApp "x", "vx", "y", "vy": used in ProjectileApp

Usage

```
setState(object, ...)
```

Arguments

`object`	a class object
`...`	additional parameters

Examples

```
# +++++++++++++++++++++++++++++++++++++++++++++++++ application: ProjectileApp.R
#                                                       test Projectile with RK4
#                                                       originally uses Euler

# suppressMessages(library(data.table))

importFromExamples("Projectile.R")      # source the class

ProjectileApp <- function(verbose = FALSE) {
    # initial values
    x <- 0; vx <- 10; y <- 0; vy <- 10
    state <- c(x, vx, y, vy, 0)                       # state vector
    dt <- 0.01

    projectile <- Projectile()
    projectile <- setState(projectile, x, vx, y, vy)

    projectile@odeSolver <- init(projectile@odeSolver, 0.123)

    # init(projectile) <-  0.123

    projectile@odeSolver <- setStepSize(projectile@odeSolver, dt)
    rowV <- vector("list")
    i <- 1
    while (getState(projectile)[3] >= 0)    {
        rowV[[i]] <- list(t  = getState(projectile)[5],
                          x  = getState(projectile)[1],
                          vx = getState(projectile)[2],
                          y  = getState(projectile)[3],     # vertical position
                          vy = getState(projectile)[4])
        projectile <- step(projectile)
        i <- i + 1
    }
    DT <- data.table::rbindlist(rowV)
    return(DT)
}


solution <- ProjectileApp()
plot(solution)
# ++++++++++++++++++++++++++++++++++++++++++++++++++      example: PendulumApp.R
# Simulation of a pendulum using the EulerRichardson ODE solver

suppressPackageStartupMessages(library(ggplot2))

importFromExamples("Pendulum.R")      # source the class

PendulumApp <- function(verbose = FALSE) {
    # initial values
    theta <- 0.2
    thetaDot <- 0
```

```
    dt <- 0.1
    pendulum <- Pendulum()
    # pendulum@state[3] <- 0      # set time to zero, t = 0
    pendulum <- setState(pendulum, theta, thetaDot)
    pendulum <- setStepSize(pendulum, dt = dt) # using stepSize in RK4
    pendulum@odeSolver <- setStepSize(pendulum@odeSolver, dt) # set new step size
    rowvec <- vector("list")
    i <- 1
    while (getState(pendulum)[3] <= 40)    {
        rowvec[[i]] <- list(t        = getState(pendulum)[3],    # time
                            theta    = getState(pendulum)[1], # angle
                            thetadot = getState(pendulum)[2]) # derivative of angle
        pendulum <- step(pendulum)
        i <- i + 1
    }
    DT <- data.table::rbindlist(rowvec)
    return(DT)
}
# show solution
solution <- PendulumApp()
plot(solution)
```

`setStepSize` *setStepSize*

Description

setStepSize uses either of two step parameters: stepSize and dt stepSize works for most of the applications dt is used in Pendulum

Usage

```
setStepSize(object, ...)
```

Arguments

`object`	a class object
`...`	additional parameters

Examples

```
# ++++++++++++++++++++++++++++++++++++++++++++++++++application:  SpringRK4App.R
# Simulation of a spring considering no friction

importFromExamples("SpringRK4.R")


# run application
SpringRK4App <- function(verbose = FALSE) {
```

```
    theta    <- 0
    thetaDot <- -0.2
    tmax     <- 22; dt <- 0.1
    spring <- SpringRK4()
    spring@state[3] <- 0      # set time to zero, t = 0
    spring <- setState(spring, theta, thetaDot)
    #  spring <- setStepSize(spring, dt = dt) # using stepSize in RK4
    spring@odeSolver <- setStepSize(spring@odeSolver, dt) # set new step size
    rowvec <- vector("list")
    i <- 1
    while (getState(spring)[3] <= tmax)    {
        rowvec[[i]] <- list(t  = getState(spring)[3],      # angle
                            y1 = getState(spring)[1],      # derivative of the angle
                            y2 = getState(spring)[2])      # time
        i <- i + 1
        spring <- step(spring)
    }
    DT <- data.table::rbindlist(rowvec)
    return(DT)
}

# show solution
solution <- SpringRK4App()
plot(solution)
# ++++++++++++++++++++++++++++++++++++++++++++++++++  example: ComparisonRK45App.R
# Compares the solution by the RK45 ODE solver versus the analytical solution
# Example file: ComparisonRK45App.R
# ODE Solver:   Runge-Kutta 45
# ODE class :   RK45
# Base class:   ODETest

importFromExamples("ODETest.R")

 ComparisonRK45App <- function(verbose = FALSE) {
     ode <- new("ODETest")                     # create an `ODETest` object
     ode_solver <- RK45(ode)                   # select the ODE solver
     ode_solver <- setStepSize(ode_solver, 1)      # set the step

     # Two ways of setting the tolerance
       # ode_solver <- setTolerance(ode_solver, 1e-8)  # set the tolerance
     setTolerance(ode_solver) <-  1e-8

     time <-  0
     rowVector <- vector("list")
     i <- 1
     while (time < 50) {
         rowVector[[i]] <- list(t  = getState(ode)[2],
                                s1 = getState(ode)[1],
                                s2 = getState(ode)[2],
                                xs = getExactSolution(ode, time),
                                counts = getRateCounts(ode),
                                time   = time
                                )
```

```
        ode_solver <- step(ode_solver)           # advance one step
        stepSize   <- getStepSize(ode_solver)
        time <- time + stepSize
        ode  <- getODE(ode_solver)                     # get updated ODE object
        i <- i + 1
    }
    return(data.table::rbindlist(rowVector))    # a data table with the results
 }
# show solution
solution <- ComparisonRK45App()                         # run the example
plot(solution)
```

---

setTolerance *setTolerance*

Description

Set the tolerance for the solver

Set the tolerance for the solver

Usage

```
setTolerance(object, tol)

setTolerance(object, ...) <- value
```

Arguments

object	a class object
tol	tolerance
...	additional parameters
value	a value to set

Details

Sets the tolerance like this: odeSolver <- setTolerance(odeSolver, tol)

Sets the tolerance like this: setTolerance(odeSolver) <- tol

Examples

```
# ++++++++++++++++++++++++++++++++++++++++++++++++  example: ComparisonRK45App.R
# Compares the solution by the RK45 ODE solver versus the analytical solution
# Example file: ComparisonRK45App.R
# ODE Solver:   Runge-Kutta 45
# ODE class :   RK45
# Base class:   ODETest

importFromExamples("ODETest.R")
```

```
 ComparisonRK45App <- function(verbose = FALSE) {
     ode <- new("ODETest")                     # create an `ODETest` object
     ode_solver <- RK45(ode)                   # select the ODE solver
     ode_solver <- setStepSize(ode_solver, 1)      # set the step

     # Two ways of setting the tolerance
       # ode_solver <- setTolerance(ode_solver, 1e-8)  # set the tolerance
     setTolerance(ode_solver) <-  1e-8

     time <-  0
     rowVector <- vector("list")
     i <- 1
     while (time < 50) {
         rowVector[[i]] <- list(t  = getState(ode)[2],
                                s1 = getState(ode)[1],
                                s2 = getState(ode)[2],
                                xs = getExactSolution(ode, time),
                                counts = getRateCounts(ode),
                                time   = time
                                )
         ode_solver <- step(ode_solver)           # advance one step
         stepSize   <- getStepSize(ode_solver)
         time <- time + stepSize
         ode  <- getODE(ode_solver)                     # get updated ODE object
         i <- i + 1
     }
     return(data.table::rbindlist(rowVector))    # a data table with the results
 }
# show solution
solution <- ComparisonRK45App()                          # run the example
plot(solution)
# ++++++++++++++++++++++++++++++++++++++++++ example: KeplerDormandPrince45App.R
# Demostration of the use of ODE solver RK45 for a particle subjected to
# a inverse-law force. The difference with the example KeplerApp is we are
# seeing the effect in thex and y axis on the particle.
# The original routine used the Verlet ODE solver

importFromExamples("KeplerDormandPrince45.R")

set_solver <- function(ode_object, solver) {
    slot(ode_object, "odeSolver") <- solver
    ode_object
}

KeplerDormandPrince45App <- function(verbose = FALSE) {
    # values for the examples
    x  <- 1
    vx <- 0
    y  <- 0
    vy <- 2 * pi
    dt <- 0.01          # step size
    tol <- 1e-3         # tolerance
```

```
    particle  <- KeplerDormandPrince45()                      # use class Kepler

    # Two ways of initializing the ODE object
      # particle  <- init(particle, c(x, vx, y, vy, 0))  # enter state vector
    init(particle) <- c(x, vx, y, vy, 0)

    odeSolver <- DormandPrince45(particle)      # select the ODE solver

    # Two ways of initializing the solver
      # odeSolver <- init(odeSolver, dt)            # start the solver
    init(odeSolver) <-  dt

    # Two ways of setting the tolerance
      # odeSolver <- setTolerance(odeSolver, tol) # this works for adaptive solvers
    setTolerance(odeSolver) <- tol
    setSolver(particle) <-  odeSolver

    initialEnergy <- getEnergy(particle)        # calculate the energy
    rowVector <- vector("list")
    i <- 1
    while (getTime(particle) < 1.5) {
    rowVector[[i]] <- list(t  = getState(particle)[5],
                           x  = getState(particle)[1],
                           vx = getState(particle)[2],
                           y  = getState(particle)[3],
                           vx = getState(particle)[4],
                           energy = getEnergy(particle) )
        particle <- doStep(particle)            # advance one step
        energy   <- getEnergy(particle)         # calculate energy
        i <- i + 1
    }
    DT <- data.table::rbindlist(rowVector)
    return(DT)
}

solution <- KeplerDormandPrince45App()
plot(solution)


importFromExamples("AdaptiveStep.R")

# running function
AdaptiveStepApp <- function(verbose = FALSE) {
    ode        <- new("Impulse")
    ode_solver <- RK45(ode)

    # Two ways to initialize the solver
      # ode_solver <- init(ode_solver, 0.1)
    init(ode_solver) <- 0.1

    # two ways to set tolerance
      # ode_solver <- setTolerance(ode_solver, 1.0e-4)
    setTolerance(ode_solver) <- 1.0e-4
```

```
    i <- 1; rowVector <- vector("list")
    while (getState(ode)[1] < 12) {
        rowVector[[i]] <- list(s1 = getState(ode)[1],
                               s2 = getState(ode)[2],
                               t  = getState(ode)[3])
        ode_solver <- step(ode_solver)
        ode <- getODE(ode_solver)
        i <- i + 1
    }
    return(data.table::rbindlist(rowVector))
}

# run application
solution <- AdaptiveStepApp()
plot(solution)
```

`showMethods2` *showMethods2*

Description

Get the methods in a class. But only those specific to the class

Usage

```
showMethods2(theClass)
```

Arguments

theClass	class to analyze

`step` *step*

Description

Advances a step within the ODE solver

Usage

```
step(object, ...)
```

Arguments

object	a class object
...	additional parameters

Examples

```
# +++++++++++++++++++++++++++++++++++++++++++++++++++ application: ReactionApp.R
# ReactionApp solves an autocatalytic oscillating chemical
# reaction (Brusselator model) using
# a fourth-order Runge-Kutta algorithm.

importFromExamples("Reaction.R")      # source the class

ReactionApp <- function(verbose = FALSE) {
    X <- 1; Y <- 5;
    dt <- 0.1

    reaction <- Reaction(c(X, Y, 0))
    solver <- RK4(reaction)
    rowvec <- vector("list")
    i <- 1
    while (getState(reaction)[3] < 100) {             # stop at t = 100
        rowvec[[i]] <- list(t = getState(reaction)[3],
                            X = getState(reaction)[1],
                            Y = getState(reaction)[2])
        solver   <- step(solver)
        reaction <- getODE(solver)
        i <-  i + 1
    }
    DT <- data.table::rbindlist(rowvec)
    return(DT)
}


solution <- ReactionApp()
plot(solution)
```

`Verlet-class` *Verlet ODE solver class*

Description

Verlet ODE solver class

Verlet generic

Verlet class constructor ODE

Usage

```
Verlet(ode, ...)

## S4 method for signature 'Verlet'
init(object, stepSize, ...)
```

```
## S4 method for signature 'Verlet'
getRateCounter(object, ...)

## S4 method for signature 'Verlet'
step(object, ...)

## S4 method for signature 'ODE'
Verlet(ode, ...)
```

Arguments

`ode`	an ODE object
`...`	additional parameters
`object`	a class object
`stepSize`	size of the step

Examples

```
# +++++++++++++++++++++++++++++++++++++++++++++++++++  example: KeplerEnergyApp.R
# Demostration of the use of the Verlet ODE solver
#

importFromExamples("KeplerEnergy.R") # source the class Kepler

KeplerEnergyApp <- function(verbose = FALSE) {
    # initial values
    x  <- 1
    vx <- 0
    y  <- 0
    vy <- 2 * pi
    dt <- 0.01
    tol <- 1e-3
    particle <- KeplerEnergy()

    # Two ways of initializing the ODE object
      # particle <- init(particle, c(x, vx, y, vy, 0))
    init(particle) <- c(x, vx, y, vy, 0)

    odeSolver <- Verlet(particle)

    # Two ways of initializing the solver
      # odeSolver <- init(odeSolver, dt)
    init(odeSolver) <-  dt

    particle@odeSolver <- odeSolver
    initialEnergy      <- getEnergy(particle)
    rowVector <- vector("list")
    i <- 1
    while (getTime(particle) <= 1.20) {
        rowVector[[i]] <- list(t  = getState(particle)[5],
```

```
                              x  = getState(particle)[1],
                              vx = getState(particle)[2],
                              y  = getState(particle)[3],
                              vy = getState(particle)[4],
                              E  = getEnergy(particle))
        particle <- doStep(particle)
        energy   <- getEnergy(particle)
        i <- i + 1
    }
    DT <- data.table::rbindlist(rowVector)
    return(DT)
}

solution <- KeplerEnergyApp()
plot(solution)

# +++++++++++++++++++++++++++++++++++++++++++++++++++++   application:  Logistic.R
# Simulates the logistic equation
importFromExamples("Logistic.R")

# Run the application
LogisticApp <- function(verbose = FALSE) {
    x  <- 0.1
    vx <- 0
    r  <- 2        # Malthusian parameter (rate of maximum population growth)
    K  <- 10.0     # carrying capacity of the environment
    dt   <- 0.01; tol  <- 1e-3; tmax <- 10

    population <- Logistic()                # create a Logistic ODE object

    # Two ways of initializing the object
      # population <- init(population, c(x, vx, 0), r, K)
    init(population) <-  list(initState = c(x, vx, 0),
                              r = r,
                              K = K)

    odeSolver <- Verlet(population)        # select the solver

    # Two ways of initializing the solver
      # odeSolver <- init(odeSolver, dt)
    init(odeSolver) <-  dt

    population@odeSolver <- odeSolver
    # setSolver(population) <-  odeSolver

    rowVector <- vector("list")
    i <- 1
    while (getTime(population) <= tmax) {
        rowVector[[i]] <- list(t = getTime(population),
                              s1 = getState(population)[1],
                              s2 = getState(population)[2])
        population <- doStep(population)
        i <- i + 1
```

```
    }
    DT <- data.table::rbindlist(rowVector)
    return(DT)
}
# show solution
solution <- LogisticApp()
plot(solution)
# ++++++++++++++++++++++++++++++++++++++++++++++++++  example: KeplerEnergyApp.R
# Demostration of the use of the Verlet ODE solver
#

importFromExamples("KeplerEnergy.R") # source the class Kepler

KeplerEnergyApp <- function(verbose = FALSE) {
    # initial values
    x  <- 1
    vx <- 0
    y  <- 0
    vy <- 2 * pi
    dt <- 0.01
    tol <- 1e-3
    particle <- KeplerEnergy()

    # Two ways of initializing the ODE object
      # particle <- init(particle, c(x, vx, y, vy, 0))
    init(particle) <- c(x, vx, y, vy, 0)

    odeSolver <- Verlet(particle)

    # Two ways of initializing the solver
      # odeSolver <- init(odeSolver, dt)
    init(odeSolver) <-  dt

    particle@odeSolver <- odeSolver
    initialEnergy      <- getEnergy(particle)
    rowVector <- vector("list")
    i <- 1
    while (getTime(particle) <= 1.20) {
        rowVector[[i]] <- list(t  = getState(particle)[5],
                               x  = getState(particle)[1],
                               vx = getState(particle)[2],
                               y  = getState(particle)[3],
                               vy = getState(particle)[4],
                               E  = getEnergy(particle))
        particle <- doStep(particle)
        energy   <- getEnergy(particle)
        i <- i + 1
    }
    DT <- data.table::rbindlist(rowVector)
    return(DT)
}

solution <- KeplerEnergyApp()
```

```
plot(solution)

# ++++++++++++++++++++++++++++++++++++++++++++++++++++   application:  Logistic.R
# Simulates the logistic equation
importFromExamples("Logistic.R")

# Run the application
LogisticApp <- function(verbose = FALSE) {
    x  <- 0.1
    vx <- 0
    r  <- 2        # Malthusian parameter (rate of maximum population growth)
    K  <- 10.0     # carrying capacity of the environment
    dt   <- 0.01; tol  <- 1e-3; tmax <- 10

    population <- Logistic()                # create a Logistic ODE object

    # Two ways of initializing the object
      # population <- init(population, c(x, vx, 0), r, K)
    init(population) <-  list(initState = c(x, vx, 0),
                              r = r,
                              K = K)

    odeSolver <- Verlet(population)        # select the solver

    # Two ways of initializing the solver
      # odeSolver <- init(odeSolver, dt)
    init(odeSolver) <-  dt

    population@odeSolver <- odeSolver
    # setSolver(population) <-  odeSolver

    rowVector <- vector("list")
    i <- 1
    while (getTime(population) <= tmax) {
        rowVector[[i]] <- list(t = getTime(population),
                               s1 = getState(population)[1],
                               s2 = getState(population)[2])
        population <- doStep(population)
        i <- i + 1
    }
    DT <- data.table::rbindlist(rowVector)
    return(DT)
}
# show solution
solution <- LogisticApp()
plot(solution)
```

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