Package ‘prioriactions’

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Type Package
Version 0.4
Title Multi-Action Conservation Planning
Description This uses a mixed integer mathematical programming (MIP) approach for building and solving multi-action planning problems, where the goal is to find an optimal combination of management actions that abate threats, in an efficient way while accounting for spatial aspects. Thus, optimizing the connectivity and conservation effectiveness of the prioritized units and of the deployed actions. The package is capable of handling different commercial (gurobi) and non-commercial (symphony) MIP solvers. Gurobi optimization solver can be installed using comprehensive instructions in the gurobi installation vignette of the prioritizr package (available in <https://prioritizr.net/articles/gurobi_installation_guide.html>). Methods used in the package refers to Salgado-Rojas et al. (2020) <doi:10.1016/j.ecolmodel.2019.108901>, Beyer et al. (2016) <doi:10.1016/j.ecolmodel.2016.02.005>, Cattarino et al. (2015) <doi:10.1371/journal.pone.0128027> and Watts et al. (2009) <doi:10.1016/j.envsoft.2009.06.005>. See the prioriactions website for more information, documentations and examples.

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     'problem_modifier.R' 'evalBudget.R' 'evalTarget.R'
     'getActions.R' 'getConnectivityPenalty.R' 'getCost.R'
     'getModelInfo.R' 'getPerformance.R' 'getPotentialBenefit.R'
     'getSolutionBenefit.R' 'inputData.R' 'package.R'
     'portfolio-class.R' 'print.R' 'problem.R' 'show.R' 'simData.R'
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R topics documented:

data-class .......................................................... 3
evalBlm ............................................................ 5
evalBudget .......................................................... 6
evalTarget ........................................................... 7
getActions ............................................................ 8
getConnectivityPenalty ........................................... 10
cost ................................................................. 11
getModelInfo ......................................................... 12
getPerformance ....................................................... 14
getPotentialBenefit ............................................... 15
getSolutionBenefit .................................................. 17
inputData ........................................................... 18
optimizationProblem-class ....................................... 22
portfolio-class ....................................................... 23
print ................................................................. 24
prioriactions ......................................................... 25
problem .............................................................. 26
show ................................................................. 29
simData ............................................................. 30
Data class

Description

This class is used to represent data of the instances of the corresponding multi-action planning problem. It includes several methods for retrieving the information of the instance (such as the spatial allocation of threats and species, the cost of management actions or the structure of the spatial connectivity across the area where the planning is carried out. This class is created using the `inputData()` function.

Value

No return value.

Fields

data list object containing data.

Methods

getActionsAmount(): integer. Number of possible actions.

data(character name): data.frame. Object stored in the data field with the corresponding name. The argument name indicates the name of arguments of the `problem` function ("pu", "features", "dist_features", "threats", "dist_threats", "sensitivity" or "boundary").

getFeatureAmount(): integer. Number of features.

getFeatureNames(): character. Names of features.

getMonitoringCosts(): numeric vector. Cost of monitoring each planning unit.

getPlanningUnitsAmount(): integer. Number of planning units.

getActionCosts(): numeric vector. Cost of actions each planning unit and threat.

getThreatNames(): character. Names of threats.

getThreatsAmount(): integer. Number of threats.

print(): Print basic information of the data instance.

show(): Call print method.
## Examples

```r
## set seed for reproducibility
set.seed(14)

## Set prioriactions path
prioriactions_path <- system.file("extdata/example_input/", package = "prioriactions")

## Load in planning unit data
pu_data <- data.table::fread(paste0(prioriactions_path,"/pu.dat"),
    data.table = FALSE)
head(pu_data)

## Load in feature data
features_data <- data.table::fread(paste0(prioriactions_path,"/features.dat"),
    data.table = FALSE)
head(features_data)

## Load in planning unit vs feature data
dist_features_data <- data.table::fread(paste0(prioriactions_path,"/dist_features.dat"),
    data.table = FALSE)
head(dist_features_data)

## Load in the threats data
threats_data <- data.table::fread(paste0(prioriactions_path,"/threats.dat"),
    data.table = FALSE)
head(threats_data)

## Load in the threats distribution data
dist_threats_data <- data.table::fread(paste0(prioriactions_path,"/dist_threats.dat"),
    data.table = FALSE)
head(dist_threats_data)

## Load in the sensitivity data
sensitivity_data <- data.table::fread(paste0(prioriactions_path,"/sensitivity.dat"),
    data.table = FALSE)
head(sensitivity_data)

## Load in the boundary data
boundary_data <- data.table::fread(paste0(prioriactions_path,"/boundary.dat"),
    data.table = FALSE)
head(boundary_data)

## Create instance
problem_data <- inputData(
    pu = pu_data, features = features_data, dist_features = dist_features_data,
    dist_threats = dist_threats_data, threats = threats_data, sensitivity = sensitivity_data,
    boundary = boundary_data)

## Summary
print(problem_data)
```
## Use class methods

```r
problem_data$getData("features")
problem_data$getFeatureAmount()
problem_data$getFeatureNames()
problem_data$getMonitoringCosts()
problem_data$getPlanningUnitsAmount()
problem_data$getActionCosts()
problem_data$getThreatNames()
problem_data$getThreatsAmount()
problem_data$print()
```

---

### `evalBlm`  
Evaluate multiple `blm` values

#### Description

Return one solution per instance for different values of `blm`. Like `prioriactions()` function, it inherits all arguments from `inputData()`, `problem()` and `solve()`.

#### Usage

```r
evalBlm(values = c(), ...)
```

#### Arguments

- **values**: numeric. Values of `blm` to verify. More than one value is needed.
- **...**: arguments inherited from `inputData()`, `problem()` and `solve()` functions.

#### Details

evalBlm() creates and solves multiple instances, of the corresponding multi-actions planning problem, for different values of `blm`. Alternatively, this could be obtained by executing function `prioriactions()` or by steps the `inputData()`, `problem()` and `solve()` functions; using, in each run, different `blm` values. However, the evalBlm() function has two advantages with respect to this manual approach: 1) it is more efficient to create the models (this is because the model is created just once and, at each iteration, only the `blm` values are updated); and 2) the output is a portfolio object, which allows obtaining information about the group of solutions (including all `get` functions).

#### Value

An object of class `portfolio`. 

Examples

# set seed for reproducibility
set.seed(14)

## Create model and solve
port <- evalBlm(pu = sim_pu_data, features = sim_features_data,
    dist_features = sim_dist_features_data,
    threats = sim_threats_data,
    dist_threats = sim_dist_threats_data,
    sensitivity = sim_sensitivity_data,
    boundary = sim_boundary_data,
    values = c(0.0, 0.01, 0.02, 0.03),
    model_type = "minimizeCosts",
    time_limit = 50,
    output_file = FALSE,
    cores = 2)

getConnectivityPenalty(port)

evalBudget  

Evaluate multiple budget values

Description

Return one solution per instance for different values of budgets. This function assumes that the maximizeBenefits option is being used (note that the minimizeCosts option does not require setting a maximum budget). Like prioriactions() function, it inherits all arguments from inputData(), problem() and solve() functions.

Usage

evalBudget(values = c(), ...)

Arguments

values numeric. Values of budget to verify. More than one value is needed.

... arguments inherited from inputData(), problem(), and solve() functions.

Details

evalBudget() creates and solves multiple instances, of the corresponding multi-actions planning problem, for different values of maximum budgets. Alternatively, this could be obtained by executing function prioriactions() or by steps the inputData(), problem() and solve() functions; using, in each run, different budgets values. However, the evalBudget() function has two advantages with respect to this manual approach: 1) it is more efficient to create the models (this is
because the model is created just once and, at each iteration, only the budget values are updated); and 2) the output is a portfolio object, which allows obtaining information about the group of solutions (including all get functions).

Value

An object of class portfolio.

Examples

# set seed for reproducibility
given.seed(14)

# Create model and solve
given <- evalBudget(pu = sim_pu_data, features = sim_features_data, 
dist_features = sim_dist_features_data, 
threats = sim_threats_data, 
dist_threats = sim_dist_threats_data, 
sensitivity = sim_sensitivity_data, 
boundary = sim_boundary_data, 
values = c(1, 10, 50, 100), 
time_limit = 50, 
output_file = FALSE, 
cores = 2)

getsolutionBenefit(given)

evalTarget

Evaluate multiple target values

Description

Return one solution per instance for different targets values. This function assumes that the minimizeCosts model is being used. As well as the prioriactions() function, it inherits all arguments from inputData(), problem(), and solve().

Usage

evalTarget(values = c(), ...)

Arguments

values numeric. Proportion of maximum value of benefits to verify (both recovery and conservation benefits). This information can be obtained with getPotentialBenefit() function. More than one value is needed.

... arguments inherited from inputData(), problem(), and solve() functions.
getActions

Details

evalTarget() creates and solves multiple instances, of the corresponding multi-actions planning problem, for different proportions of maximum benefit values as target values. It is assumed that the same proportion is applied for the maximum benefit in recovery and conservation. Alternatively, this could be obtained by executing function prioriactions() or by steps the inputData(), problem() and solve() functions; using, in each run, different targets values. However, the evalTarget() function has two advantages with respect to this manual approach: 1) it is more efficient to create the models (this is because the model is created just once and, at each iteration, only the target values are updated); and 2) the output is a portfolio object, which allows obtaining information about the group of solutions (including all get functions).

Value

An object of class portfolio.

Examples

# set seed for reproducibility
set.seed(14)

## Create model and solve
port <- evalTarget(pu = sim_pu_data, features = sim_features_data, dist_features = sim_dist_features_data, threats = sim_threats_data, dist_threats = sim_dist_threats_data, sensitivity = sim_sensitivity_data, boundary = sim_boundary_data, values = c(0.1, 0.3, 0.5), time_limit = 50, output_file = FALSE, cores = 2)

getCost(port)

getActions

Extract action information

Description

Returns the spatial deployment of the actions for each planning unit of the corresponding solution.

Usage

getActions(x, format = "wide")
**getActions**

**Arguments**

- `x`  
  solution or portfolio object.

- `format` character. Output format of the action matrix; wide format shows one column per action, while large format shows four columns: solution_name, pu, action and solution.

**Details**

getActions() function assumes that actions can be of three types:

1. **to abate specific threats**: these actions have the id corresponding to the threat to be abate.
2. **to conservation**: that indicates if the planning unit is selected to conservative any feature that is not threatened.
3. **to connectivity**: that indicates if the planning unit is selected only by connectivity (i.e. without performing conservation actions or actions against a threat in said unit).

**Value**

data.frame.

**Examples**

```r
# set seed for reproducibility
set.seed(14)

## Load data
data(sim_pu_data, sim_features_data, sim_dist_features_data,
sim_threats_data, sim_dist_threats_data, sim_sensitivity_data,
sim_boundary_data)

## Create instance
problem_data <- inputData(
  pu = sim_pu_data, features = sim_features_data, dist_features = sim_dist_features_data,
  threats = sim_threats_data, dist_threats = sim_dist_threats_data,
  sensitivity = sim_sensitivity_data, boundary = sim_boundary_data
)

## Create optimization model
problem_model <- problem(x = problem_data)

## Solve the optimization model
s <- solve(a = problem_model, time_limit = 2, output_file = FALSE, cores = 2)

# get actions information in large format
actions <- getActions(s, format = "large")
head(actions)

# get actions information in wide format
actions <- getActions(s, format = "wide")
```
getConnectivityPenalty

Extract connectivity penalty values

Description

Provides the connectivity penalty value for all actions and planning units in a solution.

Usage

getConnectivityPenalty(x)

Arguments

x solution or portfolio object.

Details

The connectivity penalty among is calculated as the sum of all connectivity penalties by each action and planning unit in the solution. This can be expressed mathematically for a set of planning units $I$ indexed by $i$ and $j$, and a set of threats $K$ indexed by $k$ as:

$$
\sum_{k \in K} \sum_{i \in I_k} \sum_{j \in I_k} x_{ik}(1 - x_{jk})c_{ij}
$$

Where, $x_{ik}$ is the decisions variable that specify whether an action has been selected to abate threat $k$ in planning unit $i$ (1) or not (0), $c_{ij}$ is the connectivity penalty that applies when a solution contains planning unit $i$ but not $j$ or vice versa.

Note that there is an action per threat, so it is assumed that the index of the threat coincides with the index of the action used to abate it.

Value

data.frame.

Examples

# set seed for reproducibility
set.seed(14)

## Load data
data(sim_pu_data, sim_features_data, sim_dist_features_data, sim_threats_data, sim_dist_threats_data, sim_sensitivity_data,
## Create data instance

```r
problem_data <- inputData(
  pu = sim_pu_data, features = sim_features_data, dist_features = sim_dist_features_data,
  threats = sim_threats_data, dist_threats = sim_dist_threats_data,
  sensitivity = sim_sensitivity_data, boundary = sim_boundary_data
)
```

## Create optimization model

```r
problem_model <- problem(x = problem_data, blm = 0.03)
```

## Solve the optimization model

```r
s <- solve(a = problem_model, time_limit = 2, output_file = FALSE, cores = 2)
```

# get connectivity penalty values

```r
getConnectivityPenalty(s)
```

---

### Description

Provides the sum of costs to actions and monitoring applied in a solution.

### Usage

```r
getCode(x)
```

### Arguments

- `x` solution or portfolio object.

### Details

The cost value is calculated as the sum of all the individual costs of actions and monitoring carried out in each of the planning units. This can be expressed mathematically for a set of planning units $I$ indexed by $i$, and a set of threats $K$ indexed by $k$ as:

\[
\text{actions} = \sum_{i \in I} \sum_{k \in K_i} x_{ik} c_{ik}
\]

\[
\text{monitoring} = \sum_{i \in I} x_i c'_i
\]

Where, $x_{ik}$ is the decisions variable that specify whether an action has been selected to abate threat $k$ in planning unit $i$ (1) or not (0), $c_{ik}$ is the action cost to abate threat $k$ in planning unit $i$ and $c'_i$ is
the monitoring cost of planning unit $i$. The cost of monitoring is applied to all planning units where some type of action has been selected (conservation action, to abate threats or connectivity). Note that there is an action per threat, so it is assumed that the index of the threat coincides with the index of the action used to abate it.

Value

data.frame.

Examples

```r
# set seed for reproducibility
set.seed(14)

## Load data
data(sim_pu_data, sim_features_data, sim_dist_features_data, sim_threats_data, sim_dist_threats_data, sim_sensitivity_data, sim_boundary_data)

## Create data instance
problem_data <- inputData(
  pu = sim_pu_data, features = sim_features_data, dist_features = sim_dist_features_data, threats = sim_threats_data, dist_threats = sim_dist_threats_data, 
  sensitivity = sim_sensitivity_data, boundary = sim_boundary_data
)

## Create optimization model
problem_model <- problem(x = problem_data)

## Solve the optimization model
s <- solve(a = problem_model, time_limit = 2, output_file = FALSE, cores = 2)

## Get costs
getCost(s)
```

---

**getModelInfo**

*Extract general information about mathematical model*

**Description**

Provides general information about the mathematical model.

**Usage**

`getModelState(x)`
getModelInfo

Arguments

- `x`: optimizationProblem, solution or portfolio object.

Details

getModelInfo() function returns five specific fields:

1. **solution_name**: indicates the name of the solution, by default is `sol`.
2. **model_sense**: returns the optimization sense (i.e., it indicates whether the objective function is minimized or maximize).
3. **n_constraints**: returns the number of constraints in the corresponding mathematical optimization model.
4. **n_variables**: returns the number of variables in the corresponding mathematical optimization model.
5. **size**: returns the size of the constraints’ coefficients matrix A number of constraints and number of variables).

Value

data.frame.

Examples

```r
# set seed for reproducibility
set.seed(14)

## Load data
data(sim_pu_data, sim_features_data, sim_dist_features_data,
sim_threats_data, sim_dist_threats_data, sim_sensitivity_data,
sim_boundary_data)

## Create data instance
problem_data <- inputData(
  pu = sim_pu_data, features = sim_features_data, dist_features = sim_dist_features_data,
  threats = sim_threats_data, dist_threats = sim_dist_threats_data,
  sensitivity = sim_sensitivity_data, boundary = sim_boundary_data)

## Create optimization model
problem_model <- problem(x = problem_data, blm = 1)

# get model information
getModelInfo(problem_model)
```
getPerformance

Extract general information about solution

Description
Provides general information about the process of solving.

Usage
getPerformance(x)

Arguments
x : solution or portfolio object.

Details
getPerformance() function returns five specific fields:

1. **solution_name**: indicates the name of the solution, by default is *sol*.
2. **objective_value**: indicates the value of the objective function of a given solution. This value depends on the type of model solved (more information in the `problem()` function).
3. **gap**: returns the relative MIP optimality gap of a solution. It is measured as the ratio between the objective function induced by the best known (primal solution) integer solution and the objective function induced by the best node in the search tree (dual solution).
4. **solving_time**: indicates the solving time of mathematical model.
5. **status**: provides the status of solver at the end of the optimization period. This can have six states:
   - *Optimal solution (according to gap tolerance)*: When the resolution of the model stop when the quality of the solution (gap) is less than or equal to gap_limit (parameter of the solve() function).
   - *No solution (model was proven to be infeasible or unbounded)*: When the model is infeasible.
   - *Feasible solution (according to time limit)*: When the resolution of the model stops when a time_limit has been reached finding a feasible solution (parameter of the solve() function).
   - *No solution (according to time limit)*: When the resolution of the model stops when a time_limit has been reached without finding a feasible solution (parameter of the solve() function).
   - *First feasible solution*: When the resolution of the model stops when it has found the first feasible solution (solution_limit = TRUE parameter in solve() function).
   - *No solution information is available*: For any other case.

Value
data.frame.
getPotentialBenefit

Examples

# set seed for reproducibility
set.seed(14)

## Load data
data(sim_pu_data, sim_features_data, sim_dist_features_data,
sim_threats_data, sim_dist_threats_data, sim_sensitivity_data,
sim_boundary_data)

## Create data instance
problem_data <- inputData(
  pu = sim_pu_data, features = sim_features_data, dist_features = sim_dist_features_data,
  threats = sim_threats_data, dist_threats = sim_dist_threats_data,
  sensitivity = sim_sensitivity_data, boundary = sim_boundary_data
)

## Create optimization model
problem_model <- problem(x = problem_data, blm = 1)

## Solve the optimization model
s <- solve(a = problem_model, time_limit = 2, output_file = FALSE, cores = 2)

# get solution gap
goingalPerformance(s)

getPotentialBenefit

Extract potential benefit of features

Description

Provides the maximum values of benefits to achieve for each feature given a set of data inputs.

Usage

getPotentialBenefit(x)

Arguments

x data-class object.

Details

For a given feature $s$, let $I_s$ be the set of planning units associated with $s$, let $r_{is}$ be the amount of feature $s$ in planning unit $i$, let $K_s$ be the set of threats associated with $s$, and let $K_i$ be the set of threats associated with $i$. The local benefit associated with $s$ in a unit $i$ is given by:
\[ b_{is} = p_{is} r_{is} b_{is} = \frac{\sum_{k \in K_i \cap K_s} x_{ik} r_{is}}{|K_i \cap K_s|} \]

Where \( x_{ik} \) is a decision variable such that \( x_{ik} = 1 \) if an action against threat \( k \) is applied in unit \( i \), and \( x_{ik} = 0 \), otherwise. This expression for the probability of persistence of the feature \( (p_{is}) \) is defined only for the cases where we work with values of binary intensities (presence or absence of threats). See the sensitivities vignette to know the work with continuous intensities.

While the total benefit is calculated as the sum of the local benefits per feature:

\[ b_s = \sum_{i \in I_s} \frac{\sum_{k \in K_i \cap K_s} x_{ik}}{|K_i \cap K_s|} r_{is} \]

Since the potential benefit is being calculated, all variables \( x_{ik} \) are assumed to be equal to 1; that is, all possible actions are carried out, and only those that have a **lock-out** status are kept out of the planning (see `inputData()` function for more information).

### Value

data.frame.

### Examples

```r
# set seed for reproducibility
set.seed(14)

## Load data
data(sim_pu_data, sim_features_data, sim_dist_features_data, sim_threats_data, sim_dist_threats_data, sim_sensitivity_data, sim_boundary_data)

## Create data instance
problem_data <- inputData(
  pu = sim_pu_data, features = sim_features_data, dist_features = sim_dist_features_data, threats = sim_threats_data, dist_threats = sim_dist_threats_data, sensitivity = sim_sensitivity_data, boundary = sim_boundary_data
)

## Get maximum benefits to obtain
getPotentialBenefit(problem_data)
```
getSolutionBenefit

Extract benefit values

Description

Returns the total benefit induced by the corresponding solution. The total benefit is computed as the sum of the benefits obtained, for all features, across all the units in the planning area.

Usage

getSolutionBenefit(x, type = "total")

Arguments

x Solution-class or Portfolio-class.

type character. Output format of the benefits matrix; total shows the total benefit by feature, while local format shows the benefit achieved per feature and planning unit.

Details

For a given feature \( s \), let \( I_s \) be the set of planning units associated with \( s \), let \( r_{is} \) is the amount of feature \( s \) in planning unit \( i \), let \( K_s \) be the set of threats associated with \( s \), and let \( K_i \) be the set of threats associated with \( i \). The local benefit associated with \( s \) in a unit \( i \) is given by:

\[
b_{is} = p_{is}r_{is}b_{is} = \frac{\sum_{k \in K_i \cap K_s} x_{ik}}{|K_i \cap K_s|} r_{is}
\]

Where \( x_{ik} \) is a decision variable such that \( x_{ik} = 1 \) if an action against threat \( k \) is applied in unit \( i \), and \( x_{ik} = 0 \), otherwise. This expression for the probability of persistence of the feature \( (p_{is}) \) is defined only for the cases where we work with values of binary intensities (presence or absence of threats). See the sensitivities vignette to know the work with continuous intensities.

While the total benefit is calculated as the sum of the local benefits per feature:

\[
b_s = \sum_{i \in I_s} \frac{\sum_{k \in K_i \cap K_s} x_{ik}}{|K_i \cap K_s|} r_{is}
\]

Value

data.frame.
Examples

```r
# set seed for reproducibility
set.seed(14)

## Load data
data(sim_pu_data, sim_features_data, sim_dist_features_data,
sim_threats_data, sim_dist_threats_data, sim_sensitivity_data,
sim_boundary_data)

## Create data instance
problem_data <- inputData(
  pu = sim_pu_data, features = sim_features_data, dist_features = sim_dist_features_data,
  threats = sim_threats_data, dist_threats = sim_dist_threats_data,
  sensitivity = sim_sensitivity_data, boundary = sim_boundary_data
)

## Get maximum benefits to obtain
getPotentialBenefit(problem_data)

## Create optimization model
problem_model <- problem(x = problem_data)

## Solve the optimization model
s <- solve(a = problem_model, time_limit = 2, output_file = FALSE, cores = 2)

# get local benefits of solution
local_benefit <- getSolutionBenefit(s, type = "local")
head(local_benefit)

# get total benefits of solution
total_benefit <- getSolutionBenefit(s, type = "total")
head(total_benefit)
```

---

**inputData**

*Creates the multi-action planning problem*

**Description**

Create the data object with information about the multi-action conservation planning problem. This function is used to specify all the data that defines the spatial prioritization problem (planning units data, feature data, threats data, and their spatial distributions.)

**Usage**

```r
inputData(pu, features, dist_features, threats, dist_threats, ...)
```
inputData

## S4 method for signature
## 'data.frame,data.frame,data.frame,data.frame,data.frame'
inputData(
  pu,
  features,
  dist_features,
  threats,
  dist_threats,
  sensitivity = NULL,
  boundary = NULL
)

Arguments

pu Object of class data.frame() that specifies the planning units (PU) of the corresponding instance and their corresponding monitoring cost and status. Each row corresponds to a different planning unit. This file is inherited from the pu.dat in Marxan. It must contain the following columns:

  id integer unique identifier for each planning unit.
  monitoring_cost numeric cost of including each planning unit in the reserve system.
  status integer (optional) value that indicate if each planning unit should be available to be selected (0), locked-in (2) as part of the solution, or locked-out (3) and excluded from the solution.

features Object of class data.frame() that specifies the conservation features to consider in the optimization problem. Each row corresponds to a different feature. This file is inherited from marxan’s spec.dat.

The prioriactions package supports two types of purposes when optimizing: focus on recovery of features threatened (through the recovery target), where only take into account benefits when taking action against threats and there is no benefit when selecting planning units where the features are not threatened; or include the benefits of the features sites where they are not threatened (through the conservation target).

Note that by default only information on recovery targets is necessary, while conservation targets equal to zero are assumed. The maximum values of benefits to achieve both recovery and conservation per feature can be verified with the getPotentialBenefit() function. For more information on the implications of these targets in the solutions see the recovery vignette.

This file must contain the following columns:

  id integer unique identifier for each conservation feature.
  target_recovery numeric amount of recovery target to achieve for each conservation feature. This field is required if a minimizeCosts model is used.
  target_conservation numeric (optional) amount of conservation target to achieve for each conservation feature. This field is used only if a model of the type minimizeCosts is applied.
  name character (optional) name for each conservation feature.
dist_features Object of class `data.frame()` that specifies the spatial distribution of conservation features across planning units. Each row corresponds to a combination of planning unit and feature. This file is inherited from marxan’s `puspr.dat`. It must contain the following columns:

- `pu` integer id of a planning unit where the conservation feature listed on the same row occurs.
- `feature` integer id of each conservation feature.
- `amount` numeric amount of the feature in the planning unit. Set to 1 to work with presence/absence.

threats Object of class `data.frame()` that specifies the threats to consider in the optimization exercise. Each row corresponds to a different threat. It must contain the following columns:

- `id` integer unique identifier for each threat.
- `blm_actions` numeric (optional) penalty of connectivity between threats. Default is 0.
- `name` character (optional) name for each threat.

dist_threats Object of class `data.frame()` that specifies the spatial distribution of threats across planning units. Each row corresponds to a combination of planning unit and threat. It must contain the following columns:

- `pu` integer id of a planning unit where the threat listed on the same row occurs.
- `threat` integer id of each threat.
- `amount` numeric amount of the threat in the planning unit. Set to 1 to work with presence/absence. Continuous amount values require that feature sensitivities to threats be established (more info in `sensitivities` vignette).
- `action_cost` numeric cost of an action to abate the threat in each planning unit.
- `status` integer (optional) value that indicates if each action to abate the threat is available to be selected (0), `locked-in` (2) as part of the solution, or `locked-out` (3) and therefore excluded from the solution.

... Unused arguments, reserved for future expansion.

sensitivity (optional) Object of class `data.frame()` that specifies the sensitivity of each feature to each threat. Each row corresponds to a combination of feature and threat. If not informed, all features are assumed to be sensitive to all threats. Sensitivity can be parameterized in two ways: `binary`; the feature is sensitive or not, or `continuous`; with response curves of the probability of persistence of the features to threats. For the first case, it is only necessary to indicate the ids of the threats and the respective features sensitive to them. In the second case, the response can be parameterized through four values: `a`, `b`, `c` and `d`. See `sensitivities` vignette for more information on continuous sensitivities. Then, the sensitivity input must contain the following columns:

- `feature` integer id of each conservation feature.
- `threat` integer id of each threat.
- `a` numeric (optional) the minimum intensity of the threat at which the features probability of persistence starts to decline. The more sensitive the feature is to the threat, the lowest this value will be. Default is 0.
b numeric (optional) the value of intensity of the threat over which the feature has a probability of persistence of 0. If it is not established, it is assumed as the maximum value of the threat across all planning units in the study area. Note that this might overestimate the sensitivity of features to threats, as they will only be assumed to disappear from planning units if the threats reach the maximum intensity value in the study area.

c numeric (optional) minimum probability of persistence of a feature when a threat reaches its maximum intensity value. Default is 0.

d numeric (optional) maximum probability of persistence of a feature in absence of a given threat. Default is 1.

Note that optional parameters a, b, c and d can be provided independently.

boundary (optional) Object of class data.frame() that specifies the spatial relationship between pair of planning units. Each row corresponds to a combination of planning unit. This file is inherited from marxan’s bound.dat. It must contain the following columns:

id1 integer id of each planning unit.

id2 integer id of each planning unit.

boundary numeric penalty applied in the objective function when only one of the planning units is present in the solution.

Value
An object of class data.

References


See Also

For more information on the correct format for Marxan input data, see the official Marxan website and Ball et al. (2009).

Examples

```r
## set seed for reproducibility
set.seed(14)

## Set prioriactions path
prioriactions_path <- system.file("extdata/example_input/", package = "prioriactions")

## Load in planning unit data
pu_data <- data.table::fread(paste0(prioriactions_path,"/pu.dat"),
                              data.table = FALSE)

head(pu_data)

## Load in feature data
```
features_data <- data.table::fread(paste0(prioriactions_path,"/features.dat"), data.table = FALSE)
head(features_data)

## Load in planning unit vs feature data
dist_features_data <- data.table::fread(paste0(prioriactions_path,"/dist_features.dat"),
        data.table = FALSE)
head(dist_features_data)

## Load in the threats data
threats_data <- data.table::fread(paste0(prioriactions_path,"/threats.dat"),
        data.table = FALSE)
head(threats_data)

## Load in the threats distribution data
dist_threats_data <- data.table::fread(paste0(prioriactions_path,"/dist_threats.dat"),
        data.table = FALSE)
head(dist_threats_data)

## Load in the sensitivity data
sensitivity_data <- data.table::fread(paste0(prioriactions_path,"/sensitivity.dat"),
        data.table = FALSE)
head(sensitivity_data)

## Load in the boundary data
boundary_data <- data.table::fread(paste0(prioriactions_path,"/boundary.dat"),
        data.table = FALSE)
head(boundary_data)

## Create data instance
problem_data <- inputData(
    pu = sim_pu_data, features = sim_features_data, dist_features = sim_dist_features_data,
    threats = sim_threats_data, dist_threats = sim_dist_threats_data,
    sensitivity = sim_sensitivity_data, boundary = sim_boundary_data
)

## Summary
print(problem_data)

---

optimizationProblem-class

*Optimization problem class*

**Description**

This class encodes the corresponding optimization model. It is created using `problem()` function.

**Value**

No return value.
Fields

\$data list object containing data of the mathematical model.
\$ConservationClass object of class `data-class()` that contains the data input.

Methods

`getData(character name)` `vector()`. Object stored in the `data` field with the corresponding name. The data correspond to the different parts of the mathematical model. The argument name can be made to the following: "obj", "rhs", "sense", "vtype", "A", "bounds" or "modelsense".

`getDataList()` `list()` of `vector()`. Object stored in the data. It contains all information relative to the mathematical model, such as "obj", "rhs", etc.

`print()` Print basic information of the optimization model.
`show()` Call print method.

Examples

```r
# set seed for reproducibility
set.seed(14)

## Load data
data(sim_pu_data, sim_features_data, sim_dist_features_data, sim_threats_data, sim_dist_threats_data, sim_sensitivity_data, sim_boundary_data)

## Create data instance
problem_data <- inputData(
pu = sim_pu_data, features = sim_features_data, dist_features = sim_dist_features_data, threats = sim_threats_data, dist_threats = sim_dist_threats_data, sensitivity = sim_sensitivity_data, boundary = sim_boundary_data
)

## Create optimization model
problem_model <- problem(x = problem_data, blm = 1)

## Use class methods
head(problem_model$getData("obj"))

problem_model$print()
```

Description

This class encodes for the solutions obtained when solving multiple instances. This includes several methods to obtain information about both the optimization process and the solution associated with the planning units and conservation actions. It is created using the `eval` functions (e.g. `evalTarget()` or `evalBudget()`).
Value

No return value.

Fields

$\text{data}$ list. Object containing data on the results of the optimization process.

Methods

getNames() character. Label indicating the name of solutions.

print() Print basic information of the model solution.

show() Call print method.

Examples

```r
# set seed for reproducibility
set.seed(14)

## Create model and solve
port <- evalBm(pu = sim_pu_data, features = sim_features_data,
               dist_features = sim_dist_features_data,
               threats = sim_threats_data,
               dist_threats = sim_dist_threats_data,
               sensitivity = sim_sensitivity_data,
               boundary = sim_boundary_data,
               values = c(0.0, 0.01, 0.02, 0.03),
               model_type = "minimizeCosts",
               time_limit = 50,
               output_file = FALSE, cores = 2)

## Use class methods
port$getNames()

port$print()
```

Description

Displays information about an object.
prioriactions

Usage

```r
## S3 method for class 'Data'
print(x, ...)

## S3 method for class 'OptimizationProblem'
print(x, ...)

## S3 method for class 'Solution'
print(x, ...)

## S3 method for class 'Portfolio'
print(x, ...)
```

Arguments

- `x` Any object.
- `...` Not used.

Value

None.

See Also

`base::print()`. 

---

prioriactions Create and solve multi-actions planning problems

Description

Create and solve a multi-actions planning problem. It can be used instead of following the sequence of the `inputData()`, `problem()` and `solve()` functions.

Usage

```r
prioriactions(...)  
```

Arguments

```r
... arguments inherited from inputData(), problem() and solve() functions.
```

Value

An object of class `solution`. 

Examples

```r
## This example uses input files included into package.

## set seed for reproducibility
set.seed(14)

## Load data
data(sim_pu_data, sim_features_data, sim_dist_features_data,
sim_threats_data, sim_dist_threats_data, sim_sensitivity_data,
sim_boundary_data)

## Create data instance
s <- prioriactions(pu = sim_pu_data, features = sim_features_data,
dist_features = sim_dist_features_data,
threats = sim_threats_data,
dist_threats = sim_dist_threats_data,
sensitivity = sim_sensitivity_data,
boundary = sim_boundary_data,
model_type = "minimizeCosts",
time_limit = 50,
output_file = FALSE,
cores = 2)

print(s)
```

---

**problem**  
*Create mathematical model*

**Description**

Create an optimization model for the multi-action conservation planning problem, following the mathematical formulations used in Salgado-Rojas *et al.* (2020).

**Usage**

```r
problem(
  x,
  model_type = "minimizeCosts",
  budget = 0,
  blm = 0,
  curve = 1,
  segments = 3
)
```
Arguments

- **x**
  - `data` object. Data used in a problem of prioritization of multiple conservation actions. This object must be created using the `problem()` function.

- **model_type**
  - character. Name of the type of model to create. With two possible values: minimizeCosts and maximizeBenefits.

- **budget**
  - numeric. Maximum budget allowed. This field is used only if a model of the type maximizeBenefits is applied.

- **blm**
  - numeric. Weight factor applied to the sum of connectivity penalties for missed connections in a solution, similar to Boundary Length Modifier (BLM) in Marxan. This argument only has an effect when the boundary is available.

- **curve**
  - integer. Type of continuous curve used to represent benefit expression. It can be a linear (1), quadratic (2) or cubic (3) function. See Details for more information.

- **segments**
  - integer. Number of segments (1, 2, 3, 4 or 5) used to approximate the non-linear expression (curve) in the calculate benefits. See Details for more information.

Details

Currently the problem function allows you to create two types of mathematical programming models:

**minimize cost (minimizeCosts):** This model seeks to find the set of actions that minimizes the overall planning costs, while meeting a set of representation targets for the conservation features.

This model can be expressed mathematically for a set of planning units \( I \) indexed by \( i \) a set of features \( S \) indexed by \( s \), and a set of threats \( K \) indexed by \( k \) as:

\[
\min \sum_{i \in I} \sum_{k \in K} x_{ik}c_{ik} + \sum_{i \in I} x_i c'_i + blm \cdot \text{connectivity}, \text{t.}: \sum_{i \in I_s} p_{is} r_{is} \geq t_s \forall s \in S
\]

Where, \( x_{ik} \) is a decisions variable that specifies whether an action to abate threat \( k \) in planning unit \( i \) has been selected (1) or not (0), \( c_{ik} \) is the cost of the action to abate the threat \( k \) in the planning unit \( i \), \( c'_i \) is the monitoring cost of planning unit \( i \), \( p_{is} \) is the probability of persistence of the feature \( s \) in the planning unit \( i \) (ranging between 0 and 1), \( r_{is} \) is the amount of feature \( s \) in planning unit \( i \). \( t_s \) is the recovery target for feature \( s \). In the case of working with conservation target, the following constraint is necessary:

\[
\sum_{i \in I_s: |K_s \cap K_i| \neq 0} z_{is} r_{is} \geq t'_s \forall s \in S
\]

With, \( z_{is} \) as the probability of persistence by conservation of the feature \( s \) in the planning unit \( i \) (ranging between 0 and 1). It is only present when there is no spatial co-occurrence between a feature and its threats (i.e. \( |K_s \cap K_i| \neq 0 \)). In the case of binary threat intensities it is assumed as 1. \( t'_s \) is the conservation target for feature \( s \).

**maximize benefits (maximizeBenefits):** The maximize benefits model seeks to find the set of actions that maximizes the sum of benefits of all features, while the cost of performing actions
and monitoring does not exceed a certain budget. Using the terminology presented above, this model can be expressed mathematically as:

$$\max \sum_{i \in I} \sum_{s \in S_i} b_{is} - blm \cdot connectivity\ s.t. \sum_{i \in I} \sum_{k \in K_i} x_{ik}c_{ik} + \sum_{i \in I} x_i c_i' \leq budget$$

Where $b_{is}$ is the benefit of the feature $s$ in a planning unit $i$ and it is calculated by multiplying the probability of persistence of the feature in the unit by its corresponding amount, i.e., $b_{is} = p_{is}r_{is}$. When we talk about recovering, the probability of persistence is a measure of the number of actions taken against the threats that affect said feature. For more information on its calculation, see the `getSolutionBenefit()` or `getPotentialBenefit()` functions references.

As a way of including the risk associated with calculating our probability of persistence of the features and in turn, avoiding that many low probabilities of persistence end up reaching the proposed targets, is that we add the curve parameter. That incorporates an exponent (values of 1: linear, 2: quadratic or 3: cubic) to the calculation of the probability of persistence. Thus penalizing the low probabilities in the sum of the benefits achieved. Since priori actions work with linear models, we use a piecewise linearization strategy to work with non-linear curves in $b_{is}$. The segments parameter indicates how well the expression approximates the curved used in $b_{is}$. A higher number implies a better approximation but increases the resolution complexity. Note that for a linear curve (curve = 1) it is not necessary to set a segment parameter.

Parameters $blm$ and $blm\_actions$ allow controlling the spatial connectivity of the selected units and of the deployed actions, respectively (similar to BLM in Marxan).

**Value**

An object of class `optimizationProblem`.

**See Also**

For more information regarding the arguments `curve` and `segments`, see the supplementary material of Salgado-Rojas et al. (2020).

**Examples**

```r
## This example uses input files included into package.

## set seed for reproducibility
set.seed(14)

## Load data
data(sim_pu_data, sim_features_data, sim_dist_features_data,
sim_threats_data, sim_dist_threats_data, sim_sensitivity_data,
sim_boundary_data)

## Create data instance
problem_data <- inputData(
  pu = sim_pu_data, features = sim_features_data, dist_features = sim_dist_features_data,
  threats = sim_threats_data, dist_threats = sim_dist_threats_data,
  sensitivity = sim_sensitivity_data, boundary = sim_boundary_data
)
```
## Create minimizeCosts model
model_min <- problem(x = problem_data, blm = 1, model_type = "minimizeCosts")

## Create maximizeBenefits model
model_max <- problem(x = problem_data, model_type = "maximizeBenefits", budget = 100)

---

### Description
Displays information about an object.

### Usage

```r
## S3 method for class 'Data'
show(x, ...)

## S3 method for class 'OptimizationProblem'
show(x, ...)

## S3 method for class 'Solution'
show(x, ...)

## S3 method for class 'Portfolio'
show(x, ...)
```

### Arguments

- `x` Any object.
- `...` Not used.

### Value
None.

### See Also

`methods::show()`.

### Examples

```r
a <- 1:4
show(a)
```
**simData**

*Simulated multi-action planning data*

**Description**

Simulated data for making prioritizations.

- `sim_pu_data` Planning units are represented as tabular data.
- `sim_features_data` Features are represented as tabular data.
- `sim_dist_features_data` The simulated distribution of four features.
- `sim_threats_data` Threats are represented as tabular data.
- `sim_dist_threats_data` The simulated threats of two threats.
- `sim_sensitivity_data` Sensitivity of features to threats as tabular data.
- `sim_boundary_data` Boundary data between one hundred planning units.

**Usage**

```r
data(sim_pu_data)
data(sim_features_data)
data(sim_dist_features_data)
data(sim_threats_data)
data(sim_dist_threats_data)
data(sim_sensitivity_data)
data(sim_boundary_data)
```

**Format**

- `sim_pu_data` data.frame object.
- `sim_features_data` data.frame object.
- `sim_dist_features_data` data.frame object.
- `sim_threats_data` data.frame object.
- `sim_dist_threats_data` data.frame object.
- `sim_sensitivity_data` data.frame object.
- `sim_boundary_data` data.frame object.
solution-class

Examples

```r
## Not run:
# load data
data(sim_pu_data, sim_features_data, sim_dist_features_data,
sim_threats_data, sim_dist_threats_data, sim_sensitivity_data,
sim_boundary_data)

# plot examples
library(raster)
r <- raster::raster(ncol=10, nrow=10, xmn=0, xmx=10, ymn=0, ymx=10)

# plot cost of pu's
values(r) <- sim_pu_data$monitoring_cost
plot(r)

# plot feature distribution of feature 1
features <- tidyr::spread(data = sim_dist_features_data, key = feature, value = amount, fill = 0)
values(r) <- features$'1'
plot(r)

## End(Not run)
```

---

**solution-class**

*Solution class*

**Description**

This class is used to represent the solution of the MIP (Mixed-Integer Programming) model. This includes several methods to obtain information about both the optimization process and the solution associated with the planning units and actions. It is created using the `solve()` function.

**Value**

No return value.

**Fields**

- `$data` list. Object containing data on the results of the optimization process.

**Methods**

- `print()` Print basic information of the model solution.
- `show()` Call print method.
Examples

```r
# set seed for reproducibility
set.seed(14)

## Load data
data(sim_pu_data, sim_features_data, sim_dist_features_data, sim_threats_data, sim_dist_threats_data, sim_sensitivity_data, sim_boundary_data)

## Create data instance
problem_data <- inputData(
  pu = sim_pu_data, features = sim_features_data, dist_features = sim_dist_features_data, threats = sim_threats_data, dist_threats = sim_dist_threats_data, sensitivity = sim_sensitivity_data, boundary = sim_boundary_data
)

## Create optimization model
problem_model <- problem(x = problem_data, blm = 1)

## Solve the optimization model
s <- solve(a = problem_model, time_limit = 5, output_file = FALSE, cores = 2)

## Use class methods
s$print()
```

---

solve  
_Solve mathematical models_

Description

Solves the optimization model associated with the multi-action conservation planning problem. This function is used to solve the mathematical model created by the `problem()` function.

Usage

```r
solve(
a, 
solver = "", 
gap_limit = 0, 
time_limit = .Machine$integer.max, 
solution_limit = FALSE, 
cores = 2, 
verbose = TRUE, 
name_output_file = "output", 
output_file = TRUE
)
```
Arguments

- **a** `optimizationProblem` object. Optimization model created for the problem of prioritization of multiple conservation actions. This object must be created using the `problem()` function.

- **solver** string. Name of solver to use to solve the model. The following solvers are supported: "gurobi" (requires the `gurobi` package), and "symphony" (requires the `Rsymphony` package). We recommend using gurobi (for more information on how to obtain an academic license [here](#)).

- **gap_limit** numeric. Value between 0 and 1 that represents the gap to optimality, i.e., a relative number that cause the optimizer to terminate when the difference between the upper and lower objective function bounds is less than the gap times the upper bound. For example, a value of 0.01 will result in the optimizer stopping when the difference between the bounds is 1 percent of the upper bound. Default is 0.0.

- **time_limit** numeric. Time limit to run the optimizer (in seconds). The solver will return the current best solution when this time limit is exceeded. Default is the maximum integer number of your machine.

- **solution_limit** logical. Indicates if the solution process should be stopped after the first feasible solution is found (TRUE), or not (FALSE).

- **cores** integer. Number of parallel cores to use in the machine to solve the problem.

- **verbose** logical. Indicates if the solver information is displayed while solving the optimization model (TRUE), or if it is not displayed (FALSE).

- **name_output_file** string. Prefix of all output names.

- **output_file** logical. Indicates if the outputs are exported as .csv files (TRUE), or they are not exported (FALSE). Currently, 5 files are exported. The distribution of actions in the solution, the distribution of the selected planning units, the benefits achieved by the features, the parameters used, and the optimization engine log.

Details

The solvers supported by the `solve()` function are described below.

**Gurobi solver** *Gurobi* is a state-of-the-art commercial optimization software with an R package interface. It is by far the fastest of the solvers available in this package, however, it is also the only solver that is not freely available. That said, licenses are available to academics at no cost. The `gurobi` package is distributed with the *Gurobi* software suite. This solver uses the `gurobi` package to solve problems.

**Symphony solver** *SYMPHONY* is an open-source integer programming solver that is part of the Computational Infrastructure for Operations Research (COIN-OR) project, an initiative to promote development of open-source tools for operations research (a field that includes linear programming). The `Rsymphony` package provides an interface to COIN-OR and is available on CRAN. This solver uses the `Rsymphony` package to solve problems.

Value

An object of class `solution`. 
See Also

For more information on how to install and obtain an academic license of the Gurobi solver, see the *Gurobi installation guide*, which can be found online at *prioritizr vignette*.

Examples

```r
## Not run:
## This example uses input files included into package.

## Load data
data(sim_pu_data, sim_features_data, sim_dist_features_data, sim_threats_data, sim_dist_threats_data, sim_sensitivity_data, sim_boundary_data)

## Create data instance
problem_data <- inputData(
  pu = sim_pu_data, features = sim_features_data, dist_features = sim_dist_features_data, threats = sim_threats_data, dist_threats = sim_dist_threats_data, sensitivity = sim_sensitivity_data, boundary = sim_boundary_data)

## Create optimization model
problem_model <- problem(x = problem_data, blm = 1)

## Solve the optimization model using a gap_limit and gurobi solver
## NOTE: The Gurobi solver must be previously installed and must have a valid license!
s1 <- solve(a = problem_model, solver = "gurobi", gap_limit = 0.01, output_file = FALSE, cores = 2)
print(s1)

## Solve the optimization model using a gap_limit and symphony solver
s2 <- solve(a = problem_model, solver = "symphony", gap_limit = 0.01, output_file = FALSE, cores = 2)
print(s2)

## Solve the optimization model using a time_limit and gurobi solver
s3 <- solve(a = problem_model, solver = "gurobi", time_limit = 10, output_file = FALSE, cores = 2)
print(s3)

## End(Not run)
```
Index

* datasets
  simData, 30
base::print(), 25
ConservationProblem-method (show), 29
Data (data-class), 3
data, 18, 21, 27
data-class, 3
data.frame, 9, 10, 12–14, 16, 17, 30
data.frame(), 3, 19–21
evalBlm, 5
evalBudget, 6
evalTarget, 7
getActions, 8
getConnectivityPenalty, 10
getCost, 11
getModelInfo, 12
getPerformance, 14
getPotentialBenefit, 15
getSolutionBenefit, 17
inputData, 18
inputData(), 3
inputData,data.frame,data.frame,data.frame,data.frame,data.frame
  (inputData), 18
list(), 23
methods::show(), 29
OptimizationProblem
  (optimizationProblem-class), 22
optimizationProblem, 13, 28, 33
optimizationProblem-class, 22
OptimizationProblem-method (show), 29
Portfolio (portfolio-class), 23
portfolio, 5, 7–11, 13, 14
portfolio-class, 23
print, 24
prioriactions, 25
problem, 26
problem(), 27
show, 29
show, (show), 29
show.Data (show), 29
show.OptimizationProblem (show), 29
show.Portfolio (show), 29
show.Solution (show), 29
sim_boundary_data (simData), 30
sim_dist_features_data (simData), 30
sim_dist_threats_data (simData), 30
sim_features_data (simData), 30
sim_pu_data (simData), 30
sim_sensitivity_data (simData), 30
sim_threats_data (simData), 30
simData, 30
Solution (solution-class), 31
solution, 9–11, 13, 14, 25, 33
solution-class, 31
Solution-method (show), 29
solve, 32
solve(), 31, 33
vector(), 3, 23

35