Package ‘prioritizr’

May 15, 2020

Type Package

Version 5.0.1

Title Systematic Conservation Prioritization in R

Description Conservation prioritization using integer programming techniques. To solve large-scale problems, users should install the ‘gurobi’ optimizer (available from <http://www.gurobi.com/>).

Imports utils, methods, assertthat (>= 0.2.0), data.table, uuid, Matrix, igraph, ape, rgeos, plyr, parallel, doParallel, magrittr, exactextractr (>= 0.2.0), fasterize (>= 1.0.2), tibble (>= 2.0.0)

Suggests testthat, knitr, roxygen2, shiny, xtable, rhandsontable, RandomFields, maptools, PBSmapping, gurobi, lpsymphony, Rsymphony, rmarkdown, prioritizrdata

Depends R (>= 3.5.0), raster, sp, sf (>= 0.8-0), proto

LinkingTo Rcpp, RcppArmadillo, BH

License GPL-3

Language en-US

LazyData true

SystemRequirements C++11


BugReports https://github.com/prioritizr/prioritizr/issues

VignetteBuilder knitr

RoxygenNote 7.1.0

Collate 'internal.R' 'ppproto.R' 'Parameter,proto.R'
   'ArrayParameter,proto.R' 'MiscParameter,proto.R'
   'Parameters,proto.R' 'ScalarParameter,proto.R' 'parameters.R'
   'waiver.R' 'ConservationModifier,proto.R' 'Penalty,proto.R'
   'Constraint,proto.R' 'Collection,proto.R' 'category_vector.R'
   'category_layer.R' 'binary_stack.R'
'ConservationProblem-proto.R' 'Decision-proto.R' 'Id.R'
'Objective-proto.R' 'OptimizationProblem-proto.R'
'OptimizationProblem-methods.R' 'Portfolio-proto.R'
'RcppExports.R' 'Solver-proto.R' 'Target-proto.R' 'zones.R'
'add_absolute_targets.R' 'add_binary_decisions.R'
'marxan_boundary_data_to_matrix.R' 'add_boundary_penalties.R'
'add_connectivity_penalties.R' 'add_contiguity_constraints.R'
'add_cuts_portfolio.R' 'add_default_decisions.R'
'add_default_objective.R' 'add_default_portfolio.R'
'add_default_solver.R' 'add_default_targets.R'
'add_extra_portfolio.R' 'add_feature_contiguity_constraints.R'
'add_feature_weights.R' 'add_gap_portfolio.R'
'add_gurobi_solver.R' 'intersecting_units.R'
'add_locked_in_constraints.R' 'add_locked_out_constraints.R'
'loglinear_interpolation.R' 'add_loglinear_targets.R'
'add_lpsymphony_solver.R'
'add_mandatory_allocation_constraints.R' 'tbl_df.R'
'add_manual_targets.R' 'add_manual_bounded_constraints.R'
'add_manual_locked_constraints.R' 'add_max_cover_objective.R'
'add_max_features_objective.R' 'add_max_phylo_div_objective.R'
'add_max_phylo_end_objective.R' 'add_max_utility_objective.R'
'add_min_set_objective.R' 'add_min_shortfall_objective.R'
'add_neighbor_contraints.R' 'add_proportion_decisions.R'
'add_relative_targets.R' 'add_rsymphony_solver.R'
'add_semicontinuous_decisions.R' 'add_shuffle_portfolio.R'
'add_top_portfolio.R' 'adjacency_matrix.R' 'boundary_matrix.R'
'branch_matrix.R' 'compile.R' 'connectivity_matrix.R'
'constraints.R' 'data.R' 'decisions.R' 'deprecated.R'
'distribute_load.R' 'fast_extract.R' 'feature_abundances.R'
'feature_names.R' 'feature_representation.R' 'ferrier_score.R'
'irreplaceability.R' 'magrittr-operators.R' 'marxan_problem.R'
'misc.R' 'new_optimization_problem.R' 'number_of_features.R'
'number_of_planning_units.R' 'number_of_total_units.R'
'number_of_zones.R' 'objectives.R' 'package.R' 'penalties.R'
'portfolios.R' 'predefined_optimization_problem.R'
'presolve_check.R' 'print.R' 'problem.R' 'proximity_matrix.R'
'rarity_weighted_richness.R' 'solve.R' 'replacement_cost.R'
'rij_matrix.R' 'run_calculations.R' 'sf.R' 'show.R'
'simulate.R' 'solvers.R' 'targets.R' 'zone_names.R' 'zzz.R'

NeedsCompilation  yes

Author  Jeffrey O Hanson [aut] (<https://orcid.org/0000-0002-4716-6134>),
Richard Schuster [aut, cre] (<https://orcid.org/0000-0003-3191-7869>),
Nina Morrell [aut],
Matthew Strimas-Mackey [aut] (<https://orcid.org/0000-0001-8929-7776>),
Matthew E Watts [aut],
Peter Arcese [aut] (<https://orcid.org/0000-0002-8097-482X>),
Joseph Bennett [aut] (<https://orcid.org/0000-0002-3901-9513>),
Hugh P Possingham [aut] (<https://orcid.org/0000-0001-7755-996X>)}
Maintainer Richard Schuster <richard.schuster@glel.carleton.ca>
Repository CRAN
Date/Publication 2020-05-15 09:50:02 UTC

R topics documented:

- add_absolute_targets .......................................................... 5
- add_binary_decisions ............................................................ 8
- add_boundary_penalties .......................................................... 9
- add_connectivity_penalties ...................................................... 14
- add_contiguity_penalties ....................................................... 21
- add_cuts_portfolio ............................................................... 25
- add_default_decisions ........................................................... 26
- add_default_solver ............................................................... 27
- add_extra_portfolio .............................................................. 28
- add_feature_contiguity_constraints ......................................... 29
- add_feature_weights ............................................................. 33
- add_gap_portfolio ............................................................... 37
- add_gurobi_solver ............................................................... 39
- add_locked_in_constraints .................................................... 40
- add_locked_out_constraints .................................................. 44
- add_loglinear_targets ........................................................... 49
- add_lsymphony_solver .......................................................... 51
- add_mandatory_allocation_constraints ................................... 52
- add_manual_bounded_constraints ........................................... 54
- add_manual_locked_constraints ............................................. 56
- add_manual_targets ............................................................. 59
- add_max_cover_objective ...................................................... 63
- add_max_features_objective ................................................... 65
- add_max_phylo_div_objective ................................................ 67
- add_max_phylo_end_objective ................................................ 71
- add_max_utility_objective ..................................................... 75
- add_min_set_objective .......................................................... 77
- add_min_shortfall_objective ................................................. 79
- add_neighbor_constraints ..................................................... 81
- add_proportion_decisions ..................................................... 85
- add_relative_targets ........................................................... 86
- add_rsymphony_solver .......................................................... 89
- add_semicontinuous_decisions .............................................. 90
- add_shuffle_portfolio .......................................................... 92
- add_top_portfolio .............................................................. 94
- adjacency_matrix ............................................................... 95
- ArrayParameter-class ............................................................ 97
- array_parameters ............................................................... 99
- as.Id ................................................................. 101
- as.list.OptimizationProblem ............................................... 102
- binary_stack ............................................................... 102
<table>
<thead>
<tr>
<th>R topics documented:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>boundary_matrix</td>
<td>103</td>
</tr>
<tr>
<td>branch_matrix</td>
<td>105</td>
</tr>
<tr>
<td>category_layer</td>
<td>106</td>
</tr>
<tr>
<td>category_vector</td>
<td>107</td>
</tr>
<tr>
<td>Collection-class</td>
<td>108</td>
</tr>
<tr>
<td>compile</td>
<td>109</td>
</tr>
<tr>
<td>connectivity_matrix</td>
<td>110</td>
</tr>
<tr>
<td>ConservationModifier-class</td>
<td>112</td>
</tr>
<tr>
<td>ConservationProblem-class</td>
<td>114</td>
</tr>
<tr>
<td>Constraint-class</td>
<td>118</td>
</tr>
<tr>
<td>constraints</td>
<td>118</td>
</tr>
<tr>
<td>Decision-class</td>
<td>120</td>
</tr>
<tr>
<td>decisions</td>
<td>120</td>
</tr>
<tr>
<td>distribute_load</td>
<td>121</td>
</tr>
<tr>
<td>fast_extract</td>
<td>123</td>
</tr>
<tr>
<td>feature_abundances</td>
<td>124</td>
</tr>
<tr>
<td>feature_names</td>
<td>126</td>
</tr>
<tr>
<td>feature_representation</td>
<td>127</td>
</tr>
<tr>
<td>ferrier_score</td>
<td>132</td>
</tr>
<tr>
<td>intersecting_units</td>
<td>134</td>
</tr>
<tr>
<td>irreplaceability</td>
<td>136</td>
</tr>
<tr>
<td>is.Id</td>
<td>138</td>
</tr>
<tr>
<td>loglinear_interpolation</td>
<td>138</td>
</tr>
<tr>
<td>marxan_boundary_data_to_matrix</td>
<td>139</td>
</tr>
<tr>
<td>marxan_problem</td>
<td>140</td>
</tr>
<tr>
<td>matrix_parameters</td>
<td>143</td>
</tr>
<tr>
<td>MiscParameter-class</td>
<td>145</td>
</tr>
<tr>
<td>misc_parameter</td>
<td>146</td>
</tr>
<tr>
<td>new_id</td>
<td>147</td>
</tr>
<tr>
<td>new_optimization_problem</td>
<td>148</td>
</tr>
<tr>
<td>new_waiver</td>
<td>149</td>
</tr>
<tr>
<td>number_of_features</td>
<td>149</td>
</tr>
<tr>
<td>number_of_planning_units</td>
<td>150</td>
</tr>
<tr>
<td>number_of_total_units</td>
<td>151</td>
</tr>
<tr>
<td>number_of_zones</td>
<td>152</td>
</tr>
<tr>
<td>Objective-class</td>
<td>153</td>
</tr>
<tr>
<td>objectives</td>
<td>154</td>
</tr>
<tr>
<td>OptimizationProblem-class</td>
<td>155</td>
</tr>
<tr>
<td>OptimizationProblem-methods</td>
<td>157</td>
</tr>
<tr>
<td>Parameter-class</td>
<td>159</td>
</tr>
<tr>
<td>parameters</td>
<td>160</td>
</tr>
<tr>
<td>Parameters-class</td>
<td>161</td>
</tr>
<tr>
<td>penalties</td>
<td>162</td>
</tr>
<tr>
<td>Penalty-class</td>
<td>163</td>
</tr>
<tr>
<td>Portfolio-class</td>
<td>164</td>
</tr>
<tr>
<td>portfolios</td>
<td>165</td>
</tr>
<tr>
<td>pproto</td>
<td>166</td>
</tr>
<tr>
<td>predefined_optimization_problem</td>
<td>167</td>
</tr>
</tbody>
</table>
Description

Set targets expressed as the actual value of features in the study area that need to be represented in the prioritization. For instance, setting a target of 10 requires that the solution secure a set of planning units for which their summed feature values are equal to or greater than 10.

Usage

```r
add_absolute_targets(x, targets)
```

## S4 method for signature 'ConservationProblem,numeric'
add_absolute_targets(x, targets)

## S4 method for signature 'ConservationProblem,matrix'
add_absolute_targets(x, targets)
add_absolute_targets

## S4 method for signature 'ConservationProblem,character'
add_absolute_targets(x, targets)

Arguments

- x: ConservationProblem-class object.
- targets: Object that specifies the targets for each feature. See the Details section for more information.

Details

Targets are used to specify the minimum amount or proportion of a feature’s distribution that needs to be protected. Most conservation planning problems require targets with the exception of the maximum cover (see `add_max_cover_objective`) and maximum utility (see `add_max_utility_objective`) problems. Attempting to solve problems with objectives that require targets without specifying targets will throw an error.

The targets for a problem can be specified in several different ways:

- `numeric` vector of target values for each feature. Additionally, for convenience, this type of argument can be a single value to assign the same target to each feature. Note that this type of argument cannot be used to specify targets for problems with multiple zones.
- `matrix` containing a target for each feature in each zone. Here, each row corresponds to a different feature in argument to `x`, each column corresponds to a different zone in argument to `x`, and each cell contains the target value for a given feature that the solution needs to secure in a given zone.
- `character` containing the names of fields (columns) in the feature data associated with the argument to `x` that contain targets. This type of argument can only be used when the feature data associated with `x` is a data.frame. This argument must contain a field (column) name for each zone.

For problems associated with multiple management zones, this function can be used to set targets that each pertain to a single feature and a single zone. To set targets which can be met through allocating different planning units to multiple zones, see the `add_manual_targets` function. An example of a target that could be met through allocations to multiple zones might be where each management zone is expected to result in a different amount of a feature and the target requires that the total amount of the feature in all zones must exceed a certain threshold. In other words, the target does not require that any single zone secure a specific amount of the feature, but the total amount held in all zones must secure a specific amount. Thus the target could, potentially, be met through allocating all planning units to any specific management zone, or through allocating the planning units to different combinations of management zones.

Value

ConservationProblem-class object with the targets added to it.

See Also

targets.
## add_absolute_targets

### Examples

```r
# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_raster, sim_features, sim_pu_zones_stack, sim_features_zones)

# create simple problem
p <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_binary_decisions()

# create problem with targets to secure 3 amounts for each feature
p1 <- p %>% add_absolute_targets(3)

# create problem with varying targets for each feature
targets <- c(1, 2, 3, 2, 1)
p2 <- p %>% add_absolute_targets(targets)

# solve problem
s <- stack(solve(p1), solve(p2))

# plot solution
plot(s, main = c("equal targets", "varying targets"), axes = FALSE,
     box = FALSE)

# create a problem with multiple management zones
p3 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>%
  add_binary_decisions()

# create a problem with targets that specify an equal amount of each feature
# to be represented in each zone
p4_targets <- matrix(2, nrow = number_of_features(sim_features_zones),
                     ncol = number_of_zones(sim_features_zones),
                     dimnames = list(feature_names(sim_features_zones),
                                     zone_names(sim_features_zones)))
print(p4_targets)
p4 <- p3 %>% add_absolute_targets(p4_targets)

# solve problem
# solve problem
s4 <- solve(p4)

# plot solution (pixel values correspond to zone identifiers)
plot(category_layer(s4), main = c("equal targets"))

# create a problem with targets that require a varying amount of each
# feature to be represented in each zone
```
add_binary_decisions

Add binary decisions

Description

Add a binary decision to a conservation planning problem. This is the classic decision of either prioritizing or not prioritizing a planning unit. Typically, this decision has the assumed action of buying the planning unit to include in a protected area network. If no decision is added to a problem then this decision class will be used by default.

Usage

add_binary_decisions(x)

Arguments

x ConservationProblem-class object.

Details

Conservation planning problems involve making decisions on planning units. These decisions are then associated with actions (e.g. turning a planning unit into a protected area). If no decision is explicitly added to a problem, then the binary decision class will be used by default. Only a single decision should be added to a ConservationProblem object. If multiple decisions are added to a problem object, then the last one to be added will be used.

Value

ConservationProblem-class object with the decisions added to it.
See Also
decisions.

Examples

# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_raster, sim_features, sim_pu_zones_stack, sim_features_zones)

# create minimal problem with binary decisions
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions()

# solve problem
s1 <- solve(p1)

# plot solution
plot(s1, main = "solution")

# build multi-zone conservation problem with binary decisions
p2 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5,
                              ncol = 3)) %>%
  add_binary_decisions()

# solve the problem
s2 <- solve(p2)

# print solution
print(s2)

# plot solution
plot(category_layer(s2), main = "solution", axes = FALSE, box = FALSE)

Description

Add penalties to a conservation planning problem to favour solutions that have planning units clumped together into contiguous areas.
Usage

```
add_boundary_penalties(
  x,  
  penalty,  
  edge_factor = rep(0.5, number_of_zones(x)),  
  zones = diag(number_of_zones(x)),  
  data = NULL
)
```

Arguments

- **x** *ConservationProblem-class* object.
- **penalty** numeric penalty that is used to scale the importance of selecting planning units that are spatially clumped together compared to the main problem objective (e.g. solution cost when the argument to `x` has a minimum set objective set using `add_min_set_objective`). Higher penalty values will return solutions with a higher degree of spatial clumping, and smaller penalty values will return solutions with a smaller degree of clumping. Note that negative penalty values will return solutions that are more spread out. This parameter is equivalent to the boundary length modifier (BLM) parameter in *Marxan*.
- **edge_factor** numeric proportion to scale planning unit edges (or borders) that do not have any neighboring planning units. For example, an edge factor of 0.5 is commonly used for planning units along the coast line. Note that this argument must have an element for each zone in the argument to `x`.
- **zones** matrix or *Matrix* object describing the clumping scheme for different zones. Each row and column corresponds to a different zone in the argument to `x`, and cell values indicate the relative importance of clumping planning units that are allocated to a pair of zones. Cell values along the diagonal of the matrix represent the relative importance of clumping planning units that are allocated to the same zone. Cell values must lay between 1 and -1, where negative values favor solutions that spread out planning units. The default argument to `zones` is an identity matrix (i.e. a matrix with ones along the matrix diagonal and zeros elsewhere), so that penalties are incurred when neighboring planning units are not assigned to the same zone. **Note that if the cells along the matrix diagonal contain markedly lower values than cells found elsewhere in the matrix, then the optimal solution may surround planning units with planning units that are allocated to different zones.**
- **data** NULL, *data.frame*, *matrix*, or *Matrix* object containing the boundary data. The boundary values correspond to the shared boundary length between different planning units and the amount of exposed boundary length that each planning unit has which is not shared with any other planning unit. Given a certain penalty value, it is more desirable to select combinations of planning units which do not expose larger boundaries that are shared between different planning units. See the Details section for more information.
Details

This function adds penalties to a conservation planning problem to penalize fragmented solutions. It was inspired by Ball et al. (2009) and Beyer et al. (2016). The penalty argument is equivalent to the boundary length modifier (BLM) used in Marxan. Note that this function can only be used to represent symmetric relationships between planning units. If asymmetric relationships are required, use the `add_connectivity_penalties` function.

The argument to `data` can be specified in several different ways:

- **NULL** the boundary data are automatically calculated using the `boundary_matrix` function. This argument is the default. Note that the boundary data must be manually defined using one of the other formats below when the planning unit data in the argument to `x` is not spatially referenced (e.g., in `data.frame` or numeric format).
- **matrix, Matrix** where rows and columns represent different planning units and the value of each cell represents the amount of shared boundary length between two different planning units. Cells that occur along the matrix diagonal represent the amount of exposed boundary associated with each planning unit that has no neighbor (e.g., these values might pertain the length of coastline in a planning unit).
- **data.frame** containing the columns "id1", "id2", and "boundary". The values in the column "boundary" show the total amount of shared boundary between the two planning units indicated the columns "id1" and "id2". This format follows the standard Marxan input format. Note that this function requires symmetric boundary data, and so the argument to `data` cannot have the columns "zone1" and code"zone2" to specify different amounts of shared boundary lengths for different zones. Instead, when dealing with problems with multiple zones, the argument to `zones` should be used to control the relative importance of spatially clumping planning units together when they are allocated to different zones.

The boundary penalties are calculated using the following equations. Let $I$ represent the set of planning units (indexed by $i$ or $j$), $Z$ represent the set of management zones (indexed by $z$ or $y$), and $X_{iz}$ represent the decision variable for planning unit $i$ for in zone $z$ (e.g., with binary values one indicating if planning unit is allocated or not). Also, let $p$ represent the argument to penalty, $E$ represent the argument to edge_factor, $B$ represent the matrix argument to data (e.g., generated using `boundary_matrix`), and $W$ represent the matrix argument to zones.

$$
\sum_{i} \sum_{j} \sum_{z} (\text{ifelse}(i == j, E_z, 1) \times W_{zz} B_{ij}) + \sum_{i} \sum_{j} \sum_{z} \sum_{y} (-2 \times p \times X_{iz} \times X_{jy} \times W_{zy} \times B_{ij})
$$

Note that when the problem objective is to maximize some measure of benefit and not minimize some measure of cost, the term $p$ is replaced with $-p$.

Value

`ConservationProblem-class` object with the penalties added to it.

References

add_boundary_penalties


See Also
penalties.

Examples

# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_raster, sim_features, sim_pu_zones_stack, sim_features_zones)

# create minimal problem
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions() %>%
  add_default_solver()

# create problem with low boundary penalties
p2 <- p1 %>% add_boundary_penalties(50, 1)

# create problem with high boundary penalties but outer edges receive
# half the penalty as inner edges
p3 <- p1 %>% add_boundary_penalties(500, 0.5)

# create a problem using precomputed boundary data
bmat <- boundary_matrix(sim_pu_raster)
p4 <- p1 %>% add_boundary_penalties(50, 1, data = bmat)

# solve problems
s <- stack(solve(p1), solve(p2), solve(p3), solve(p4))

# plot solutions
plot(s, main = c("basic solution", "small penalties", "high penalties",
  "precomputed data"), axes = FALSE, box = FALSE)

# create minimal problem with multiple zones and limit the run-time for
# solver to 10 seconds so this example doesn't take too long
p5 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(0.2, nrow = 5, ncol = 3)) %>%
  add_binary_decisions() %>%
  add_default_solver(time_limit = 10)

# create zone matrix which favors clumping planning units that are
# allocated to the same zone together - note that this is the default
zm6 <- diag(3)
print(zm6)
# create problem with the zone matrix and low penalties
p6 <- p5 %>% add_boundary_penalties(50, zone = zm6)

# create another problem with the same zone matrix and higher penalties
p7 <- p5 %>% add_boundary_penalties(500, zone = zm6)

# create zone matrix which favors clumping units that are allocated to
# different zones together
zm8 <- matrix(1, ncol = 3, nrow = 3)
diag(zm8) <- 0
print(zm8)

# create problem with the zone matrix
p8 <- p5 %>% add_boundary_penalties(500, zone = zm8)

# create zone matrix which strongly favors clumping units
# that are allocated to the same zone together. It will also prefer
# clumping planning units in zones 1 and 2 together over having
# these planning units with no neighbors in the solution
zm9 <- diag(3)
zm9[upper.tri(zm9)] <- c(0.3, 0, 0)
zm9[lower.tri(zm9)] <- zm9[upper.tri(zm9)]
print(zm9)

# create problem with the zone matrix
p9 <- p5 %>% add_boundary_penalties(500, zone = zm9)

# create zone matrix which favors clumping planning units in zones 1 and 2
# together, and favors planning units in zone 3 being spread out
# (i.e. negative clumping)
zm10 <- diag(3)
zm10[3, 3] <- -1
print(zm10)

# create problem with the zone matrix
p10 <- p5 %>% add_boundary_penalties(500, zone = zm10)

# solve problems
s2 <- stack(category_layer(solve(p5)), category_layer(solve(p6)),
            category_layer(solve(p7)), category_layer(solve(p8)),
            category_layer(solve(p9)), category_layer(solve(p10)))

# plot solutions
plot(s2, main = c("basic solution", "within zone clumping (low)",
    "within zone clumping (high)", "between zone clumping",
    "within + between clumping", "negative clumping"),
     axes = FALSE, box = FALSE)
**add_connectivity_penalties**

*Add connectivity penalties*

**Description**

Add penalties to a conservation planning problem to favor solutions that select planning units with high connectivity between them.

**Usage**

```r
## S4 method for signature 'ConservationProblem,ANY,ANY,matrix'
add_connectivity_penalties(x, penalty, zones, data)

## S4 method for signature 'ConservationProblem,ANY,ANY,Matrix'
add_connectivity_penalties(x, penalty, zones, data)

## S4 method for signature 'ConservationProblem,ANY,ANY,dgCMatrix'
add_connectivity_penalties(x, penalty, zones, data)

## S4 method for signature 'ConservationProblem,ANY,ANY,data.frame'
add_connectivity_penalties(x, penalty, zones, data)

## S4 method for signature 'ConservationProblem,ANY,ANY,array'
add_connectivity_penalties(x, penalty, zones, data)
```

**Arguments**

- **x**  
  `ConservationProblem-class` object.

- **penalty**  
  numeric penalty that is used to scale the importance of selecting planning units with strong connectivity between them compared to the main problem objective (e.g. solution cost when the argument to x has a minimum set objective set using `add_min_set_objective`). Higher penalty values can be used to obtain solutions with a high degree of connectivity, and smaller penalty values can be used to obtain solutions with a small degree of connectivity. Note that negative penalty values can be used to obtain solutions that have very little connectivity.

- **zones**  
  matrix or Matrix object describing the level of connectivity between different zones. Each row and column corresponds to a different zone in the argument to x, and cell values indicate the level of connectivity between each combination of zones. Cell values along the diagonal of the matrix represent the level of connectivity between planning units allocated to the same zone. Cell values must lay between 1 and -1, where negative values favor solutions with weak connectivity. The default argument to zones is an identity matrix (i.e. a matrix with ones along the matrix diagonal and zeros elsewhere), so that planning units are only considered to be connected when they are allocated to the same zone.
This argument is required when the argument to data is a matrix or Matrix object. If the argument to data is an array or data.frame with zone data, this argument must explicitly be set to NULL otherwise an error will be thrown.

**data** matrix, Matrix, data.frame, or array object containing connectivity data. The connectivity values correspond to the strength of connectivity between different planning units. Thus connections between planning units that are associated with higher values are more favorable in the solution. See the Details section for more information.

**Details**

This function uses connectivity data to penalize solutions that have low connectivity. It can accommodate symmetric and asymmetric relationships between planning units. Although Marxan penalizes connections between planning units with high connectivity values, it is important to note that this function favors connections between planning units with high connectivity values. This function was inspired by Beger et al. (2010).

The argument to data can be specified in several different ways:

- **matrix, Matrix** where rows and columns represent different planning units and the value of each cell represents the strength of connectivity between two different planning units. Cells that occur along the matrix diagonal are treated as weights which indicate that planning units are more desirable in the solution. The argument to zones can be used to control the strength of connectivity between planning units in different zones. The default argument for zones is to treat planning units allocated to different zones as having zero connectivity.

- **data.frame** containing the fields (columns) "id1", "id2", and "boundary". Here, each row denotes the connectivity between two planning units following the Marxan format. The data can be used to denote symmetric or asymmetric relationships between planning units. By default, input data is assumed to be symmetric unless asymmetric data is also included (e.g. if data is present for planning units 2 and 3, then the same amount of connectivity is expected for planning units 3 and 2, unless connectivity data is also provided for planning units 3 and 2). If the argument to x contains multiple zones, then the columns "zone1" and "zone2" can optionally be provided to manually specify the connectivity values between planning units when they are allocated to specific zones. If the columns "zone1" and "zone2" are present, then the argument to zones must be NULL.

- **array** containing four-dimensions where cell values indicate the strength of connectivity between planning units when they are assigned to specific management zones. The first two dimensions (i.e. rows and columns) indicate the strength of connectivity between different planning units and the second two dimensions indicate the different management zones. Thus the data[1,2,3,4] indicates the strength of connectivity between planning unit 1 and planning unit 2 when planning unit 1 is assigned to zone 3 and planning unit 2 is assigned to zone 4.

The connectivity penalties are calculated using the following equations. Let $I$ represent the set of planning units (indexed by $i$ or $j$), $Z$ represent the set of management zones (indexed by $z$ or $y$), and $X_{iz}$ represent the decision variable for planning unit $i$ for in zone $z$ (e.g. with binary values one indicating if planning unit is allocated or not). Also, let $p$ represent the argument to penalty, $D$ represent the argument to data, and $W$ represent the argument to zones.

If the argument to data is supplied as a matrix or Matrix object, then the penalties are calculated as:
\[
\sum_i \sum_j \sum_z \sum_y (-p \times X_{iz} \times X_{jy} \times D_{ij} \times W_{zy})
\]

Otherwise, if the argument to `data` is supplied as a `data.frame` or `array` object, then the penalties are calculated as:

\[
\sum_i \sum_j \sum_z \sum_y (-p \times X_{iz} \times X_{jy} \times D_{ijzy})
\]

Note that when the problem objective is to maximize some measure of benefit and not minimize some measure of cost, the term \(-p\) is replaced with \(p\).

Value

`ConservationProblem-class` object with the penalties added to it.

References


See Also

`penalties`.

Examples

```r
# set seed for reproducibility
set.seed(600)

# load Matrix package for visualizing matrices
require(Matrix)

# load data
data(sim_pu_polygons, sim_pu_zones_stack, sim_features, sim_features_zones)

# define function to rescale values between zero and one so that we
# can compare solutions from different connectivity matrices
rescale <- function(x, to = c(0, 1), from = range(x, na.rm = TRUE)) {
  (x - from[1]) / diff(from) * diff(to) + to[1]
}

# create basic problem
p1 <- problem(sim_pu_polygons, sim_features, "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2)
```
# create a symmetric connectivity matrix where the connectivity between
# two planning units corresponds to their shared boundary length
b_matrix <- boundary_matrix(sim_pu_polygons)

# standardize matrix values to lay between zero and one
b_matrix[] <- rescale(b_matrix[])

# visualize connectivity matrix
image(b_matrix)

# create a symmetric connectivity matrix where the connectivity between
# two planning units corresponds to their spatial proximity
# i.e. planning units that are further apart share less connectivity
centroids <- rgeos::gCentroid(sim_pu_polygons, byid = TRUE)
d_matrix <- (1 / (as(dist(centroids@coords), "Matrix") + 1))

# standardize matrix values to lay between zero and one
d_matrix[] <- rescale(d_matrix[])

# remove connections between planning units without connectivity to
# reduce run-time
d_matrix[d_matrix < 0.7] <- 0

# visualize connectivity matrix
image(d_matrix)

# create a symmetric connectivity matrix where the connectivity
# between adjacent two planning units corresponds to their combined
# value in a field in the planning unit attribute data
# for example, this field could describe the extent of native vegetation in
# each planning unit and we could use connectivity penalties to identify
# solutions that cluster planning units together that both contain large
# amounts of native vegetation
c_matrix <- connectivity_matrix(sim_pu_polygons, "cost")

# standardize matrix values to lay between zero and one
c_matrix[] <- rescale(c_matrix[])

# visualize connectivity matrix
image(c_matrix)

# create an asymmetric connectivity matrix. Here, connectivity occurs between
# adjacent planning units and, due to rivers flowing southwards
# through the study area, connectivity from northern planning units to
# southern planning units is ten times stronger than the reverse.
ac_matrix <- matrix(0, length(sim_pu_polygons), length(sim_pu_polygons))
ac_matrix <- as(ac_matrix, "Matrix")
adjacent_units <- rgeos::gIntersects(sim_pu_polygons, byid = TRUE)
for (i in seq_len(length(sim_pu_polygons))) {
  for (j in seq_len(length(sim_pu_polygons))) {
    if (adjacent_units[i, j] == TRUE) {
      ac_matrix[i, j] <- 1
    }
  }
}

# visualize connectivity matrix
image(ac_matrix)
# find if planning units are adjacent
if (adjacent_units[i, j]) {
    # find if planning units lay north and south of each other
    # i.e. they have the same x-coordinate
    if (centroids@coords[i, 1] == centroids@coords[j, 1]) {
        if (centroids@coords[i, 2] > centroids@coords[j, 2]) {
            # if i is north of j add 10 units of connectivity
            ac_matrix[i, j] <- ac_matrix[i, j] + 10
        } else if (centroids@coords[i, 2] < centroids@coords[j, 2]) {
            # if i is south of j add 1 unit of connectivity
            ac_matrix[i, j] <- ac_matrix[i, j] + 1
        }
    }
}
}

# standardize matrix values to lay between zero and one
ac_matrix[] <- rescale(ac_matrix[])

# visualize asymmetric connectivity matrix
image(ac_matrix)

# create penalties
penalties <- c(10, 25)

# create problems using the different connectivity matrices and penalties
p2 <- list(p1,
    p1 %>% add_connectivity_penalties(penalties[1], data = b_matrix),
    p1 %>% add_connectivity_penalties(penalties[2], data = b_matrix),
    p1 %>% add_connectivity_penalties(penalties[1], data = d_matrix),
    p1 %>% add_connectivity_penalties(penalties[2], data = d_matrix),
    p1 %>% add_connectivity_penalties(penalties[1], data = c_matrix),
    p1 %>% add_connectivity_penalties(penalties[2], data = c_matrix),
    p1 %>% add_connectivity_penalties(penalties[1], data = ac_matrix),
    p1 %>% add_connectivity_penalties(penalties[2], data = ac_matrix))

# assign names to the problems
names(p2) <- c("basic problem",
    paste0("b_matrix (", penalties, ")"),
    paste0("d_matrix (", penalties, ")"),
    paste0("c_matrix (", penalties, ")"),
    paste0("ac_matrix (", penalties, ")"))

# solve problems
s2 <- lapply(p2, solve)

# plot solutions
par(mfrow = c(3, 3))
for (i in seq_along(s2)) {
    plot(s2[[i]], main = names(p2)[i], cex = 1.5, col = "white")
    plot(s2[[i]][s2[[i]]$solution_1 == 1], col = "darkgreen", add = TRUE)
'add_connectivity_penalties

)

# create minimal multi-zone problem and limit solver to one minute
# to obtain solutions in a short period of time
p3 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(0.15, nrow = 5, ncol = 3)) %>%
  add_binary_decisions() %>%
  add_default_solver(time_limit = 60)

# create matrix showing which planning units are adjacent to other units
a_matrix <- adjacency_matrix(sim_pu_zones_stack)

# visualize matrix
image(a_matrix)

# create a zone matrix where connectivities are only present between
# planning units that are allocated to the same zone
zm1 <- as(diag(3), "Matrix")

# print zone matrix
print(zm1)

# create a zone matrix where connectivities are strongest between
# planning units allocated to different zones
zm2 <- matrix(1, ncol = 3, nrow = 3)
diag(zm2) <- 0
zm2 <- as(zm2, "Matrix")

# print zone matrix
print(zm2)

# create a zone matrix that indicates that connectivities between planning
# units assigned to the same zone are much higher than connectivities
# assigned to different zones
zm3 <- matrix(0.1, ncol = 3, nrow = 3)
diag(zm3) <- 1
zm3 <- as(zm3, "Matrix")

# print zone matrix
print(zm3)

# create a zone matrix that indicates that connectivities between planning
# units allocated to zone 1 are very high, connectivities between planning
# units allocated to zones 1 and 2 are moderately high, and connectivities
# planning units allocated to other zones are low
zm4[1, 1] <- 1
zm4[1, 2] <- 0.5
zm4[2, 1] <- 0.5
zm4 <- as(zm4, "Matrix")
# print zone matrix
print(zm4)

# create a zone matrix with strong connectivities between planning units
# allocated to the same zone, moderate connectivities between planning
# unit allocated to zone 1 and zone 2, and negative connectivities between
# planning units allocated to zone 3 and the other two zones
zm5 <- matrix(-1, ncol = 3, nrow = 3)
zm5[1, 2] <- 0.5
zm5[2, 1] <- 0.5
diag(zm5) <- 1
zm5 <- as(zm5, "Matrix")

# print zone matrix
print(zm5)

# create vector of penalties to use creating problems
penalties2 <- c(5, 15)

# create multi-zone problems using the adjacent connectivity matrix and
# different zone matrices
p4 <- list(
  p3,
  p3 %>% add_connectivity_penalties(penalties2[1], zm1, a_matrix),
  p3 %>% add_connectivity_penalties(penalties2[2], zm1, a_matrix),
  p3 %>% add_connectivity_penalties(penalties2[1], zm2, a_matrix),
  p3 %>% add_connectivity_penalties(penalties2[2], zm2, a_matrix),
  p3 %>% add_connectivity_penalties(penalties2[1], zm3, a_matrix),
  p3 %>% add_connectivity_penalties(penalties2[2], zm3, a_matrix),
  p3 %>% add_connectivity_penalties(penalties2[1], zm4, a_matrix),
  p3 %>% add_connectivity_penalties(penalties2[2], zm4, a_matrix),
  p3 %>% add_connectivity_penalties(penalties2[1], zm5, a_matrix),
  p3 %>% add_connectivity_penalties(penalties2[2], zm5, a_matrix))

# assign names to the problems
names(p4) <- c("basic problem",
              paste0("zm", rep(seq_len(5), each = 2), " (",
                        rep(penalties2, 2), ")")

# solve problems
s4 <- lapply(p4, solve)
s4 <- lapply(s4, category_layer)
s4 <- stack(s4)

# plot solutions
plot(s4, main = names(p4), axes = FALSE, box = FALSE)

# create an array to manually specify the connectivities between
# each planning unit when they are allocated to each different zone
# for real-world problems, these connectivities would be generated using
# data - but here these connectivity values are assigned as random
```r
# ones or zeros
c_array <- array(0, c(rep(ncell(sim_pu_zones_stack[[1]]), 2), 3, 3))
for (z1 in seq_len(3))
  for (z2 in seq_len(3))
    c_array[, , z1, z2] <- round(runif(ncell(sim_pu_zones_stack[[1]]) ^ 2,
                                       0, 0.505))

# create a problem with the manually specified connectivity array
# note that the zones argument is set to NULL because the connectivity
data is an array
p5 <- list(p3,
            p3 %>% add_connectivity_penalties(15, zones = NULL, c_array))

# assign names to the problems
names(p5) <- c("basic problem", "connectivity array")

# solve problems
s5 <- lapply(p5, solve)
s5 <- lapply(s5, category_layer)
s5 <- stack(s5)

# plot solutions
plot(s5, main = names(p5), axes = FALSE, box = FALSE)
```

---

**add_contiguity_constraints**

*Add contiguity constraints*

**Description**

Add constraints to a conservation planning problem to ensure that all selected planning units are spatially connected with each other and form a single contiguous unit.

**Usage**

```r
## S4 method for signature 'ConservationProblem,ANY,ANY'
add_contiguity_constraints(x, zones, data)

## S4 method for signature 'ConservationProblem,ANY,data.frame'
add_contiguity_constraints(x, zones, data)

## S4 method for signature 'ConservationProblem,ANY,matrix'
add_contiguity_constraints(x, zones, data)
```

**Arguments**

- `x` *ConservationProblem-class* object.
zones: matrix or Matrix object describing the connection scheme for different zones. Each row and column corresponds to a different zone in the argument to x, and cell values must contain binary numeric values (i.e. one or zero) that indicate if connected planning units (as specified in the argument to data) should be still considered connected if they are allocated to different zones. The cell values along the diagonal of the matrix indicate if planning units should be subject to contiguity constraints when they are allocated to a given zone. Note arguments to zones must be symmetric, and that a row or column has a value of one then the diagonal element for that row or column must also have a value of one. The default argument to zones is an identity matrix (i.e. a matrix with ones along the matrix diagonal and zeros elsewhere), so that planning units are only considered connected if they are both allocated to the same zone.

data: NULL, matrix, Matrix, data.frame object showing which planning units are connected with each other. The argument defaults to NULL which means that the connection data is calculated automatically using the adjacency_matrix function. See the Details section for more information.

Details

This function uses connection data to identify solutions that form a single contiguous unit. In earlier versions of the prioritizr package, it was known as the add_connected_constraints function. It was inspired by the mathematical formulations detailed in Onal and Briers (2006).

The argument to data can be specified in several ways:

- NULL: connection data should be calculated automatically using the adjacency_matrix function. This is the default argument. Note that the connection data must be manually defined using one of the other formats below when the planning unit data in the argument to x is not spatially referenced (e.g. in data.frame or numeric format).
- matrix, Matrix: where rows and columns represent different planning units and the value of each cell indicates if the two planning units are connected or not. Cell values should be binary numeric values (i.e. one or zero). Cells that occur along the matrix diagonal have no effect on the solution at all because each planning unit cannot be a connected with itself.
- data.frame containing the fields (columns) "id1", "id2", and "boundary". Here, each row denotes the connectivity between two planning units following the Marxan format. The field boundary should contain binary numeric values that indicate if the two planning units specified in the fields "id1" and "id2" are connected or not. This data can be used to describe symmetric or asymmetric relationships between planning units. By default, input data is assumed to be symmetric unless asymmetric data is also included (e.g. if data is present for planning units 2 and 3, then the same amount of connectivity is expected for planning units 3 and 2, unless connectivity data is also provided for planning units 3 and 2).

Value

ConservationProblem-class object with the constraints added to it.

References

See Also

continuity_constraints.

Examples

# load data
data(sim_pu_raster, sim_features, sim_pu_zones_stack, sim_features_zones)

# create minimal problem
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>
  add_relative_targets(0.2) %>
  add_binary_decisions()

# create problem with added connected constraints
p2 <- p1 %>% add_contiguity_constraints()

# solve problems
s <- stack(solve(p1), solve(p2))

# plot solutions
plot(s, main = c("basic solution", "connected solution"), axes = FALSE,
     box = FALSE)

# create minimal problem with multiple zones, and limit the solver to
# 30 seconds to obtain solutions in a feasible period of time
p3 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>
  add_relative_targets(matrix(0.2, ncol = 3, nrow = 5)) %>
  add_default_solver(time_limit = 30) %>
  add_binary_decisions()

# create problem with added constraints to ensure that the planning units
# allocated to each zone form a separate contiguous unit
z4 <- diag(3)
print(z4)
p4 <- p3 %>% add_contiguity_constraints(z4)

# create problem with added constraints to ensure that the planning
# units allocated to each zone form a separate contiguous unit,
# except for planning units allocated to zone 2 which do not need
# form a single contiguous unit
z5 <- diag(3)
z5[3, 3] <- 0
print(z5)
p5 <- p3 %>% add_contiguity_constraints(z5)

# create problem with added constraints that ensure that the planning
# units allocated to zones 1 and 2 form a contiguous unit
z6 <- diag(3)
z6[1, 2] <- 1
z6[2, 1] <- 1
```
print(z6)
p6 <- p3 %>% add_contiguity_constraints(z6)

# solve problems
s2 <- lapply(list(p3, p4, p5, p6), solve)
s2 <- lapply(s2, category_layer)
s2 <- stack(s2)

# plot solutions
plot(s2, axes = FALSE, box = FALSE,
    main = c("basic solution", "p4", "p5", "p6"))

# create a problem that has a main "reserve zone" and a secondary
# "corridor zone" to connect up import areas. Here, each feature has a
# target of 30 % of its distribution. If a planning unit is allocated to the
# "reserve zone", then the prioritization accrues 100 % of the amount of
# each feature in the planning unit. If a planning unit is allocated to the
# "corridor zone" then the prioritization accrues 40 % of the amount of each
# feature in the planning unit. Also, the cost of managing a planning unit
# in the "corridor zone" is 45 % of that when it is managed as the
# "reserve zone". Finally, the problem has constraints which
# ensure that all of the selected planning units form a single contiguous
# unit, so that the planning units allocated to the "corridor zone" can
# link up the planning units allocated to the "reserve zone"

# create planning unit data
pus <- sim_pu_zones_stack[1, 1]
print(pus)

# create biodiversity data
fts <- zones(sim_features, sim_features * 0.4,
    feature_names = names(sim_features),
    zone_names = c("reserve zone", "corridor zone"))
print(fts)

# create targets
targets <- tibble::tibble(feature = names(sim_features),
    zone = list(zone_names(fts))[^5],
    target = cellStats(sim_features, "sum") * 0.2,
    type = rep("absolute", 5))
print(targets)

# create zones matrix
z7 <- matrix(1, ncol = 2, nrow = 2)
print(z7)

# create problem
p7 <- problem(pus, fts) %>%
    add_min_set_objective() %>%
    add_manual_targets(target) %>%
    add_contiguity_constraints(z7) %>%
    add_binary_decisions()
```
# solve problems
s7 <- category_layer(solve(p7))

# plot solutions
plot(s7, "solution", axes = FALSE, box = FALSE)

---

## Description

Generate a portfolio of solutions for a conservation planning problem using Bender's cuts (discussed in Rodrigues et al. 2000). This is recommended as a replacement for `add_gap_portfolio` when the Gurobi software is not available.

## Usage

```r
add_cuts_portfolio(x, number_solutions = 10L)
```

## Arguments

- `x`  
  ConservationProblem-class object.

- `number_solutions`  
  integer number of attempts to generate different solutions. Defaults to 10.

## Details

This strategy for generating a portfolio of solutions involves solving the problem multiple times and adding additional constraints to forbid previously obtained solutions. In general, this strategy is most useful when problems take a long time to solve and benefit from having multiple threads allocated for solving an individual problem. Please note that version 4.0.1 attempted to use the Gurobi solution pool to speed up the process of obtaining multiple solutions. However, it would sometimes return solutions that were not within the specified optimality gap. To address this, we have added alternative methods for generating solution portfolios, please refer to the portfolios documentation for more information.

## Value

ConservationProblem-class object with the portfolio added to it.

## References

add_default_decisions

See Also

portfolios.

Examples

```r
# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_raster, sim_features, sim_pu_zones_stack, sim_features_zones)

# create minimal problem with cuts portfolio
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_cuts_portfolio(10) %>%
  add_default_solver(gap = 0.2, verbose = FALSE)

# solve problem and generate 10 solutions within 20 % of optimality
s1 <- solve(p1)

# plot solutions in portfolio
plot(stack(s1), axes = FALSE, box = FALSE)

# build multi-zone conservation problem with cuts portfolio
p2 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5,
                             ncol = 3)) %>%
  add_binary_decisions() %>%
  add_cuts_portfolio(10) %>%
  add_default_solver(gap = 0.2, verbose = FALSE)

# solve the problem
s2 <- solve(p2)

# print solution
str(s2, max.level = 1)

# plot solutions in portfolio
plot(stack(lapply(s2, category_layer)), main = "solution", axes = FALSE,
     box = FALSE)
```
**Description**

This function adds the default decision types to a conservation planning problem. The default types are binary and are added using the `add_binary_decisions` function.

**Usage**

```r
add_default_decisions(x)
```

**Arguments**

- `x` *ConservationProblem-class* object.

**See Also**

`decisions`.

---

**Description**

Identify the best solver currently installed on the system and specify that it should be used to solve a conservation planning problem. Ranked from best to worst, the available solvers that can be used are: *gurobi* (add_gurobi_solver), *Rsymphony* (add_rsymphony_solver), then *lpsymphony* (add_lpsymphony_solver).

**Usage**

```r
add_default_solver(x, ...)
```

**Arguments**

- `x` *ConservationProblem-class* object.
- `...` arguments passed to the solver.

**See Also**

`solvers`.
add_extra_portfolio  Add an extra portfolio

Description

Generate a portfolio of solutions for a conservation planning problem by storing feasible solutions discovered during the optimization process. This method is useful for quickly obtaining multiple solutions, but does not provide any guarantees on the number of solutions, or the quality of solutions.

Usage

add_extra_portfolio(x)

Arguments

x  ConservationProblem-class object.

Details

This strategy for generating a portfolio requires problems to be solved using the Gurobi software suite (i.e. using add_gurobi_solver). Specifically, version 8.0.0 (or greater) of the gurobi package must be installed.

Value

ConservationProblem-class object with the portfolio added to it.

See Also

portfolios.

Examples

# set seed for reproducibility
set.seed(600)

# load data
data(sim_pu_raster, sim_features)

# create minimal problem with a portfolio for extra solutions
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.05) %>%
  add_extra_portfolio() %>%
  add_default_solver(gap = 0, verbose = FALSE)

# solve problem and generate portfolio
```r
s1 <- solve(p1)

# print number of solutions found
print(length(s1))

# plot solutions
plot(stack(s1), axes = FALSE, box = FALSE)

# create multi-zone problem with a portfolio for extra solutions
p2 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5,
                              ncol = 3)) %>%
  add_extra_portfolio() %>%
  add_default_solver(gap = 0, verbose = FALSE)

# solve problem and generate portfolio
s2 <- solve(p2)

# print number of solutions found
print(length(s2))

# plot solutions in portfolio
plot(stack(lapply(s2, category_layer)), main = "solution", axes = FALSE,
     box = FALSE)
```

---

**Description**

Add feature contiguity constraints to ensure that each feature is represented in a contiguous unit of dispersible habitat. These constraints are a more advanced version of those implemented in the `add_contiguity_constraints` function, because they ensure that each feature is represented in a contiguous unit and not that the entire solution should form a contiguous unit. Additionally, this function can use data showing the distribution of dispersible habitat for each feature to ensure that all features can disperse throughout the areas designated for their conservation.

**Usage**

```r
## S4 method for signature 'ConservationProblem,ANY,Matrix'
add_feature_contiguity_constraints(x, zones, data)

## S4 method for signature 'ConservationProblem,ANY,data.frame'
add_feature_contiguity_constraints(x, zones, data)

## S4 method for signature 'ConservationProblem,ANY,matrix'
```
add_feature_contiguity_constraints(x, zones, data)

## S4 method for signature 'ConservationProblem,ANY,ANY'
add_feature_contiguity_constraints(x, zones, data)

**Arguments**

- **x** `ConservationProblem-class` object.
- **zones** matrix, Matrix or list object describing the connection scheme for different zones. For matrix or and Matrix arguments, each row and column corresponds to a different zone in the argument to `x`, and cell values must contain binary numeric values (i.e. one or zero) that indicate if connected planning units (as specified in the argument to `data`) should be still considered connected if they are allocated to different zones. The cell values along the diagonal of the matrix indicate if planning units should be subject to contiguity constraints when they are allocated to a given zone. Note arguments to `zones` must be symmetric, and that a row or column has a value of one then the diagonal element for that row or column must also have a value of one. If the connection scheme between different zones should differ among the features, then the argument to `zones` should be a list of matrix or Matrix objects that shows the specific scheme for each feature using the conventions described above. The default argument to `zones` is an identity matrix (i.e. a matrix with ones along the matrix diagonal and zeros elsewhere), so that planning units are only considered connected if they are both allocated to the same zone.

- **data** NULL, matrix, Matrix, data.frame or list of matrix, Matrix, or data.frame objects. The argument to `data` shows which planning units should be treated as being connected when implementing constraints to ensure that features are represented in contiguous units. If different features have different dispersal capabilities, then it may be desirable to specify which sets of planning units should be treated as being connected for which features using a list of objects. The default argument is NULL which means that the connection data is calculated automatically using the `adjacency_matrix` function and so all adjacent planning units are treated as being connected for all features. See the Details section for more information.

**Details**

This function uses connection data to identify solutions that represent features in contiguous units of dispersible habitat. In earlier versions of the `prioritizr` package, it was known as the `add_corridor_constraints` function but has since been renamed for clarity. It was inspired by the mathematical formulations detailed in Onal and Briers (2006) and Cardeira et al. 2010. For an example that has used these constraints, see Hanson, Fuller, and Rhodes (2018). Please note that these constraints require the expanded formulation and therefore cannot be used with feature data that have negative values. **Please note that adding these constraints to a problem will drastically increase the amount of time required to solve it.**

The argument to `data` can be specified in several ways:

- **NULL** connection data should be calculated automatically using the `adjacency_matrix` function. This is the default argument and means that all adjacent planning units are treated as potential...
add_feature_contiguity_constraints

tially dispersible for all features. Note that the connection data must be manually defined using one of the other formats below when the planning unit data in the argument to x is not spatially referenced (e.g. in data.frame or numeric format).

matrix, Matrix where rows and columns represent different planning units and the value of each cell indicates if the two planning units are connected or not. Cell values should be binary numeric values (i.e. one or zero). Cells that occur along the matrix diagonal have no effect on the solution at all because each planning unit cannot be a connected with itself. Note that pairs of connected planning units are treated as being potentially dispersible for all features.

data.frame containing the fields (columns) "id1", "id2", and "boundary". Here, each row denotes the connectivity between two planning units following the Marxan format. The field boundary should contain binary numeric values that indicate if the two planning units specified in the fields "id1" and "id2" are connected or not. This data can be used to describe symmetric or asymmetric relationships between planning units. By default, input data is assumed to be symmetric unless asymmetric data is also included (e.g. if data is present for planning units 2 and 3, then the same amount of connectivity is expected for planning units 3 and 2, unless connectivity data is also provided for planning units 3 and 2). Note that pairs of connected planning units are treated as being potentially dispersible for all features.

list containing matrix, Matrix, or data.frame objects showing which planning units should be treated as connected for each feature. Each element in the list should correspond to a different feature (specifically, a different target in the problem), and should contain a matrix, Matrix, or data.frame object that follows the conventions detailed above.

Value

ConservationProblem-class object with the constraints added to it.

References


See Also

constraints.

Examples

# load data
data(sim_pu_raster, sim_pu_zones_stack, sim_features, sim_features_zones)

# create minimal problem
pl <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%

add_relative_targets(0.3)

# create problem with contiguity constraints
p2 <- p1 %>% add_contiguity_constraints()

# create problem with constraints to represent features in contiguous
# units
p3 <- p1 %>% add_feature_contiguity_constraints()

# create problem with constraints to represent features in contiguous
# units that contain highly suitable habitat values
# (specifically in the top 1.5th percentile)
cm4 <- lapply(seq_len(nlayers(sim_features)), function(i) {
  # create connectivity matrix using the i'th feature's habitat data
  m <- connectivity_matrix(sim_pu_raster, sim_features[[i]])
  # convert matrix to TRUE/FALSE values in top 20th percentile
  m <- m > quantile(as.vector(m), 1 - 0.015, names = FALSE)
  # convert matrix from TRUE/FALSE to sparse matrix with 0/1s
  m <- as(m, "dgCMatrix")
  # remove 0s from the sparse matrix
  m <- Matrix::drop0(m)
  # return matrix
  m
})

p4 <- p1 %>% add_feature_contiguity_constraints(data = cm4)

# solve problems
s1 <- stack(solve(p1), solve(p2), solve(p3), solve(p4))

# plot solutions
plot(s1, axes = FALSE, box = FALSE,
     main = c("basic solution", "contiguity constraints",
              "feature contiguity constraints",
              "feature contiguity constraints with data"))

# create minimal problem with multiple zones, and limit the solver to
# 30 seconds to obtain solutions in a feasible period of time
p5 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(0.1, ncol = 3, nrow = 5)) %>%
  add_default_solver(time_limit = 30) %>%
  add_binary_decisions()

# create problem with contiguity constraints that specify that the
# planning units used to conserve each feature in different management
# zones must form separate contiguous units
p6 <- p5 %>% add_feature_contiguity_constraints(diag(3))

# create problem with contiguity constraints that specify that the
# planning units used to conserve each feature must form a single
# contiguous unit if the planning units are allocated to zones 1 and 2
# and do not need to form a single contiguous unit if they are allocated
# to zone 3
zm7 <- matrix(0, ncol = 3, nrow = 3)
zm7[seq_len(2), seq_len(2)] <- 1
print(zm7)
p7 <- p5 %>% add_feature_contiguity_constraints(zm7)

# create problem with contiguity constraints that specify that all of
# the planning units in all three of the zones must conserve first feature
# in a single contiguous unit but the planning units used to conserve the
# remaining features do not need to be contiguous in any way
zm8 <- lapply(seq_len(number_of_features(sim_features_zones)), function(i)
  matrix(ifelse(i == 1, 1, 0), ncol = 3, nrow = 3))
print(zm8)
p8 <- p5 %>% add_feature_contiguity_constraints(zm8)

# solve problems
s2 <- lapply(list(p5, p6, p7, p8), solve)
s2 <- stack(lapply(s2, category_layer))

# plot solutions
plot(s2, main = c("p5", "p6", "p7", "p8"), axes = FALSE, box = FALSE)

---

**Description**

Conservation planning problems that aim to maximize the representation of features given a budget often will not able to conserve all of the features unless the budget is very high. In such budget-limited problems, it may be desirable to prefer the representation of some features over other features. This information can be incorporated into the problem using weights. Weights can be applied to a problem to favor the representation of some features over other features when making decisions about how the budget should be allocated.

**Usage**

```r
## S4 method for signature 'ConservationProblem,numeric'
add_feature_weights(x, weights)
```

```r
## S4 method for signature 'ConservationProblem,matrix'
add_feature_weights(x, weights)
```

**Arguments**

- `x`: `ConservationProblem-class` object.
- `weights`: numeric or matrix of weights. See the Details section for more information.
Details

Weights can only be applied to problems that have an objective that is budget limited (e.g. `add_max_cover_objective`). They can be applied to problems that aim to maximize phylogenetic representation (`add_max_phylo_div_objective`) to favor the representation of specific features over the representation of some phylogenetic branches. Weights cannot be negative values and must have values that are equal to or larger than zero. Note that planning unit costs are scaled to 0.01 to identify the cheapest solution among multiple optimal solutions. This means that the optimization process will favor cheaper solutions over solutions that meet feature targets (or occurrences) when feature weights are lower than 0.01.

numeric containing weights for each feature. Note that this type of argument cannot be used to specify weights for problems with multiple zones.

matrix containing weights for each feature in each zone. Here, each row corresponds to a different feature in argument to x, each column corresponds to a different zone in argument to x, and each cell contains the weight value for a given feature that the solution can to secure in a given zone. Note that if the problem contains targets created using `add_manual_targets` then a matrix should be supplied containing a single column that indicates that weight for fulfilling each target.

Value

`ConservationProblem-class` object with the weights added to it.

See Also

`objectives`.

Examples

```r
# load ape package
require(ape)

# load data
data(sim_pu_raster, sim_features, sim_phylogeny, sim_pu_zones_stack, sim_features_zones)

# create minimal problem that aims to maximize the number of features
# adequately conserved given a total budget of 3800. Here, each feature
# needs 20 % of its habitat for it to be considered adequately conserved
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_max_features_objective(budget = 3800) %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions()

# create weights that assign higher importance to features with less
# suitable habitat in the study area
(w2 <- exp((1 / cellStats(sim_features, "sum")) * 200))

# create problem using rarity weights
p2 <- p1 %>% add_feature_weights(w2)
```
# create manually specified weights that assign higher importance to certain features. These weights could be based on a pre-calculated index (e.g., an index measuring extinction risk where higher values denote higher extinction risk)

\[
w3 \leftarrow c(0, 0, 0, 100, 200)
\]
\[
p3 \leftarrow \text{p1} \%\% \text{add_feature_weights(w3)}
\]

# solve problems
\[
s1 \leftarrow \text{stack(solve(p1), solve(p2), solve(p3))}
\]

# plot solutions
\[
\text{plot(s1, main = c("equal weights", "rarity weights", "manual weights"),}
\]
\[
\text{axes = FALSE, box = FALSE)}
\]

# plot the example phylogeny
\[
\text{par(mfrow = c(1, 1))}
\]
\[
\text{plot(sim_phylogeny, main = "simulated phylogeny")}
\]

# create problem with a maximum phylogenetic diversity objective, where each feature needs 10% of its distribution to be secured for it to be adequately conserved and a total budget of 1900

\[
p4 \leftarrow \text{problem(sim_pu_raster, sim_features)} \%\% \text{add_max_phylo_div_objective(1900, sim_phylogeny)} \%\% \text{add_relative_targets(0.1)} \%\% \text{add_binary_decisions()}
\]

# solve problem
\[
s4 \leftarrow \text{solve(p4)}
\]

# plot solution
\[
\text{plot(s4, main = "solution", axes = FALSE, box = FALSE)}
\]

# find which features have their targets met
\[
targets_met4 \leftarrow \text{cellStats(s4 * sim_features, "sum") > (0.1 * cellStats(sim_features, "sum"))}
\]

# plot the example phylogeny and color the represented features in red
\[
\text{plot(sim_phylogeny, main = "represented features",}
\]
\[
\text{tip.color = replace(rep("black", nlayers(sim_features)),}
\]
\[
\text{which(targets_met4), "red")}
\]

# we can see here that the third feature ("layer.3", i.e. sim_features[[3]]) is not represented in the solution. Let us pretend that it is absolutely critical this feature is adequately conserved in the solution. For example, this feature could represent a species that plays an important role in the ecosystem, or a species that is important commercial activities (e.g., eco-tourism). So, to generate a solution that conserves the third feature whilst also aiming to maximize phylogenetic diversity, we will create a set of weights that assign a particularly high weighting to the third feature

\[
w5 \leftarrow c(0, 0, 1000, 0, 0)
\]
# we can see that this weighting (i.e. w5[3]) has a much higher value than
# the branch lengths in the phylogeny so solutions that represent this
# feature be much closer to optimality
print(sim_phylogeny$edge.length)

# create problem with high weighting for the third feature and solve it
s5 <- p4 %>% add_feature_weights(w5) %>% solve()

# plot solution
plot(s5, main = "solution", axes = FALSE, box = FALSE)

# find which features have their targets met
targets_met5 <- cellStats(s5 * sim_features, "sum") >
  (0.1 * cellStats(sim_features, "sum"))

# plot the example phylogeny and color the represented features in red
# here we can see that this solution only adequately conserves the
# third feature. This means that, given the budget, we are faced with the
# trade-off of conserving either the third feature, or a phylogenetically
# diverse set of three different features.
plot(sim_phylogeny, main = "represented features",
     tip.color = replace(rep("black", nlayers(sim_features)),
                        which(targets_met5), "red"))

# create multi-zone problem with maximum features objective,
# with 10 % representation targets for each feature, and set
# a budget such that the total maximum expenditure in all zones
# cannot exceed 3000
p6 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
    add_max_features_objective(3000) %>%
    add_relative_targets(matrix(0.1, ncol = 3, nrow = 5)) %>%
    add_binary_decisions()

# create weights that assign equal weighting for the representation
# of each feature in each zone except that it does not matter if
# feature 1 is represented in zone 1 and it really important
# that feature 3 is really in zone 1
w7 <- matrix(1, ncol = 3, nrow = 5)
w7[1, 1] <- 0
w7[3, 1] <- 100

# create problem with weights
p7 <- p6 %>% add_feature_weights(w7)

# solve problems
s6 <- solve(p6)
s7 <- solve(p7)

# plot solutions
plot(stack(category_layer(s6), category_layer(s7)),
     main = c("equal weights", "manual weights"), axes = FALSE, box = FALSE)
# create minimal problem to show the correct method for setting
# weights for problems with manual targets
p8 <- problem(sim_pu_raster, sim_features) %>%
  add_max_features_objective(budget = 1500) %>%
  add_manual_targets(data.frame(feature = c("layer.1", "layer.4"),
                          type = "relative",
                          target = 0.1)) %>%
  add_feature_weights(matrix(c(1, 200), ncol = 1)) %>%
  add_binary_decisions()

# solve problem
s8 <- solve(p8)

# plot solution
plot(s8, main = "solution", axes = FALSE, box = FALSE)

---

**add_gap_portfolio**  

Add a gap portfolio

**Description**

Generate a portfolio of solutions for a conservation planning problem by finding a certain number of solutions that are all within a pre-specified optimality gap. This method is useful for generating multiple solutions that can be used to calculate selection frequencies for moderate and large-sized problems (similar to Marxan).

**Usage**

```r
add_gap_portfolio(x, number_solutions, pool_gap = 0.1)
```

**Arguments**

- `x`  
  ConservationProblem-class object.
- `number_solutions`  
  integer number of solutions required.
- `pool_gap`  
  numeric gap to optimality for solutions in the portfolio. This relative gap specifies a threshold worst-case performance for solutions in the portfolio. For example, value of 0.1 will result in the portfolio returning solutions that are within 10% of an optimal solution. Note that the gap specified in the solver (i.e. add_gurobi_solver) must be less than or equal to the gap specified to generate the portfolio. Defaults to 0.1.

**Details**

This strategy for generating a portfolio requires problems to be solved using the Gurobi software suite (i.e. using add_gurobi_solver). Specifically, version 9.0.0 (or greater) of the gurobi package must be installed. Note that the number of solutions returned may be less than the argument to number_solutions, if the total number of solutions that meet the optimality gap is less than the number of solutions requested.
Value

`ConservationProblem-class` object with the portfolio added to it.

See Also

`portfolios`.

Examples

```r
# set seed for reproducibility
set.seed(600)

# load data
data(sim_pu_raster, sim_features)

# create minimal problem with a portfolio containing 10 solutions within 20% 
# of optimality
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.05) %>%
  add_gap_portfolio(number_solutions = 5, pool_gap = 0.2) %>%
  add_default_solver(gap = 0, verbose = FALSE)

# solve problem and generate portfolio
s1 <- solve(p1)

# print number of solutions found
print(length(s1))

# plot solutions
plot(stack(s1), axes = FALSE, box = FALSE)

# create multi-zone problem with a portfolio containing 10 solutions within 
# 20% of optimality
p2 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5, 
                               ncol = 3)) %>%
  add_gap_portfolio(number_solutions = 5, pool_gap = 0.2) %>%
  add_default_solver(gap = 0, verbose = FALSE)

# solve problem and generate portfolio
s2 <- solve(p2)

# print number of solutions found
print(length(s2))

# plot solutions in portfolio
plot(stack(lapply(s2, category_layer)), main = "solution", axes = FALSE, 
     box = FALSE)
```
add_gurobi_solver

Add a Gurobi solver

Description

Specify that the Gurobi software should be used to solve a conservation planning problem. This function can also be used to customize the behavior of the solver. It requires the gurobi package.

Usage

```r
add_gurobi_solver(
  x,
  gap = 0.1,
  time_limit = .Machine$integer.max,
  presolve = 2,
  threads = 1,
  first_feasible = 0,
  numeric_focus = FALSE,
  verbose = TRUE
)
```

Arguments

- `x` ConservationProblem-class object.
- `gap` numeric gap to optimality. This gap is relative when solving problems using gurobi, and will 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.
- `time_limit` numeric time limit in seconds to run the optimizer. The solver will return the current best solution when this time limit is exceeded.
- `presolve` integer number indicating how intensively the solver should try to simplify the problem before solving it. The default value of 2 indicates to that the solver should be very aggressive in trying to simplify the problem.
- `threads` integer number of threads to use for the optimization algorithm. The default value of 1 will result in only one thread being used.
- `first_feasible` logical should the first feasible solution be be returned? If first_feasible is set to TRUE, the solver will return the first solution it encounters that meets all the constraints, regardless of solution quality. Note that the first feasible solution is not an arbitrary solution, rather it is derived from the relaxed solution, and is therefore often reasonably close to optimality. Defaults to FALSE.
- `numeric_focus` logical should extra attention be paid to verifying the accuracy of numerical calculations? This may be useful when dealing problems that may suffer from numerical instability issues. Beware that it will likely substantially increase run time (sets the Gurobi numericFocus parameter to 3). Defaults to FALSE.
- `verbose` logical should information be printed while solving optimization problems?
Details

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.

Value

ConservationProblem-class object with the solver added to it.

See Also

`solvers`.

Examples

```r
# load data
data(sim_pu_raster, sim_features)

# create problem
p <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions()

# if the package is installed then add solver and generate solution
if (require("gurobi")) {
  # specify solver and generate solution
  s <- p %>% add_gurobi_solver(gap = 0.1, presolve = 2, time_limit = 5) %>%
    solve()

  # plot solutions
  plot(stack(sim_pu_raster, s), main = c("planning units", "solution"),
    axes = FALSE, box = FALSE)
}
```

Description

Add constraints to a conservation planning `problem` to ensure that specific planning units are selected (or allocated to a specific zone) in the solution. For example, it may be desirable to lock in planning units that are inside existing protected areas so that the solution fills in the gaps in the existing reserve network. If specific planning units should be locked out of a solution, use `add_locked_out_constraints`. For problems with non-binary planning unit allocations (e.g. proportions), the `add_manual_locked_constraints` function can be used to lock planning unit allocations to a specific value.
add_locked_in_constraints

Usage

```r
add_locked_in_constraints(x, locked_in)
## S4 method for signature 'ConservationProblem,numeric'
add_locked_in_constraints(x, locked_in)
## S4 method for signature 'ConservationProblem,logical'
add_locked_in_constraints(x, locked_in)
## S4 method for signature 'ConservationProblem,matrix'
add_locked_in_constraints(x, locked_in)
## S4 method for signature 'ConservationProblem,character'
add_locked_in_constraints(x, locked_in)
## S4 method for signature 'ConservationProblem,Spatial'
add_locked_in_constraints(x, locked_in)
## S4 method for signature 'ConservationProblem,sf'
add_locked_in_constraints(x, locked_in)
## S4 method for signature 'ConservationProblem,Raster'
add_locked_in_constraints(x, locked_in)
```

Arguments

- `x`: `ConservationProblem-class` object.
- `locked_in`: Object that determines which planning units that should be locked in. See the Details section for more information.

Details

The locked planning units can be specified in several different ways. Generally, the locked data should correspond to the planning units in the argument to `x`. To help make working with `Raster-class` planning unit data easier, the locked data should correspond to cell indices in the `Raster-class` data. For example, integer arguments should correspond to cell indices and logical arguments should have a value for each cell—regardless of which planning unit cells contain NA values.

- integer vector of indices pertaining to which planning units should be locked for the solution. This argument is only compatible with problems that contain a single zone.
- logical vector containing TRUE and/or FALSE values that indicate which planning units should be locked in the solution. This argument is only compatible with problems that contain a single zone.
- matrix containing logical TRUE and/or FALSE values which indicate if certain planning units are should be locked to a specific zone in the solution. Each row corresponds to a planning unit, each column corresponds to a zone, and each cell indicates if the planning unit should be locked to a given zone. Thus each row should only contain at most a single TRUE value.
character field (column) name(s) that indicate if planning units should be locked for the solution. This type of argument is only compatible if the planning units in the argument to \( x \) are a 
\texttt{Spatial-class}, \texttt{sf}, or \texttt{data.frame} object. The fields (columns) must have logical (i.e. \texttt{TRUE} or \texttt{FALSE}) values indicating if the planning unit is to be locked for the solution. For problems containing multiple zones, this argument should contain a field (column) name for each management zone.

\textbf{Spatial-class or sf} planning units in \( x \) that spatially intersect with the argument to \( y \) (according to \texttt{intersecting_units} are locked for to the solution. Note that this option is only available for problems that contain a single management zone.

\textbf{Raster-class} planning units in \( x \) that intersect with non-zero and non-\texttt{NA} raster cells are locked for the solution. For problems that contain multiple zones, the \texttt{Raster-class} object must contain a layer for each zone. Note that for multi-band arguments, each pixel must only contain a non-zero value in a single band. Additionally, if the cost data in \( x \) is a \texttt{Raster-class} object, we recommend standardizing \texttt{NA} values in this dataset with the cost data. In other words, the pixels in \( x \) that have \texttt{NA} values should also have \texttt{NA} values in the locked data.

\textbf{Value}

\texttt{ConservationProblem-class} object with the constraints added to it.

\textbf{See Also}

\texttt{constraints}.

\textbf{Examples}

```r
# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_polygons, sim_features, sim_locked_in_raster)

# create minimal problem
p1 <- problem(sim_pu_polygons, sim_features, "cost") %>%
   add_min_set_objective() %>%
   add_relative_targets(0.2) %>%
   add_binary_decisions()

# create problem with added locked in constraints using integers
p2 <- p1 %>% add_locked_in_constraints(which(sim_pu_polygons$locked_in))

# create problem with added locked in constraints using a field name
p3 <- p1 %>% add_locked_in_constraints("locked_in")

# create problem with added locked in constraints using raster data
p4 <- p1 %>% add_locked_in_constraints(sim_locked_in_raster)

# create problem with added locked in constraints using spatial polygon data
locked_in <- sim_pu_polygons[sim_pu_polygons$locked_in == 1, ]
p5 <- p1 %>% add_locked_in_constraints(locked_in)
```
# solve problems
s1 <- solve(p1)
s2 <- solve(p2)
s3 <- solve(p3)
s4 <- solve(p4)
s5 <- solve(p5)

# plot solutions
par(mfrow = c(3, 2), mar = c(0, 0, 4.1, 0))
plot(s1, main = "none locked in")
plot(s1[s1$solution_1 == 1, ], col = "darkgreen", add = TRUE)
plot(s2, main = "locked in (integer input)")
plot(s2[s2$solution_1 == 1, ], col = "darkgreen", add = TRUE)
plot(s3, main = "locked in (character input)")
plot(s3[s3$solution_1 == 1, ], col = "darkgreen", add = TRUE)
plot(s4, main = "locked in (raster input)")
plot(s4[s4$solution_1 == 1, ], col = "darkgreen", add = TRUE)
plot(s5, main = "locked in (polygon input)")
plot(s5[s5$solution_1 == 1, ], col = "darkgreen", add = TRUE)

# create minimal multi-zone problem with spatial data
p6 <- problem(sim_pu_zones_polygons, sim_features_zones,
              cost_column = c("cost_1", "cost_2", "cost_3")[3]) %>%
  add_min_set_objective() %>%
  add_absolute_targets(matrix(rpois(15, 1), nrow = 5,
                              ncol = 3)) %>%
  add_binary_decisions()

# create multi-zone problem with locked in constraints using matrix data
locked_matrix <- sim_pu_zones_polygons@data[, c("locked_1", "locked_2",
                                             "locked_3")]
locked_matrix <- as.matrix(locked_matrix)
p7 <- p6 %>% add_locked_in_constraints(locked_matrix)

# solve problem
s6 <- solve(p6)

# create new column representing the zone id that each planning unit
# was allocated to in the solution
s6$solution <- category_vector(s6@data[, c("solution_1_zone_1",
                                       "solution_1_zone_2",
                                       "solution_1_zone_3")])

# plot solution
spplot(s6, zcol = "solution", main = "solution", axes = FALSE, box = FALSE)
# create multi-zone problem with locked in constraints using field names
p8 <- p6 %>% add_locked_in_constraints(c("locked_1", "locked_2", "locked_3"))

# solve problem
s8 <- solve(p8)

# create new column representing the zone id that each planning unit
# was allocated to in the solution
s8$solution <- category_vector(s8@data[, c("solution_1_zone_1",
                                    "solution_1_zone_2",
                                    "solution_1_zone_3")])
s8$solution[s8$solution == 1 & s8$solution_1_zone_1 == 0] <- 0
s8$solution <- factor(s8$solution)

# plot solution
spplot(s8, zcol = "solution", main = "solution", axes = FALSE, box = FALSE)

# create multi-zone problem with raster planning units
p9 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>%
  add_absolute_targets(matrix(rpois(15, 1), nrow = 5, ncol = 3)) %>%
  add_binary_decisions()

# create raster stack with locked in units
locked_in_stack <- sim_pu_zones_stack[[1]]
locked_in_stack[!is.na(locked_in_stack)] <- 0
locked_in_stack <- locked_in_stack[[c(1, 1, 1)]]
locked_in_stack[[1]][[1]] <- 1
locked_in_stack[[2]][[2]] <- 1
locked_in_stack[[3]][[3]] <- 1

# plot locked in stack
plot(locked_in_stack)

# add locked in raster units to problem
p9 <- p9 %>% add_locked_in_constraints(locked_in_stack)

# solve problem
s9 <- solve(p9)

# plot solution
plot(category_layer(s9), main = "solution", axes = FALSE, box = FALSE)
Description

Add constraints to a conservation planning problem to ensure that specific planning units are not selected (or allocated to a specific zone) in the solution. For example, it may be useful to lock out planning units that have been degraded and are not suitable for conserving species. If specific planning units should be locked in to the solution, use `add_locked_out_constraints`. For problems with non-binary planning unit allocations (e.g., proportions), the `add_manual_locked_constraints` function can be used to lock planning unit allocations to a specific value.

Usage

```r
add_locked_out_constraints(x, locked_out)
```

Arguments

- `x`  
  ConservationProblem-class object.
- `locked_out`  
  Object that determines which planning units that should be locked out. See the Details section for more information.

Details

The locked planning units can be specified in several different ways. Generally, the locked data should correspond to the planning units in the argument to `x`. To help make working with Raster-class planning unit data easier, the locked data should correspond to cell indices in the Raster-class data. For example, integer arguments should correspond to cell indices and logical arguments should have a value for each cell—regardless of which planning unit cells contain NA values.

- `integer vector` of indices pertaining to which planning units should be locked for the solution. This argument is only compatible with problems that contain a single zone.
logical vector containing TRUE and/or FALSE values that indicate which planning units should be locked in the solution. This argument is only compatible with problems that contain a single zone.

matrix containing logical TRUE and/or FALSE values which indicate if certain planning units are should be locked to a specific zone in the solution. Each row corresponds to a planning unit, each column corresponds to a zone, and each cell indicates if the planning unit should be locked to a given zone. Thus each row should only contain at most a single TRUE value.

character field (column) name(s) that indicate if planning units should be locked for the solution. This type of argument is only compatible if the planning units in the argument to x are a Spatial-class, sf, or data.frame object. The fields (columns) must have logical (i.e. TRUE or FALSE) values indicating if the planning unit is to be locked for the solution. For problems containing multiple zones, this argument should contain a field (column) name for each management zone.

Spatial-class or sf planning units in x that spatially intersect with the argument to y (according to intersecting_units are locked for to the solution. Note that this option is only available for problems that contain a single management zone.

Raster-class planning units in x that intersect with non-zero and non-NA raster cells are locked for the solution. For problems that contain multiple zones, the Raster-class object must contain a layer for each zone. Note that for multi-band arguments, each pixel must only contain a non-zero value in a single band. Additionally, if the cost data in x is a Raster-class object, we recommend standardizing NA values in this dataset with the cost data. In other words, the pixels in x that have NA values should also have NA values in the locked data.

Value

ConservationProblem-class object with the constraints added to it.

See Also

constraints.

Examples

# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_polygons, sim_features, sim_locked_out_raster)

# create minimal problem
p1 <- problem(sim_pu_polygons, sim_features, "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions()

# create problem with added locked out constraints using integers
p2 <- p1 %>% add_locked_out_constraints(which(sim_pu_polygons$locked_out))

# create problem with added locked out constraints using a field name
add_locked_out_constraints

p3 <- p1 %>% add_locked_out_constraints("locked_out")

# create problem with added locked out constraints using raster data
p4 <- p1 %>% add_locked_out_constraints(sim_locked_out_raster)

# create problem with added locked out constraints using spatial polygon data
locked_out <- sim_pu_polygons[which(sim_pu_polygons$locked_out == 1),]
p5 <- p1 %>% add_locked_out_constraints(locked_out)

# solve problems
s1 <- solve(p1)
s2 <- solve(p2)
s3 <- solve(p3)
s4 <- solve(p4)
s5 <- solve(p5)

# plot solutions
par(mfrow = c(3,2), mar = c(0, 0, 4.1, 0))
plot(s1, main = "none locked out")
plot(s1[s1$solution_1 == 1,], col = "darkgreen", add = TRUE)

plot(s2, main = "locked out (integer input)"
plot(s2[s2$solution_1 == 1,], col = "darkgreen", add = TRUE)

plot(s3, main = "locked out (character input)"
plot(s3[s3$solution_1 == 1,], col = "darkgreen", add = TRUE)

plot(s4, main = "locked out (raster input)"
plot(s4[s4$solution_1 == 1,], col = "darkgreen", add = TRUE)

plot(s5, main = "locked out (polygon input)"
plot(s5[s5$solution_1 == 1,], col = "darkgreen", add = TRUE)

# create minimal multi-zone problem with spatial data
p6 <- problem(sim_pu_zones_polygons, sim_features_zones,
  cost_column = c("cost_1", "cost_2", "cost_3"))
  add_min_set_objective() %>%
  add_absolute_targets(matrix(rpois(15, 1), nrow = 5, ncol = 3)) %>%
  add_binary_decisions()

# create multi-zone problem with locked out constraints using matrix data
locked_matrix <- sim_pu_zones_polygons@data[, c("locked_1", "locked_2",
  "locked_3")]
locked_matrix <- as.matrix(locked_matrix)
p7 <- p6 %>% add_locked_out_constraints(locked_matrix)

# solve problem
s6 <- solve(p6)

# create new column representing the zone id that each planning unit
# was allocated to in the solution
\begin{verbatim}

add_locked_out_constraints

s6$solution <- category_vector(s6@data[, c("solution_1_zone_1",
                  "solution_1_zone_2",
                  "solution_1_zone_3")])

s6$solution <- factor(s6$solution)

# plot solution
spplot(s6, zcol = "solution", main = "solution", axes = FALSE, box = FALSE)

# create multi-zone problem with locked out constraints using field names
p8 <- p6 %>% add_locked_out_constraints(c("locked_1", "locked_2",
                  "locked_3"))

# solve problem
s8 <- solve(p8)

# create new column in s8 representing the zone id that each planning unit
# was allocated to in the solution
s8$solution <- category_vector(s8@data[, c("solution_1_zone_1",
                  "solution_1_zone_2",
                  "solution_1_zone_3")])

s8$solution[s8$solution == 1 & s8$solution_1_zone_1 == 0] <- 0
s8$solution <- factor(s8$solution)

# plot solution
spplot(s8, zcol = "solution", main = "solution", axes = FALSE, box = FALSE)

# create multi-zone problem with raster planning units
p9 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>%
  add_absolute_targets(matrix(rpois(15, 1), nrow = 5, ncol = 3)) %>%
  add_binary_decisions()

# create raster stack with locked out units
locked_out_stack <- sim_pu_zones_stack[[1]]
locked_out_stack[!is.na(locked_out_stack)] <- 0
locked_out_stack[locked_out_stack[[c(1, 1, 1)]]]
locked_out_stack[[1]][1] <- 1
locked_out_stack[[2]][2] <- 1
locked_out_stack[[3]][3] <- 1

# plot locked out stack
plot(locked_out_stack)

# add locked out raster units to problem
p9 <- p9 %>% add_locked_out_constraints(locked_out_stack)

# solve problem
s9 <- solve(p9)

# plot solution
plot(category_layer(s9), main = "solution", axes = FALSE, box = FALSE)
\end{verbatim}
add_loglinear_targets Add targets using log-linear scaling

Description

Add targets to a conservation planning problem by log-linearly interpolating the targets between thresholds based on the total amount of each feature in the study area (Rodrigues et al. 2004). Additionally, caps can be applied to targets to prevent features with massive distributions from being over-represented in solutions (Butchart et al. 2015). Note that the behavior of this function has changed substantially from versions prior to 5.0.0.

Usage

```r
add_loglinear_targets(
  x,
  lower_bound_amount,
  lower_bound_target,
  upper_bound_amount,
  upper_bound_target,
  cap_amount = NULL,
  cap_target = NULL,
  abundances = feature_abundances(x, na.rm = FALSE)$absolute_abundance
)
```

Arguments

- `x` ConservationProblem-class object.
- `lower_bound_amount` numeric threshold.
- `lower_bound_target` numeric relative target that should be applied to features with a total amount that is less than or equal to `lower_bound_amount`.
- `upper_bound_amount` numeric threshold.
- `upper_bound_target` numeric relative target that should be applied to features with a total amount that is greater than or equal to `upper_bound_amount`.
- `cap_amount` numeric total amount at which targets should be capped. Defaults to NULL so that targets are not capped.
- `cap_target` numeric amount-based target to apply to features which have a total amount greater than argument to `cap_amount`. Defaults to NULL so that targets are not capped.
- `abundances` numeric total amount of each feature to use when calculating the targets. Defaults to the feature abundances in the study area (calculated using the `feature_abundances` function).
Details

Targets are used to specify the minimum amount or proportion of a feature’s distribution that needs to be protected. All conservation planning problems require adding targets with the exception of the maximum cover problem (see `add_max_cover_objective`), which maximizes all features in the solution and therefore does not require targets.

Seven parameters are used to calculate the targets: `lower_bound_amount` specifies the first range size threshold, `lower_bound_target` specifies the relative target required for species with a range size equal to or less than the first threshold, `upper_bound_amount` specifies the second range size threshold, `upper_bound_target` specifies the relative target required for species with a range size equal to or greater than the second threshold, `cap_amount` specifies the third range size threshold, `cap_target` specifies the absolute target that is uniformly applied to species with a range size larger than that third threshold, and finally `abundances` specifies the range size for each feature that should be used when calculating the targets.

Note that the target calculations do not account for the size of each planning unit. Therefore, the feature data should account for the size of each planning unit if this is important (e.g. pixel values in the argument to `features` in the function `problem` could correspond to amount of land occupied by the feature in km² units).

This function can only be applied to `ConservationProblem-class` objects that are associated with a single zone.

Value

`ConservationProblem-class` object with the targets added to it.

References


See Also

`targets`, `loglinear_interpolation`.

Examples

```r
# load data
data(sim_pu_raster, sim_features)

# create problem using loglinear targets
p <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_loglinear_targets(10, 0.9, 100, 0.2) %>%
  add_binary_decisions()
```
# solve problem
s <- solve(p)

# plot solution
plot(s, main = "solution", axes = FALSE, box = FALSE)

---

**add_lpsymphony_solver**  
*Add a SYMPHONY solver with lpsymphony*

**Description**

Specify that the SYMPHONY software should be used to solve a conservation planning problem using the lpsymphony package. This function can also be used to customize the behavior of the solver. It requires the lpsymphony package.

**Usage**

```r
add_lpsymphony_solver(
  x,
  gap = 0.1,
  time_limit = -1,
  first_feasible = 0,
  verbose = TRUE
)
```

**Arguments**

- **x**  
  ConservationProblem-class object.

- **gap**  
  numeric gap to optimality. This gap is absolute and expresses the acceptable deviance from the optimal objective. For example, solving a minimum set objective problem with a gap of 5 will cause the solver to terminate when the cost of the solution is within 5 cost units from the optimal solution.

- **time_limit**  
  numeric time limit in seconds to run the optimizer. The solver will return the current best solution when this time limit is exceeded.

- **first_feasible**  
  logical should the first feasible solution be returned? If first_feasible is set to TRUE, the solver will return the first solution it encounters that meets all the constraints, regardless of solution quality. Note that the first feasible solution is not an arbitrary solution, rather it is derived from the relaxed solution, and is therefore often reasonably close to optimality.

- **verbose**  
  logical should information be printed while solving optimization problems? Defaults to TRUE.
Details

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 lpsymphony package is distributed through Bioconductor. This functionality is provided because the lpsymphony package may be easier to install to install on Windows and Mac OSX systems than the Rsymphony package.

Value

ConservationProblem-class object with the solver added to it.

See Also

solvers.

Examples

# load data
data(sim_pu_raster, sim_features)

# create problem
p <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions()

# if the package is installed then add solver and generate solution
# note that this solver is skipped on Linux systems due to the fact
# that the lpsymphony package randomly crashes on these systems
if (require(lpsymphony) &
  isTRUE(Sys.info()[["sysname"]]) != "Linux") {
  # specify solver and generate solution
  s <- p %>%
  add_lpsymphony_solver(time_limit = 5) %>%
  solve()

  # plot solutions
  plot(stack(sim_pu_raster, s), main = c("planning units", "solution"))
}

Description

Add mandatory allocation constraints

This function can only be used with problems that contain multiple zones.
## add_mandatory_allocation_constraints

**Usage**

```r
## S4 method for signature 'ConservationProblem'
add_mandatory_allocation_constraints(x)
```

**Arguments**

- `x`  
  ConservationProblem-class object.

**Details**

For a conservation planning problem with multiple management zones, it may sometimes be desirable to obtain a solution that assigns each and every single planning unit to a zone. For example, when developing land-use plans, some decision makers may require that each and every single parcel of land has been allocated a specific land-use type. In other words are no "left over" areas. Although it might seem tempting to simply solve the problem and manually assign "left over" planning units to a default zone afterwards (e.g. an "other", "urban", or "grazing" land-use), this could result in highly sub-optimal solutions if there penalties for siting the default land-use adjacent to other zones. Instead, this function can be used to specify that all planning units in a problem with multiple zones must be allocated to a management zone (i.e. zone allocation is mandatory).

**Value**

ConservationProblem-class object with the constraints added to it.

**See Also**

constraints.

**Examples**

```r
# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_zones_stack, sim_features_zones)

# create multi-zone problem with minimum set objective
targets_matrix <- matrix(rpois(15, 1), nrow = 5, ncol = 3)

# create minimal problem with minimum set objective
p1 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
    add_min_set_objective() %>%
    add_absolute_targets(targets_matrix) %>%
    add_binary_decisions()

# create another problem that is the same as p1, but has constraints
# to mandate that every planning unit in the solution is assigned to
# zone
p2 <- p1 %>% add_mandatory_allocation_constraints()

# solve problems
```
add_manual_bounded_constraints

Add manually specified bounds constraints

Description

Add constraints to a conservation planning problem to ensure that the planning unit values (e.g. proportion, binary) in a solution range between specific lower and upper bounds. This function offers more fine-grained control than the add_manual_locked_constraints function and is most useful for problems involving proportion-type or semi-continuous decisions.

Usage

add_manual_bounded_constraints(x, data)

## S4 method for signature 'ConservationProblem, data.frame'
add_manual_bounded_constraints(x, data)

## S4 method for signature 'ConservationProblem, tbl_df'
add_manual_bounded_constraints(x, data)

Arguments

x ConservationProblem-class object.
data data.frame or tibble object. See the Details section for more information.

Details

The argument to data must contain the following fields (columns):

"pu" integer planning unit identifier.
"zone" character names of zones. Note that this argument is optional for arguments to x that contain a single zone.
"lower" numeric values indicating the minimum value that each planning unit can be allocated to in each zone in the solution.
"upper" numeric values indicating the maximum value that each planning unit can be allocated to in each zone in the solution.

Value

ConservationProblem-class object with the constraints added to it.

See Also

constraints.

Examples

```r
# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_polygons, sim_features, sim_pu_zones_polygons, sim_features_zones)

# create minimal problem
p1 <- problem(sim_pu_polygons, sim_features, "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions()

# create problem with locked in constraints using add_locked_constraints
p2 <- p1 %>% add_locked_in_constraints("locked_in")

# create identical problem using add_manual_bounded_constraints
bounds_data <- data.frame(pu = which(sim_pu_polygons$locked_in),
  lower = 1, upper = 1)
p3 <- p1 %>% add_manual_bounded_constraints(bounds_data)

# solve problems
s1 <- solve(p1)
s2 <- solve(p2)
s3 <- solve(p3)

# plot solutions
par(mfrow = c(1,3), mar = c(0, 0, 4.1, 0))
plot(s1, main = "none locked in")
plot(s1[s1$solution_1 == 1, ], col = "darkgreen", add = TRUE)
plot(s2, main = "add_locked_in_constraints")
plot(s2[s2$solution_1 == 1, ], col = "darkgreen", add = TRUE)
plot(s3, main = "add_bounds_constraints")
plot(s3[s3$solution_1 == 1, ], col = "darkgreen", add = TRUE)

# create minimal problem with multiple zones
```
p4 <- problem(sim_pu_zones_polygons, sim_features_zones, c("cost_1", "cost_2", "cost_3")) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5, ncol = 3)) %>%
  add_binary_decisions()

# create data.frame with the following constraints:
# planning units 1, 2, and 3 must be allocated to zone 1 in the solution
# planning units 4, and 5 must be allocated to zone 2 in the solution
# planning units 8 and 9 must not be allocated to zone 3 in the solution
bounds_data2 <- data.frame(pu = c(1, 2, 3, 4, 5, 8, 9),
    zone = c(rep("zone_1", 3), rep("zone_2", 2),
    rep("zone_3", 2)),
    lower = c(rep(1, 5), rep(0, 2)),
    upper = c(rep(1, 5), rep(0, 2)))

# print bounds data
print(bounds_data2)

# create problem with added constraints
p5 <- p4 %>% add_manual_bounded_constraints(bounds_data2)

# solve problem
s4 <- solve(p4)
s5 <- solve(p5)

# create two new columns representing the zone id that each planning unit
# was allocated to in the two solutions
s4$solution <- category_vector(s4$data[, c("solution_1_zone_1",
   "solution_1_zone_2",
   "solution_1_zone_3")])
s4$solution <- factor(s4$solution)

s4$solution_bounded <- category_vector(s5$data[, c("solution_1_zone_1",
   "solution_1_zone_2",
   "solution_1_zone_3")])
s4$solution_bounded <- factor(s4$solution_bounded)

# plot solutions
spplot(s4, zcol = c("solution", "solution_bounded"), axes = FALSE,
   box = FALSE)
Description

Add constraints to a conservation planning problem to ensure that solutions allocate (or do not allocate) specific planning units to specific management zones. This function offers more fine-grained control than the `add_locked_in_constraints` and `add_locked_out_constraints` functions.

Usage

```r
add_manual_locked_constraints(x, data)
```

## S4 method for signature 'ConservationProblem, data.frame'
```r
add_manual_locked_constraints(x, data)
```

## S4 method for signature 'ConservationProblem, tbl_df'
```r
add_manual_locked_constraints(x, data)
```

Arguments

- `x`: ConservationProblem-class object.
- `data`: data.frame or tibble object. See the Details section for more information.

Details

The argument to data must contain the following fields (columns):

- "pu" integer planning unit identifier.
- "zone" character names of zones. Note that this argument is optional for arguments to `x` that contain a single zone.
- "status" numeric values indicating how much of each planning unit should be allocated to each zone in the solution. For example, the numeric values could be binary values (i.e. zero or one) for problems containing binary-type decision variables (using the `add_binary_decisions` function). Alternatively, the numeric values could be proportions (e.g. 0.5) for problems containing proportion-type decision variables (using the `add_proportion_decisions`).

Value

ConservationProblem-class object with the constraints added to it.

See Also

`constraints`.

Examples

```r
# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_polygons, sim_features, sim_pu_zones_polygons,
    sim_features_zones)
```
# create minimal problem
p1 <- problem(sim_pu_polygons, sim_features, "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions()

# create problem with locked in constraints using add_locked_constraints
p2 <- p1 %>% add_locked_in_constraints("locked_in")

# create identical problem using add_manual_locked_constraints
locked_data <- data.frame(pu = which(sim_pu_polygons$locked_in),
                           status = 1)
p3 <- p1 %>% add_manual_locked_constraints(locked_data)

# solve problems
s1 <- solve(p1)
s2 <- solve(p2)
s3 <- solve(p3)

# plot solutions
par(mfrow = c(1, 3), mar = c(0, 0, 4.1, 0))
plot(s1, main = "none locked in")
plot(s1[s1$solution_1 == 1, ], col = "darkgreen", add = TRUE)
plot(s2, main = "add_locked_in_constraints")
plot(s2[s2$solution_1 == 1, ], col = "darkgreen", add = TRUE)
plot(s3, main = "add_manual_constraints")
plot(s3[s3$solution_1 == 1, ], col = "darkgreen", add = TRUE)

# create minimal problem with multiple zones
p4 <- problem(sim_pu_zones_polygons, sim_features_zones,
              c("cost_1", "cost_2", "cost_3")) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5,
                               ncol = 3)) %>%
  add_binary_decisions()

# create data.frame with the following constraints:
# planning units 1, 2, and 3 must be allocated to zone 1 in the solution
# planning units 4 and 5 must be allocated to zone 2 in the solution
# planning units 8 and 9 must not be allocated to zone 3 in the solution
locked_data2 <- data.frame(pu = c(1, 2, 3, 4, 5, 8, 9),
                           zone = c(rep("zone_1", 3), rep("zone_2", 2),
                                   rep("zone_3", 2)),
                           status = c(rep(1, 5), rep(0, 2)))

# print locked constraint data
print(locked_data2)

# create problem with added constraints
p5 <- p4 %>% add_manual_locked_constraints(locked_data2)

# solve problem
s4 <- solve(p4)
s5 <- solve(p5)

# create two new columns representing the zone id that each planning unit
# was allocated to in the two solutions
s4$solution <- category_vector(s4@data[, c("solution_1_zone_1",
    "solution_1_zone_2",
    "solution_1_zone_3")])
s4$solution <- factor(s4$solution)

s4$solution_locked <- category_vector(s5@data[, c("solution_1_zone_1",
    "solution_1_zone_2",
    "solution_1_zone_3")])
s4$solution_locked <- factor(s4$solution_locked)

# plot solutions
spplot(s4, zcol = c("solution", "solution_locked"), axes = FALSE,
    box = FALSE)

---

add_manual_targets  
Add manual targets

Description

Set targets for a conservation planning problem by manually specifying all the required information for each target. This function is useful because it can be used to customize all aspects of a target. For most cases, targets can be specified using the link{add_absolute_targets} and add_relative_targets functions. However, this function can be used to (i) mix absolute and relative targets for different features and zones, (ii) set targets that pertain to the allocations of planning units in multiple zones, and (iii) set targets that require different senses (e.g. targets which specify the solution should not exceed a certain quantity using "\(\leq\)" values).

Usage

add_manual_targets(x, targets)

## S4 method for signature 'ConservationProblem,data.frame'
add_manual_targets(x, targets)

## S4 method for signature 'ConservationProblem,tbl_df'
add_manual_targets(x, targets)

Arguments

x  ConservationProblem-class object.

targets  data.frame or tibble object. See the Details section for more information.
Details

Targets are used to specify the minimum amount or proportion of a feature’s distribution that needs to be protected. Most conservation planning problems require targets with the exception of the maximum cover (see \texttt{add_max_cover_objective}) and maximum utility (see \texttt{add_max_utility_objective}) problems. Attempting to solve problems with objectives that require targets without specifying targets will throw an error.

The targets argument should contain the following fields (columns):

"feature" character name of features in argument to \texttt{x}.

"zone" character name of zones in argument to \texttt{x}. This field (column) is optional for arguments to \texttt{x} that do not contain multiple zones.

"type" character describing the type of target. Acceptable values include "absolute" and "relative". These values correspond to \texttt{add_absolute_targets} and \texttt{add_relative_targets} respectively.

"sense" character sense of the target. Acceptable values include: ">=" , "<=" , and "=". This field (column) is optional and if it is missing then target senses will default to ">=" values.

"target" numeric target threshold.

Value

\texttt{ConservationProblem-class} object with the targets added to it.

See Also

\texttt{targets}.

Examples

```r
# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_raster, sim_features, sim_pu_zones_stack, sim_features_zones)

# create problem with 10 % relative targets
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions()

# solve problem
s1 <- solve(p1)

# plot solution
plot(s1, main = "solution", axes = FALSE, box = FALSE)

# create equivalent problem using add_manual_targets
p2 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_manual_targets()
```
add_manual_targets(data.frame(feature = names(sim_features),
    type = "relative", sense = ">=",
    target = 0.1)) %>%

add_binary_decisions()

# solve problem
s2 <- solve(p2)

# plot solution
plot(s2, main = "solution", axes = FALSE, box = FALSE)

# create problem with targets set for only a few features
p3 <- problem(sim_pu_raster, sim_features) %>%
    add_min_set_objective() %>%
    add_manual_targets(data.frame(
        feature = names(sim_features)[1:3], type = "relative",
        sense = ">=",
        target = 0.1)) %>%
    add_binary_decisions()

# solve problem
s3 <- solve(p3)

# plot solution
plot(s3, main = "solution", axes = FALSE, box = FALSE)

# create problem that aims to secure at least 10 % of the habitat for one
# feature whilst ensuring that the solution does not capture more than
# 20 units habitat for different feature
# create problem with targets set for only a few features
p4 <- problem(sim_pu_raster, sim_features[[1:2]]) %>%
    add_min_set_objective() %>%
    add_manual_targets(data.frame(
        feature = names(sim_features)[1:2], type = "relative",
        sense = c("="),
        target = c(0.1, 0.2))) %>%
    add_binary_decisions()

# solve problem
s4 <- solve(p4)

# plot solution
plot(s4, main = "solution", axes = FALSE, box = FALSE)

# create a multi-zone problem that requires a specific amount of each
# feature in each zone
targets_matrix <- matrix(rpois(15, 1), nrow = 5, ncol = 3)

p5 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
    add_min_set_objective() %>%
    add_absolute_targets(targets_matrix) %>%
    add_binary_decisions()

# solve problem
s5 <- solve(p5)
# plot solution
plot(category_layer(s5), main = "solution", axes = FALSE, box = FALSE)

# create equivalent problem using add_manual_targets
targets_dataframe <- expand.grid(feature = feature_names(sim_features_zones),
                      zone = zone_names(sim_features_zones),
                      sense = ">=",
                      type = "absolute")
targets_dataframe$target <- c(targets_matrix)
p6 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>%
  add_manual_targets(targets_dataframe) %>%
  add_binary_decisions()

# solve problem
s6 <- solve(p6)

# plot solution
plot(category_layer(s6), main = "solution", axes = FALSE, box = FALSE)

# create a problem that requires a total of 20 units of habitat to be
# captured for two species. This can be achieved through representing
# habitat in two zones. The first zone represents a full restoration of the
# habitat and a second zone represents a partial restoration of the habitat
# Thus only half of the benefit that would have been gained from the full
# restoration is obtained when planning units are allocated a partial
# restoration

# create data
spp_zone1 <- as.list(sim_features_zones)[[1]][[1:2]]
spp_zone2 <- spp_zone1 * 0.5
costs <- sim_pu_zones_stack[[1:2]]

# create targets
targets_dataframe2 <- tibble::tibble(
  feature = names(spp_zone1),
  zone = list(c("z1", "z2"), c("z1", "z2")),
  sense = c("="),
  type = c("absolute", "absolute"),
  target = c(20, 20))

# create problem
p7 <- problem(costs, zones(spp_zone1, spp_zone2,
  feature_names = names(spp_zone1),
  zone_names = c("z1", "z2"))) %>%
  add_min_set_objective() %>%
  add_manual_targets(targets_dataframe2) %>%
  add_binary_decisions()

# solve problem
s7 <- solve(p7)

# plot solution
plot(category_layer(s7), main = "solution", axes = FALSE, box = FALSE)
add_max_cover_objective

Add maximum coverage objective

Description

Set the objective of a conservation planning problem to represent at least one instance of as many features as possible within a given budget. This type of objective does not use targets, and feature weights should be used instead to increase the representation of different features in solutions. **Note that the mathematical formulation underpinning this function is different from versions prior to 3.0.0.0.** See the Details section for more information on the changes since this version.

Usage

add_max_cover_objective(x, budget)

Arguments

- x: ConservationProblem-class object.
- budget: numeric value specifying the maximum expenditure of the prioritization. For problems with multiple zones, the argument to budget can be a single numeric value to specify a budget for the entire solution or a numeric vector to specify a budget for each each management zone.

Details

A problem objective is used to specify the overall goal of the conservation planning problem. Please note that all conservation planning problems formulated in the prioritizr package require the addition of objectives—failing to do so will return an error message when attempting to solve problem.

The maximum coverage objective seeks to find the set of planning units that maximizes the number of represented features, while keeping cost within a fixed budget. Here, features are treated as being represented if the reserve system contains at least a single instance of a feature (i.e. an amount greater than 1). This formulation has often been used in conservation planning problems dealing with binary biodiversity data that indicate the presence/absence of suitable habitat (e.g. Church & Velle 1974). Additionally, weights can be used to favor the representation of certain features over other features (see add_feature_weights). Check out the add_max_features_objective for a more generalized formulation which can accommodate user-specified representation targets.

This formulation is based on the historical maximum coverage reserve selection formulation (Church & Velle 1974; Church et al. 1996). The maximum coverage objective for the reserve design problem can be expressed mathematically for a set of planning units (\(I\) indexed by \(i\)) and a set of features (\(J\) indexed by \(j\)) as:

\[
\text{Maximize} \sum_{i=1}^{I} -sc_i x_i + \sum_{j=1}^{J} y_j w_j \quad \text{subject to} \quad \sum_{i=1}^{I} x_{ij} r_{ij} \geq y_j \times 1 \forall j \in J \sum_{i=1}^{I} x_i c_i \leq B
\]
Here, \( x_i \) is the \texttt{decisions} variable (e.g. specifying whether planning unit \( i \) has been selected (1) or not (0)), \( r_{ij} \) is the amount of feature \( j \) in planning unit \( i \), \( y_j \) indicates if the solution has meet the target \( t_j \) for feature \( j \), and \( w_j \) is the weight for feature \( j \) (defaults to 1 for all features; see \texttt{add_feature_weights} to specify weights). Additionally, \( B \) is the budget allocated for the solution, \( c_i \) is the cost of planning unit \( i \), and \( s \) is a scaling factor used to shrink the costs so that the problem will return a cheapest solution when there are multiple solutions that represent the same amount of all features within the budget.

Note that this formulation is functionally equivalent to the \texttt{add_max_features_objective} function with absolute targets set to 1. Please note that in versions prior to 3.0.0.0, this objective function implemented a different mathematical formulation. To the \texttt{add_max_utility_objective} function.

\textbf{Value}

A \texttt{ConservationProblem-class} object with the objective added to it.

\textbf{References}


\textbf{See Also}

\texttt{add_feature_weights}, \texttt{objectives}.

\textbf{Examples}

```r
# load data
data(sim_pu_raster, sim_pu_zones_stack, sim_features, sim_features_zones)

# threshold the feature data to generate binary biodiversity data
sim_binary_features <- sim_features
thresholds <- raster::quantile(sim_features, probs = 0.95, names = FALSE, na.rm = TRUE)
for (i in seq_len(raster::nlayers(sim_features)))
  sim_binary_features[[i]] <- as.numeric(raster::values(sim_features[[i]]) > thresholds[[i]])

# create problem with maximum utility objective
p1 <- problem(sim_pu_raster, sim_binary_features) %>%
  add_max_cover_objective(500) %>%
  add_binary_decisions()

# solve problem
s1 <- solve(p1)

# plot solution
plot(s1, main = "solution", axes = FALSE, box = FALSE)
```
# threshold the multi-zone feature data to generate binary biodiversity data
sim_binary_features_zones <- sim_features_zones
for (z in number_of_zones(sim_features_zones)) {
  thresholds <- raster::quantile(sim_features_zones[z], probs = 0.95,
                                names = FALSE, na.rm = TRUE)
  for (i in seq_len(number_of_features(sim_features_zones))) {
    sim_binary_features_zones[z][i] <- as.numeric(
      raster::values(sim_features_zones[z][i]) > thresholds[i])
  }
}

# create multi-zone problem with maximum utility objective that
# has a single budget for all zones
p2 <- problem(sim_pu_zones_stack, sim_binary_features_zones) %>%
  add_max_cover_objective(800) %>%
  add_binary_decisions()

# solve problem
s2 <- solve(p2)

# plot solution
plot(category_layer(s2), main = "solution", axes = FALSE, box = FALSE)

# create multi-zone problem with maximum utility objective that
# has separate budgets for each zone
p3 <- problem(sim_pu_zones_stack, sim_binary_features_zones) %>%
  add_max_cover_objective(c(400, 400, 400)) %>%
  add_binary_decisions()

# solve problem
s3 <- solve(p3)

# plot solution
plot(category_layer(s3), main = "solution", axes = FALSE, box = FALSE)

---

add_max_features_objective

*Add maximum feature representation objective*

**Description**

Set the objective of a conservation planning problem to fulfill as many targets as possible while ensuring that the cost of the solution does not exceed a budget.

**Usage**

add_max_features_objective(x, budget)
**Arguments**

- **x**: ConservationProblem-class object.
- **budget**: numeric value specifying the maximum expenditure of the prioritization. For problems with multiple zones, the argument to budget can be a single numeric value to specify a budget for the entire solution or a numeric vector to specify a budget for each management zone.

**Details**

A problem objective is used to specify the overall goal of the conservation planning problem. Please note that all conservation planning problems formulated in the prioritizr package require the addition of objectives—failing to do so will return an error message when attempting to solve problem.

The maximum feature representation objective is an enhanced version of the maximum coverage objective `add_max_cover_objective` because targets can be used to ensure that a certain amount of each feature is required in order for them to be adequately represented (similar to the minimum set objective (see `add_min_set_objective`). This objective finds the set of planning units that meets representation targets for as many features as possible while staying within a fixed budget (inspired by Cabeza and Moilanen 2001). Additionally, weights can be used `add_feature_weights`). If multiple solutions can meet the same number of weighted targets while staying within budget, the cheapest solution is returned.

The maximum feature objective for the reserve design problem can be expressed mathematically for a set of planning units ($I$ indexed by $i$) and a set of features ($J$ indexed by $j$) as:

$$
\text{Maximize} \sum_{i=1}^{I} -sc_i x_i + \sum_{j=1}^{J} \text{y}_j w_j \text{subject to} \sum_{i=1}^{I} x_i r_{ij} \geq y_j t_j \forall j \in J \sum_{i=1}^{I} x_i c_i \leq B
$$

Here, $x_i$ is the decisions variable (e.g. specifying whether planning unit $i$ has been selected (1) or not (0)), $r_{ij}$ is the amount of feature $j$ in planning unit $i$, $t_j$ is the representation target for feature $j$, $y_j$ indicates if the solution has meet the target $t_j$ for feature $j$, and $w_j$ is the weight for feature $j$ (defaults to 1 for all features; see `add_feature_weights` to specify weights). Additionally, $B$ is the budget allocated for the solution, $c_i$ is the cost of planning unit $i$, and $s$ is a scaling factor used to shrink the costs so that the problem will return a cheapest solution when there are multiple solutions that represent the same amount of all features within the budget.

**Value**

ConservationProblem-class object with the objective added to it.

**References**


**See Also**

`add_feature_weights`, `objectives`.
Examples

```r
# load data
data(sim_pu_raster, sim_pu_zones_stack, sim_features, sim_features_zones)

# create problem with maximum features objective
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_max_features_objective(1800) %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions()

# solve problem
s1 <- solve(p1)

# plot solution
plot(s1, main = "solution", axes = FALSE, box = FALSE)

# create multi-zone problem with maximum features objective,
# with 10 % representation targets for each feature, and set
# a budget such that the total maximum expenditure in all zones
# cannot exceed 3000
p2 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_max_features_objective(3000) %>%
  add_relative_targets(matrix(0.1, ncol = 3, nrow = 5)) %>%
  add_binary_decisions()

# solve problem
s2 <- solve(p2)

# plot solution
plot(category_layer(s2), main = "solution", axes = FALSE, box = FALSE)

# create multi-zone problem with maximum features objective,
# with 10 % representation targets for each feature, and set
# separate budgets for each management zone
p3 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_max_features_objective(c(3000, 3000, 3000)) %>%
  add_relative_targets(matrix(0.1, ncol = 3, nrow = 5)) %>%
  add_binary_decisions()

# solve problem
s3 <- solve(p3)

# plot solution
plot(category_layer(s3), main = "solution", axes = FALSE, box = FALSE)
```

---

`add_max_phylo_div_objective`

*Add maximum phylogenetic diversity objective*
Description

Set the objective of a conservation planning problem to maximize the phylogenetic diversity of the species represented in the solution subject to a budget. This objective is similar to the maximum features objective except that emphasis is placed on representing a phylogenetically diverse set of species, rather than as many features as possible (subject to weights). This function was inspired by Faith (1992) and Rodrigues et al. (2002).

Usage

```r
add_max_phylo_div_objective(x, budget, tree)
```

Arguments

- **x**: ConservationProblem-class object.
- **budget**: numeric value specifying the maximum expenditure of the prioritization. For problems with multiple zones, the argument to budget can be a single numeric value to specify a budget for the entire solution or a numeric vector to specify a budget for each each management zone.
- **tree**: phylo object specifying a phylogenetic tree for the conservation features.

Details

A problem objective is used to specify the overall goal of the conservation planning problem. Please note that all conservation planning problems formulated in the prioritizr package require the addition of objectives—failing to do so will return an error message when attempting to solve problem.

The maximum phylogenetic diversity objective finds the set of planning units that meets representation targets for a phylogenetic tree while staying within a fixed budget. If multiple solutions can meet all targets while staying within budget, the cheapest solution is chosen. Note that this objective is similar to the maximum features objective in that it allows for both a budget and targets to be set for each feature. However, unlike the maximum feature objective, the aim of this objective is to maximize the total phylogenetic diversity of the targets met in the solution, so if multiple targets are provided for a single feature, the problem will only need to meet a single target for that feature for the phylogenetic benefit for that feature to be counted when calculating the phylogenetic diversity of the solution. In other words, for multi-zone problems, this objective does not aim to maximize the phylogenetic diversity in each zone, but rather this objective aims to maximize the phylogenetic diversity of targets that can be met through allocating planning units to any of the different zones in a problem. This can be useful for problems where targets pertain to the total amount held for each feature across multiple zones. For example, each feature might have a non-zero amount of suitable habitat in each planning unit when the planning units are assigned to a (i) not restored, (ii) partially restored, or (iii) completely restored management zone. Here each target corresponds to a single feature and can be met through the total amount of habitat in planning units present to the three zones. In earlier versions of the prioritizr package, this function was named add_max_phylo_div_objective.

The maximum phylogenetic diversity objective for the reserve design problem can be expressed mathematically for a set of planning units ($I$ indexed by $i$) and a set of features ($J$ indexed by $j$) as:

$$
\text{Maximize } \sum_{i=1}^{I} -sc_ix_i + \sum_{j=1}^{J} m_bl_b \text{subject to } \sum_{i=1}^{I} x_i r_{ij} \geq y_j \forall j \in Jm_b \leq y_j \forall j \in T(b) \sum_{i=1}^{I} x_ic_i \leq B
$$
Here, $x_i$ is the **decisions** variable (e.g., specifying whether planning unit $i$ has been selected (1) or not (0)), $r_{ij}$ is the amount of feature $j$ in planning unit $i$, $t_j$ is the representation target for feature $j$, $y_j$ indicates if the solution has meet the target $t_j$ for feature $j$. Additionally, $T$ represents a phylogenetic tree containing features $j$ and has the branches $b$ associated within lengths $l_b$. The binary variable $m_b$ denotes if at least one feature associated with the branch $b$ has met its representation as indicated by $y_j$. For brevity, we denote the features $j$ associated with branch $b$ using $T(b)$. Finally, $B$ is the budget allocated for the solution, $c_i$ is the cost of planning unit $i$, and $s$ is a scaling factor used to shrink the costs so that the problem will return a cheapest solution when there are multiple solutions that represent the same amount of all features within the budget.

**Value**

ConservationProblem-class object with the objective added to it.

**References**


**See Also**

objectives, branch_matrix.

**Examples**

```r
# load ape package
require(ape)

# load data
data(sim_pu_raster, sim_features, sim_phylogeny, sim_pu_zones_stack,
     sim_features_zones)

# plot the simulated phylogeny
par(mfrow = c(1, 1))
plot(sim_phylogeny, main = "phylogeny")

# create problem with a maximum phylogenetic diversity objective,
# it to be adequately conserved and a total budget of 1900
p1 <- problem(sim_pu_raster, sim_features) %>%
    add_max_phylo_div_objective(1900, sim_phylogeny) %>%
    add_relative_targets(0.1) %>%
    add_binary_decisions()

# solve problem
s1 <- solve(p1)

# plot solution
```
plot(s1, main = "solution", axes = FALSE, box = FALSE)

# find which features have their targets met
r1 <- feature_representation(p1, s1)
r1$target_met <- r1$relative_held > 0.1
print(r1)

# plot the phylogeny and color the adequately represented features in red
plot(sim_phylogeny, main = "adequately represented features",
tip.color = replace(
  rep("black", nlayers(sim_features)),
sim_phylogeny$tip.label %in% r1$feature[r1$target_met],
  "red"))

# rename the features in the example phylogeny for use with the
# multi-zone data
sim_phylogeny$tip.label <- feature_names(sim_features_zones)

# create targets for a multi-zone problem. Here, each feature needs a total
# of 10 units of habitat to be conserved among the three zones to be
# considered adequately conserved
targets <- tibble::tibble(
  feature = feature_names(sim_features_zones),
  zone = list(zone_names(sim_features_zones))[rep(1,
    number_of_features(sim_features_zones))],
  type = rep("absolute", number_of_features(sim_features_zones)),
  target = rep(10, number_of_features(sim_features_zones)))

# create a multi-zone problem with a maximum phylogenetic diversity
# objective, where the total expenditure in all zones is 5000.
p2 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_max_phylo_div_objective(5000, sim_phylogeny) %>%
  add_manual_targets(targets) %>%
  add_binary_decisions()

# solve problem
s2 <- solve(p2)

# plot solution
plot(category_layer(s2), main = "solution", axes = FALSE, box = FALSE)

# calculate total amount of habitat conserved for each feature among
# all three management zones
amount_held2 <- numeric(number_of_features(sim_features_zones))
for (z in seq_len(number_of_zones(sim_features_zones)))
  amount_held2 <- amount_held2 +
    cellStats(sim_features_zones[[z]] * s2[[z]], "sum")

# find which features have their targets met
targets_met2 <- amount_held2 >= targets$target
print(targets_met2)

# plot the phylogeny and color the adequately represented features in red
add_max_phylo_end_objective

Add maximum phylogenetic endemism objective

Description

Set the objective of a conservation planning problem to maximize the phylogenetic endemism of the features represented in the solution subject to a budget. This objective is similar to `add_max_phylo_end_objective` except that emphasis is placed on representing species with geographically restricted evolutionary histories, instead representing as much evolutionary history as possible. This function was inspired by Faith (1992), Rodrigues et al. (2002), and Rosauer et al. (2009).

Usage

`add_max_phylo_end_objective(x, budget, tree)`
Arguments

- `x`  
  ConservationProblem-class object.
- `budget`  
  numeric value specifying the maximum expenditure of the prioritization. For problems with multiple zones, the argument to `budget` can be a single numeric value to specify a budget for the entire solution or a numeric vector to specify a budget for each each management zone.
- `tree`  
  phylo object specifying a phylogenetic tree for the conservation features.

Details

A problem objective is used to specify the overall goal of the conservation planning problem. Please note that all conservation planning problems formulated in the `prioritizr` package require the addition of objectives—failing to do so will return an error message when attempting to solve problem.

The maximum phylogenetic endemism objective finds the set of planning units that meets representation targets for a phylogenetic tree while staying within a fixed budget. If multiple solutions can meet all targets while staying within budget, the cheapest solution is chosen. Note that this objective is similar to the maximum features objective (`add_max_features_objective`) in that it allows for both a budget and targets to be set for each feature. However, unlike the maximum feature objective, the aim of this objective is to maximize the total phylogenetic endemism of the targets met in the solution, so if multiple targets are provided for a single feature, the problem will only need to meet a single target for that feature for the phylogenetic benefit for that feature to be counted when calculating the phylogenetic endemism of the solution. In other words, for multi-zone problems, this objective does not aim to maximize the phylogenetic endemism in each zone, but rather this objective aims to maximize the phylogenetic endemism of targets that can be met through allocating planning units to any of the different zones in a problem. This can be useful for problems where targets pertain to the total amount held for each feature across multiple zones. For example, each feature might have a non-zero amount of suitable habitat in each planning unit when the planning units are assigned to a (i) not restored, (ii) partially restored, or (iii) completely restored management zone. Here each target corresponds to a single feature and can be met through the total amount of habitat in planning units present to the three zones. In earlier versions of the `prioritizr` package, this function was named `add_max_phylo_end_objective`.

The maximum phylogenetic endemism objective for the reserve design problem can be expressed mathematically for a set of planning units ($I$ indexed by $i$) and a set of features ($J$ indexed by $j$) as:

$$\text{Maximize} \sum_{i=1}^{I} -sc_i x_i + \sum_{j=1}^{J} m_{b} \frac{1}{a_{b}} \text{subject to} \sum_{i=1}^{I} x_i r_{ij} \geq t_j \forall j \in J m_{b} \leq y_j \forall j \in T(b) \sum_{i=1}^{I} x_i c_i \leq B$$

Here, $x_i$ is the decisions variable (e.g. specifying whether planning unit $i$ has been selected (1) or not (0)), $r_{ij}$ is the amount of feature $j$ in planning unit $i$, $t_j$ is the representation target for feature $j$, $y_j$ indicates if the solution has meet the target $t_j$ for feature $j$. Additionally, $T$ represents a phylogenetic tree containing features $j$ and has the branches $b$ associated within lengths $l$. Each branch $b \in B$ is associated with a total amount $a_b$ indicating the total geographic extent or amount of habitat. The $a_b$ variable for a given branch is calculated by summing the $r_{ij}$ data for all features $j \in J$ that are associated with the branch. The binary variable $m_b$ denotes if at least one feature associated with the branch $b$ has met its representation as indicated by $y_j$. For brevity, we denote the features $j$ associated with branch $b$ using $T(b)$. Finally, $B$ is the budget allocated for the solution,
`c[i]` is the cost of planning unit `i`, and `s` is a scaling factor used to shrink the costs so that the problem will return a cheapest solution when there are multiple solutions that represent the same amount of all features within the budget.

**Value**

A `ConservationProblem-class` object with the objective added to it.

**References**


**See Also**

`objectives`, `branch_matrix`.

**Examples**

```r
# load ape package
require(ape)

# load data
data(sim_pu_raster, sim_features, sim_phylogeny, sim_pu_zones_stack, sim_features_zones)

# plot the simulated phylogeny
par(mfrow = c(1, 1))
plot(sim_phylogeny, main = "phylogeny")

# create problem with a maximum phylogenetic endemism objective, where each feature needs 10 % of its distribution to be secured for it to be adequately conserved and a total budget of 1900
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_max_phylo_end_objective(1900, sim_phylogeny) %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions()

# solve problem
s1 <- solve(p1)

# plot solution
plot(s1, main = "solution", axes = FALSE, box = FALSE)

# find which features have their targets met
```
r1 <- feature_representation(p1, s1)
r1$target_met <- r1$relative_held > 0.1
print(r1)

# plot the phylogeny and color the adequately represented features in red
plot(sim_phylogeny, main = "adequately represented features",
    tip.color = replace(
        rep("black", nlayers(sim_features)),
        sim_phylogeny$tip.label %in% r1$feature[r1$target_met],
        "red")

# rename the features in the example phylogeny for use with the
# multi-zone data
sim_phylogeny$tip.label <- feature_names(sim_features_zones)

# create targets for a multi-zone problem. Here, each feature needs a total
# of 10 units of habitat to be conserved among the three zones to be
# considered adequately conserved
targets <- tibble::tibble(
    feature = feature_names(sim_features_zones),
    zone = list(zone_names(sim_features_zones))[rep(1,
        number_of_features(sim_features_zones))],
    type = rep("absolute", number_of_features(sim_features_zones)),
    target = rep(10, number_of_features(sim_features_zones)))

# create a multi-zone problem with a maximum phylogenetic endemism
# objective, where the total expenditure in all zones is 5000.
p2 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
    add_max_phylo_end_objective(5000, sim_phylogeny) %>%
    add_manual_targets(targets) %>%
    add_binary_decisions()

# solve problem
s2 <- solve(p2)

# plot solution
plot(category_layer(s2), main = "solution", axes = FALSE, box = FALSE)

# calculate total amount of habitat conserved for each feature among
# all three management zones
amount_held2 <- numeric(number_of_features(sim_features_zones))
for (z in seq_len(number_of_zones(sim_features_zones)))
    amount_held2 <- amount_held2 +
        cellStats(sim_features_zones[[z]] * s2[[z]], "sum")

# find which features have their targets met
targets_met2 <- amount_held2 >= targets$target
print(targets_met2)

# plot the phylogeny and color the adequately represented features in red
plot(sim_phylogeny, main = "adequately represented features",
    tip.color = replace(rep("black", nlayers(sim_features)),
        which(targets_met2), "red"))
# create a multi-zone problem with a maximum phylogenetic endemism objective, where each zone has a separate budget.

p3 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
    add_max_phylo_end_objective(c(2500, 500, 2000), sim_phylogeny) %>%
    add_manual_targets(targets) %>%
    add_binary_decisions()

# solve problem
s3 <- solve(p3)

# plot solution
plot(category_layer(s3), main = "solution", axes = FALSE, box = FALSE)

# calculate total amount of habitat conserved for each feature among all three management zones
amount_held3 <- numeric(number_of_features(sim_features_zones))
for (z in seq_len(number_of_zones(sim_features_zones)))
    amount_held3 <- amount_held3 +
        cellStats(sim_features_zones[[z]] * s3[[z]], "sum")

# find which features have their targets met
targets_met3 <- amount_held3 >= targets$target
print(targets_met3)

# plot the phylogeny and color the adequately represented features in red
plot(sim_phylogeny, main = "adequately represented features",
     tip.color = replace(rep("black", nlayers(sim_features)),
                      which(targets_met3), "red"))

---

**add_max_utility_objective**

*Add maximum utility objective*

**Description**

Set the objective of a conservation planning problem to secure as much of the features as possible without exceeding a budget. This type of objective does not use targets, and feature weights should be used instead to increase the representation of different features in solutions. Note that this objective does not aim to maximize as much of each feature as possible and so often results in solutions that are heavily biased towards specific features.

**Usage**

```
add_max_utility_objective(x, budget)
```
Arguments

- **x**: `ConservationProblem-class` object.
- **budget**: numeric value specifying the maximum expenditure of the prioritization. For problems with multiple zones, the argument to budget can be a single numeric value to specify a budget for the entire solution or a numeric vector to specify a budget for each each management zone.

Details

A problem objective is used to specify the overall goal of the conservation planning problem. Please note that all conservation planning problems formulated in the `prioritizr` package require the addition of objectives—failing to do so will return an error message when attempting to solve problem.

The maximum utility objective seeks to find the set of planning units that maximizes the overall level of representation across a suite of conservation features, while keeping cost within a fixed budget. Additionally, weights can be used to favor the representation of certain features over other features (see `add_feature_weights`). This objective can be expressed mathematically for a set of planning units ($I$ indexed by $i$) and a set of features ($J$ indexed by $j$) as:

$$\text{Maximize } \sum_{i=1}^{I} -sc_i x_i + \sum_{j=1}^{J} a_j w_j \sum_{i=1}^{I} x_i r_{ij} \text{ subject to } \sum_{i=1}^{I} x_i c_i \leq B$$

Here, $x_i$ is the decisions variable (e.g., specifying whether planning unit $i$ has been selected (1) or not (0)), $r_{ij}$ is the amount of feature $j$ in planning unit $i$, $A_j$ is the amount of feature $j$ represented in the solution, and $w_j$ is the weight for feature $j$ (defaults to 1 for all features; see `add_feature_weights` to specify weights). Additionally, $B$ is the budget allocated for the solution, $c_i$ is the cost of planning unit $i$, and $s$ is a scaling factor used to shrink the costs so that the problem will return a cheapest solution when there are multiple solutions that represent the same amount of all features within the budget.

Please note that in versions prior to 3.0.0.0, this objective function was implemented in the `add_max_cover_objective` but has since been renamed as `add_max_utility_objective` to avoid confusion with historical formulations of the maximum coverage problem.

Value

`ConservationProblem-class` object with the objective added to it.

See Also

`add_feature_weights`, `objectives`.

Examples

```r
# load data
data(sim_pu_raster, sim_pu_zones_stack, sim_features, sim_features_zones)

# create problem with maximum utility objective
p1 <- problem(sim_pu_raster, sim_features) %>%
```
add_min_set_objective

Description

Set the objective of a conservation planning problem to minimize the cost of the solution whilst ensuring that all targets are met. This objective is similar to that used in Marxan and is detailed in Rodrigues et al. (2000).

Usage

add_min_set_objective(x)
Arguments

x ConservationProblem-class object.

Details

A problem objective is used to specify the overall goal of the conservation planning problem. Please note that all conservation planning problems formulated in the prioritizr package require the addition of objectives—failing to do so will return an error message when attempting to solve problem.

In the context of systematic reserve design, the minimum set objective seeks to find the set of planning units that minimizes the overall cost of a reserve network, while meeting a set of representation targets for the conservation features. This objective is equivalent to a simplified Marxan reserve design problem with the Boundary Length Modifier (BLM) set to zero.

The minimum set objective for the reserve design problem can be expressed mathematically for a set of planning units (\( I \) indexed by \( i \)) and a set of features (\( J \) indexed by \( j \)) as:

\[
\text{Minimize} \sum_{i=1}^{I} x_i c_i \text{subject to} \sum_{i=1}^{I} x_i r_{ij} \geq T_j \forall j \in J
\]

Here, \( x_i \) is the decisions variable (e.g. specifying whether planning unit \( i \) has been selected (1) or not (0)), \( c_i \) is the cost of planning unit \( i \), \( r_{ij} \) is the amount of feature \( j \) in planning unit \( i \), and \( T_j \) is the target for feature \( j \). The first term is the objective function and the second is the set of constraints. In words this says find the set of planning units that meets all the representation targets while minimizing the overall cost.

Value

ConservationProblem-class object with the objective added to it.

References


See Also

objectives, targets.

Examples

```r
# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_raster, sim_features, sim_pu_zones_stack, sim_features_zones)

# create minimal problem with minimum set objective
p1 <- problem(sim_pu_raster, sim_features) %>%
    add_min_set_objective()
```
add_min_shortfall_objective

    add_relative_targets(0.1) %>%
    add_binary_decisions()

    # solve problem
    s1 <- solve(p1)

    # plot solution
    plot(s1, main = "solution", axes = FALSE, box = FALSE)

    # create multi-zone problem with minimum set objective
    targets_matrix <- matrix(rpois(15, 1), nrow = 5, ncol = 3)
    p2 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
    add_min_set_objective() %>%
    add_absolute_targets(targets_matrix) %>%
    add_binary_decisions()

    # solve problem
    s2 <- solve(p2)

    # plot solution
    plot(category_layer(s2), main = "solution", axes = FALSE, box = FALSE)

---

add_min_shortfall_objective

Add minimum shortfall objective

Description

Set the objective of a conservation planning problem to minimize the shortfall for as many targets as possible while ensuring that the cost of the solution does not exceed a budget.

Usage

add_min_shortfall_objective(x, budget)

Arguments

x ConservationProblem-class object.

budget numeric value specifying the maximum expenditure of the prioritization. For problems with multiple zones, the argument to budget can be a single numeric value to specify a budget for the entire solution or a numeric vector to specify a budget for each each management zone.
Details

A problem objective is used to specify the overall goal of the conservation planning problem. Please note that all conservation planning problems formulated in the `prioritizr` package require the addition of objectives—failing to do so will return an error message when attempting to solve problem.

The minimum shortfall representation objective aims to find the set of planning units that minimize the shortfall for the representation targets—that is, the fraction of each target that remains unmet—for as many features as possible while staying within a fixed budget (inspired by Table 1, equation IV, Arponen et al. 2005). Additionally, weights can be used to favor the representation of certain features over other features (see `add_feature_weights`).

The minimum shortfall objective for the reserve design problem can be expressed mathematically for a set of planning units (\(I\) indexed by \(i\)) and a set of features (\(J\) indexed by \(j\)) as:

\[
\text{Minimize} \sum_{j=1}^{J} w_j \frac{y_j}{t_j} \text{subject to} \sum_{i=1}^{I} x_i r_{ij} + y_j \geq t_j \forall j \in J \sum_{i=1}^{I} x_i c_i \leq B
\]

Here, \(x_i\) is the decisions variable (e.g. specifying whether planning unit \(i\) has been selected (1) or not (0)), \(r_{ij}\) is the amount of feature \(j\) in planning unit \(i\), \(t_j\) is the representation target for feature \(j\), \(y_j\) denotes the representation shortfall for the target \(t_j\) for feature \(j\), and \(w_j\) is the weight for feature \(j\) (defaults to 1 for all features; see `add_feature_weights` to specify weights). Additionally, \(B\) is the budget allocated for the solution, \(c_i\) is the cost of planning unit \(i\). Note that \(y_j\) is a continuous variable bounded between zero and infinity, and denotes the shortfall for target \(j\).

Value

`ConservationProblem-class` object with the objective added to it.

References


See Also

`add_feature_weights`, `objectives`.

Examples

```
# load data
data(sim_pu_raster, sim_pu_zones_stack, sim_features, sim_features_zones)

# create problem with minimum shortfall objective
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_shortfall_objective(1800) %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions()

# solve problem
```
```
s1 <- solve(p1)

# plot solution
plot(s1, main = "solution", axes = FALSE, box = FALSE)

# create multi-zone problem with minimum shortfall objective,
# with 10% representation targets for each feature, and set
# a budget such that the total maximum expenditure in all zones
# cannot exceed 3000
p2 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_shortfall_objective(3000) %>%
  add_relative_targets(matrix(0.1, ncol = 3, nrow = 5)) %>%
  add_binary_decisions()

# solve problem
s2 <- solve(p2)

# plot solution
plot(category_layer(s2), main = "solution", axes = FALSE, box = FALSE)

# create multi-zone problem with minimum shortfall objective,
# with 10% representation targets for each feature, and set
# separate budgets for each management zone
p3 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_shortfall_objective(c(3000, 3000, 3000)) %>%
  add_relative_targets(matrix(0.1, ncol = 3, nrow = 5)) %>%
  add_binary_decisions()

# solve problem
s3 <- solve(p3)

# plot solution
plot(category_layer(s3), main = "solution", axes = FALSE, box = FALSE)
```

---

**add_neighbor_constraints**

*Add neighbor constraints*

**Description**

Add constraints to a conservation planning problem to ensure that all selected planning units in the solution have at least a certain number of neighbors that are also selected in the solution.

**Usage**

```r
## S4 method for signature 'ConservationProblem,ANY,ANY,ANY'
add_neighbor_constraints(x, k, zones, data)
```
add_neighbor_constraints

## S4 method for signature 'ConservationProblem,ANY,ANY,data.frame'
add_neighbor_constraints(x, k, zones, data)

## S4 method for signature 'ConservationProblem,ANY,ANY,matrix'
add_neighbor_constraints(x, k, zones, data)

## S4 method for signature 'ConservationProblem,ANY,ANY,array'
add_neighbor_constraints(x, k, zones, data)

Arguments

x  ConservationProblem-class object.
k  integer minimum number of neighbors for selected planning units in the solution. For problems with multiple zones, the argument to k must have an element for each zone.
zones  matrix or Matrix object describing the neighborhood scheme for different zones. Each row and column corresponds to a different zone in the argument to x, and cell values must contain binary numeric values (i.e. one or zero) that indicate if neighboring planning units (as specified in the argument to data) should be considered neighbors if they are allocated to different zones. The cell values along the diagonal of the matrix indicate if planning units that are allocated to the same zone should be considered neighbors or not. The default argument to zones is an identity matrix (i.e. a matrix with ones along the matrix diagonal and zeros elsewhere), so that planning units are only considered neighbors if they are both allocated to the same zone.
data  NULL, matrix, Matrix, data.frame, or array object showing which planning units are neighbors with each other. The argument defaults to NULL which means that the neighborhood data is calculated automatically using the adjacency_matrix function. See the Details section for more information.

Details

This function uses neighborhood data identify solutions that surround planning units with a minimum number of neighbors. It was inspired by the mathematical formulations detailed in Billionnet (2013) and Beyer et al. (2016).

The argument to data can be specified in several ways:

NULL  neighborhood data should be calculated automatically using the adjacency_matrix function. This is the default argument. Note that the neighborhood data must be manually defined using one of the other formats below when the planning unit data in the argument to x is not spatially referenced (e.g. in data.frame or numeric format).
matrix, Matrix  where rows and columns represent different planning units and the value of each cell indicates if the two planning units are neighbors or not. Cell values should be binary numeric values (i.e. one or zero). Cells that occur along the matrix diagonal have no effect on the solution at all because each planning unit cannot be a neighbor with itself.

data.frame  containing the fields (columns) "id1", "id2", and "boundary". Here, each row denotes the connectivity between two planning units following the Marxan format. The field
boundary should contain binary numeric values that indicate if the two planning units specified in the fields "id1" and "id2" are neighbors or not. This data can be used to describe symmetric or asymmetric relationships between planning units. By default, input data is assumed to be symmetric unless asymmetric data is also included (e.g. if data is present for planning units 2 and 3, then the same amount of connectivity is expected for planning units 3 and 2, unless connectivity data is also provided for planning units 3 and 2). If the argument to x contains multiple zones, then the columns "zone1" and "zone2" can optionally be provided to manually specify if the neighborhood data pertain to specific zones. The fields "zone1" and "zone2" should contain the character names of the zones. If the columns "zone1" and "zone2" are present, then the argument to zones must be NULL.

array containing four-dimensions where binary numeric values indicate if planning unit should be treated as being neighbors with every other planning unit when they are allocated to every combination of management zone. The first two dimensions (i.e. rows and columns) correspond to the planning units, and second two dimensions correspond to the management zones. For example, if the argument to data had a value of 1 at the index data[1,2,3,4] this would indicate that planning unit 1 and planning unit 2 should be treated as neighbors when they are allocated to zones 3 and 4 respectively.

Value

ConservationProblem-class object with the constraint added to it.

References


See Also

constraints, penalties.

Examples

# load data
data(sim_pu_raster, sim_features, sim_pu_zones_stack, sim_features_zones)

# create minimal problem
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1)

# create problem with constraints that require 1 neighbor
# and neighbors are defined using a rook-style neighborhood
p2 <- p1 %>% add_neighbor_constraints(1)

# create problem with constraints that require 2 neighbor
# and neighbors are defined using a rook-style neighborhood
p3 <- p1 %>% add_neighbor_constraints(2)
# create problem with constraints that require 3 neighbors
# and neighbors are defined using a queen-style neighborhood
p4 <- p1 %>% add_neighbor_constraints(3,
data = adjacency_matrix(sim_pu_raster, directions = 8))

# solve problems
s1 <- stack(list(solve(p1), solve(p2), solve(p3), solve(p4)))

# plot solutions
plot(s1, box = FALSE, axes = FALSE,
     main = c("basic solution", "1 neighbor", "2 neighbors", "3 neighbors"))

# create minimal problem with multiple zones
p5 <- problem(sim_pu_zones_stack, sim_features_zones) %>%%
    add_min_set_objective() %>%
    add_relative_targets(matrix(0.1, ncol = 3, nrow = 5))

# create problem where selected planning units require at least 2 neighbors
# for each zone and planning units are only considered neighbors if they
# are allocated to the same zone
z6 <- diag(3)
print(z6)
p6 <- p5 %>% add_neighbor_constraints(rep(2, 3), z6)

# create problem where the planning units in zone 1 don't explicitly require
# any neighbors, planning units in zone 2 require at least 1 neighbors, and
# planning units in zone 3 require at least 2 neighbors. As before, planning
# units are still only considered neighbors if they are allocated to the
# same zone
p7 <- p5 %>% add_neighbor_constraints(c(0, 1, 2), z6)

# create problem given the same constraints as outlined above, except
# that when determining which selected planning units are neighbors,
# planning units that are allocated to zone 1 and zone 2 can also treated
# as being neighbors with each other
z8 <- diag(3)
z8[1, 2] <- 1
z8[2, 1] <- 1
print(z8)
p8 <- p5 %>% add_neighbor_constraints(c(0, 1, 2), z8)

# solve problems
s2 <- list(p5, p6, p7, p8)
s2 <- lapply(s2, solve)
s2 <- lapply(s2, category_layer)
s2 <- stack(s2)
names(s2) <- c("basic problem", "p6", "p7", "p8")

# plot solutions
plot(s2, main = names(s2), box = FALSE, axes = FALSE)
add_proportion_decisions

Add proportion decisions

Description
Add a proportion decision to a conservation planning problem. This is a relaxed decision where a part of a planning unit can be prioritized as opposed to the entire planning unit. Typically, this decision has the assumed action of buying a fraction of a planning unit to include in decisions will solve much faster than problems that use binary-type decisions.

Usage
add_proportion_decisions(x)

Arguments
x ConservationProblem-class object.

Details
Conservation planning problems involve making decisions on planning units. These decisions are then associated with actions (e.g. turning a planning unit into a protected area). If no decision is explicitly added to a problem, then the binary decision class will be used by default. Only a single decision should be added to a ConservationProblem object. If multiple decisions are added to a problem object, then the last one to be added will be used.

Value
ConservationProblem-class object with the decisions added to it.

See Also
decisions.

Examples
# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_raster, sim_features, sim_pu_zones_stack, sim_features_zones)

# create minimal problem with proportion decisions
pl <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_proportion_decisions()
# solve problem
s1 <- solve(p1)

# plot solutions
plot(s1, main = "solution")

# build multi-zone conservation problem with proportion decisions
p2 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
   add_min_set_objective() %>%
   add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5,
                                 ncol = 3)) %>%
   add_proportion_decisions()

# solve the problem
s2 <- solve(p2)

# print solution
print(s2)

# plot solution
# panels show the proportion of each planning unit allocated to each zone
plot(s2, axes = FALSE, box = FALSE)

---

**add_relative_targets**  
*Add relative targets*

**Description**

Set targets as a proportion (between 0 and 1) of the maximum level of representation of features in the study area. Please note that proportions are scaled according to the features’ total abundances in the study area (including any locked out planning units, or planning units with NA cost data) using the `feature_abundances` function.

**Usage**

```r
add_relative_targets(x, targets)

## S4 method for signature 'ConservationProblem,numeric'
add_relative_targets(x, targets)

## S4 method for signature 'ConservationProblem,matrix'
add_relative_targets(x, targets)

## S4 method for signature 'ConservationProblem,character'
add_relative_targets(x, targets)
```
Arguments

x  ConservationProblem-class object.

targets  Object that specifies the targets for each feature. See the Details section for more information.

Details

Targets are used to specify the minimum amount or proportion of a feature’s distribution that needs to be protected. Most conservation planning problems require targets with the exception of the maximum cover (see add_max_cover_objective) and maximum utility (see add_max_utility_objective) problems. Attempting to solve problems with objectives that require targets without specifying targets will throw an error.

The targets for a problem can be specified in several different ways:

numeric vector of target values for each feature. Additionally, for convenience, this type of argument can be a single value to assign the same target to each feature. Note that this type of argument cannot be used to specify targets for problems with multiple zones.

matrix containing a target for each feature in each zone. Here, each row corresponds to a different feature in argument to x, each column corresponds to a different zone in argument to x, and each cell contains the target value for a given feature that the solution needs to secure in a given zone.

character containing the names of fields (columns) in the feature data associated with the argument to x that contain targets. This type of argument can only be used when the feature data associated with x is a data.frame. This argument must contain a field (column) name for each zone.

For problems associated with multiple management zones, this function can be used to set targets that each pertain to a single feature and a single zone. To set targets which can be met through allocating different planning units to multiple zones, see the add_manual_targets function. An example of a target that could be met through allocations to multiple zones might be where each management zone is expected to result in a different amount of a feature and the target requires that the total amount of the feature in all zones must exceed a certain threshold. In other words, the target does not require that any single zone secure a specific amount of the feature, but the total amount held in all zones must secure a specific amount. Thus the target could, potentially, be met through allocating all planning units to any specific management zone, or through allocating the planning units to different combinations of management zones.

Value

ConservationProblem-class object with the targets added to it.

See Also
targets.
Examples

```r
# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_raster, sim_features)

# create base problem
p <- problem(sim_pu_raster, sim_features) %>%
    add_min_set_objective() %>%
    add_binary_decisions()

# create problem with 10% targets
p1 <- p %>% add_relative_targets(0.1)

# create problem with varying targets for each feature
targets <- c(0.1, 0.2, 0.3, 0.4, 0.5)
p2 <- p %>% add_relative_targets(targets)

# solve problem
s <- stack(solve(p1), solve(p2))

# plot solution
plot(s, main = c("10% targets", "varying targets"), axes = FALSE, box = FALSE)

# create a problem with multiple management zones
p3 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
    add_min_set_objective() %>%
    add_binary_decisions()

# create a problem with targets that specify an equal amount of each feature to be represented in each zone
p4_targets <- matrix(0.1, nrow = 5, ncol = 3,
dimnames = list(feature_names(sim_features_zones),
    zone_names(sim_features_zones)))
print(p4_targets)
p4 <- p3 %>% add_relative_targets(p4_targets)

# solve problem
s4 <- solve(p4)

# plot solution (pixel values correspond to zone identifiers)
plot(category_layer(s4), main = c("equal targets"))

# create a problem with targets that require a varying amount of each feature to be represented in each zone
p5_targets <- matrix(runif(15, 0.01, 0.2), nrow = 5, ncol = 3,
dimnames = list(feature_names(sim_features_zones),
    zone_names(sim_features_zones)),
```
print(p5_targets)

p5 <- p3 %>% add_relative_targets(p4_targets)
# solve problem

# solve problem
s5 <- solve(p5)

# plot solution (pixel values correspond to zone identifiers)
plot(category_layer(s5), main = c("varying targets"))

---

**add_rsymphony_solver**  
*Add a SYMPHONY solver with Rsymphony*

### Description

Specify that the SYMPHONY software should be used to solve a conservation planning problem using the Rsymphony package. This function can also be used to customize the behavior of the solver. It requires the Rsymphony package.

### Usage

```r
add_rsymphony_solver(
  x,
  gap = 0.1,
  time_limit = -1,
  first_feasible = 0,
  verbose = TRUE
)
```

### Arguments

- **x**  
  *ConservationProblem-class* object.

- **gap**  
  numeric gap to optimality. This gap is absolute and expresses the acceptable deviation from the optimal objective. For example, solving a minimum set objective problem with a gap of 5 will cause the solver to terminate when the cost of the solution is within 5 cost units from the optimal solution.

- **time_limit**  
  numeric time limit in seconds to run the optimizer. The solver will return the current best solution when this time limit is exceeded.

- **first_feasible**  
  logical should the first feasible solution be returned? If `first_feasible` is set to `TRUE`, the solver will return the first solution it encounters that meets all the constraints, regardless of solution quality. Note that the first feasible solution is not an arbitrary solution, rather it is derived from the relaxed solution, and is therefore often reasonably close to optimality.

- **verbose**  
  logical should information be printed while solving optimization problems? Defaults to `TRUE`. 
Details

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

ConservationProblem-class object with the solver added to it.

See Also

solvers.

Examples

```r
# load data
data(sim_pu_raster, sim_features)

# create problem
p <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions()

# if the package is installed then add solver and generate solution
if (require("Rsymphony")) {
  # specify solver and generate solution
  s <- p %>%
    add_rsymphony_solver(time_limit = 10) %>%
    solve()

  # plot solutions
  plot(stack(sim_pu_raster, s), main = c("planning units", "solution"),
       axes = FALSE, box = FALSE)
}
```

Description

Add a semi-continuous decision to a conservation planning problem. This is a relaxed decision where a part of a planning unit can be prioritized, as opposed to the entire planning unit, which is the default function (see add_binary_decisions). This decision is similar to the add_proportion_decisions.
function except that it has an upper bound parameter. By default, the decision can range from prioritizing none (0 %) to all (100 %) of a planning unit. However, an upper bound can be specified to ensure that at most only a fraction (e.g. 80 %) of a planning unit can be preserved. This type of decision may be useful when it is not practical to conserve entire planning units.

Usage

add_semicontinuous_decisions(x, upper_limit)

Arguments

x ConservationProblem-class object.
upper_limit numeric value specifying the maximum proportion of a planning unit that can be reserved (e.g. set to 0.8 for 80 %).

Details

Conservation planning problems involve making decisions on planning units. These decisions are then associated with actions (e.g. turning a planning unit into a protected area). If no decision is explicitly added to a problem, then the binary decision class will be used by default. Only a single decision should be added to a ConservationProblem object. If multiple decisions are added to a problem object, then the last one to be added will be used.

Value

ConservationProblem-class object with the decisions added to it.

See Also

decisions.

Examples

# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_raster, sim_features, sim_pu_zones_stack, sim_features_zones)

# create minimal problem with semi-continuous decisions
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_semicontinuous_decisions(0.5)

# solve problem
s1 <- solve(p1)

# plot solutions
plot(s1, main = "solution")
```r
# build multi-zone conservation problem with semi-continuous decisions
p2 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5, ncol = 3)) %>%
  add_semicontinuous_decisions(0.5)

# solve the problem
s2 <- solve(p2)

# print solution
print(s2)

# plot solution
# panels show the proportion of each planning unit allocated to each zone
plot(s2, axes = FALSE, box = FALSE)
```

---

### add_shuffle_portfolio

**Add a shuffle portfolio**

#### Description

Generate a portfolio of solutions for a conservation planning problem by randomly reordering the data prior to solving the problem. This is recommended as a replacement for `add_top_portfolio` when the Gurobi software is not available.

#### Usage

```r
add_shuffle_portfolio(
  x,       # ConservationProblem-class object.
  number_solutions = 10L,  # integer number of attempts to generate different solutions. Defaults to 10.
  threads = 1L,           # integer number of threads to use for the generating the solution portfolio. Defaults to 1.
  remove_duplicates = TRUE  # logical should duplicate solutions be removed? Defaults to TRUE.
)
```

#### Arguments

- **x**: ConservationProblem-class object.
- **number_solutions**: integer number of attempts to generate different solutions. Defaults to 10.
- **threads**: integer number of threads to use for the generating the solution portfolio. Defaults to 1.
- **remove_duplicates**: logical should duplicate solutions be removed? Defaults to TRUE.
Details

This strategy for generating a portfolio of solutions often results in different solutions, depending on optimality gap, but may return duplicate solutions. In general, this strategy is most effective when problems are quick to solve and multiple threads are available for solving each problem separately.

Value

ConservationProblem-class object with the portfolio added to it.

See Also

portfolios.

Examples

# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_raster, sim_features, sim_pu_zones_stack, sim_features_zones)

# create minimal problem with shuffle portfolio
p1 <- problem(sim_pu_raster, sim_features) %>%
    add_min_set_objective() %>%
    add_relative_targets(0.2) %>%
    add_shuffle_portfolio(10, remove_duplicates = FALSE) %>%
    add_default_solver(gap = 0.2, verbose = FALSE)

# solve problem and generate 10 solutions within 20 % of optimality
s1 <- solve(p1)

# plot solutions in portfolio
plot(stack(s1), axes = FALSE, box = FALSE)

# build multi-zone conservation problem with shuffle portfolio
p2 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
    add_min_set_objective() %>%
    add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5, ncol = 3)) %>%
    add_binary_decisions() %>%
    add_shuffle_portfolio(10, remove_duplicates = FALSE) %>%
    add_default_solver(gap = 0.2, verbose = FALSE)

# solve the problem
s2 <- solve(p2)

# print solution
str(s2, max.level = 1)

# plot solutions in portfolio
Description

Add a top portfolio

Description

Generate a portfolio of solutions for a conservation planning problem by finding a pre-specified number of solutions that are closest to optimality (i.e. the top solutions).

Usage

```r
add_top_portfolio(x, number_solutions)
```

Arguments

- `x`: `ConservationProblem-class` object.
- `number_solutions`: integer number of solutions required.

Details

This strategy for generating a portfolio requires problems to be solved using the Gurobi software suite (i.e. using `add_gurobi_solver`). Specifically, version 9.0.0 (or greater) of the `gurobi` package must be installed. Note that the number of solutions returned may be less than the argument to `number_solutions`, if the total number of feasible solutions is less than the number of solutions requested.

Value

`ConservationProblem-class` object with the portfolio added to it.

See Also

- `portfolios`.

Examples

```r
# set seed for reproducibility
set.seed(600)

# load data
data(sim_pu_raster, sim_features)

# create minimal problem with a portfolio for the top 5 solutions
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_top_portfolio(5)
```
adjacency_matrix

```
add_min_set_objective() %>%
add_relative_targets(0.05) %>%
add_top_portfolio(number_solutions = 5) %>%
add_default_solver(gap = 0, verbose = FALSE)

# solve problem and generate portfolio
s1 <- solve(p1)

# print number of solutions found
print(length(s1))

# plot solutions
plot(stack(s1), axes = FALSE, box = FALSE)

# create multi-zone problem with a portfolio for the top 5 solutions
p2 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5,
                            ncol = 3)) %>%
  add_top_portfolio(number_solutions = 5) %>%
  add_default_solver(gap = 0, verbose = FALSE)

# solve problem and generate portfolio
s2 <- solve(p2)

# print number of solutions found
print(length(s2))

# plot solutions in portfolio
plot(stack(lapply(s2, category_layer)), main = "solution", axes = FALSE,
     box = FALSE)
```

**adjacency_matrix**  

**Adjacency matrix**

**Description**

Create a matrix showing which planning units are spatially adjacent to each other. Note that this also include planning units that overlap with each other too.

**Usage**

```r
adjacency_matrix(x, ...)

## S3 method for class 'Raster'
adjacency_matrix(x, directions = 4L, ...)

## S3 method for class 'SpatialPolygons'
adjacency_matrix(x, ...)
```
adjacency_matrix

## S3 method for class 'SpatialLines'
adjacency_matrix(x, ...)

## S3 method for class 'SpatialPoints'
adjacency_matrix(x, ...)

## S3 method for class 'sf'
adjacency_matrix(x, ...)

## Default S3 method:
adjacency_matrix(x, ...)

Arguments

x  

Raster-class, SpatialPolygons-class, SpatialLines-class, or sf object representing planning units.

...  

not used.

directions  

integer If x is a Raster-class object, the number of directions in which cells should be considered adjacent: 4 (rook’s case), 8 (queen’s case), 16 (knight and one-cell queen moves), or "bishop" for cells with one-cell diagonal moves.

Details

Spatial processing is completed using st_intersects for Spatial-class and sf objects, and adjacent for Raster-class objects. Prior to version 5.0.0, this function was named connected_matrix. It has been renamed to be consistent with other spatial association matrix functions.

Value

dsCMatrix-class sparse symmetric matrix. Each row and column represents a planning unit. Cells values indicate if different planning units are adjacent to each other or not (using ones and zeros). To reduce computational burden, cells among the matrix diagonal are set to zero. Furthermore, if the argument to x is a Raster-class object, then cells with NA values are set to zero too.

Examples

# load data
data(sim_pu_raster, sim_pu_sf, sim_pu_lines)

# create adjacency matrix using raster data
## crop raster to 9 cells
r <- crop(sim_pu_raster, c(0, 0.3, 0, 0.3))

## make adjacency matrix
am_raster <- adjacency_matrix(r)

# create adjacency matrix using polygons (sf) data
## subset 9 polygons
ply <- sim_pu_sf[c(1:2, 10:12, 20:22), ]
## make adjacency matrix

am_ply <- adjacency_matrix(ply)

# create adjacency matrix using lines (Spatial) data
## subset 9 lines
lns <- sim_pu_lines[c(1:2, 10:12, 20:22), ]

## make adjacency matrix
am_lns <- adjacency_matrix(lns)

# plot data and the adjacency matrices

par(mfrow = c(4,2))

## plot raster and adjacency matrix
plot(r, main = "raster", axes = FALSE, box = FALSE)
plot(raster(as.matrix(am_raster)), main = "adjacency matrix", axes = FALSE, box = FALSE)

## plot polygons (sf) and adjacency matrix
plot(r, main = "polygons (sf)", axes = FALSE, box = FALSE)
plot(raster(as.matrix(am_ply)), main = "adjacency matrix", axes = FALSE, box = FALSE)

## plot lines (Spatial) and adjacency matrix
plot(r, main = "lines (Spatial)", axes = FALSE, box = FALSE)
plot(raster(as.matrix(am_lns)), main = "adjacency matrix", axes = FALSE, box = FALSE)

---

### ArrayParameter-class

**Array parameter prototype**

#### Description

This prototype is used to represent a parameter has multiple values. Each value is has a label to differentiate values. **Only experts should interact directly with this prototype.**

#### Fields

- **$id** character identifier for parameter.
- **$name** character name of parameter.
- **$value** numeric vector of values.
- **$label** character vector of names for each value.
- **$default** numeric vector of default values.
- **$length** integer number of values.
- **$class** character class of values.
$lower_limit$ numeric vector specifying the minimum permitted values.
$upper_limit$ numeric vector specifying the maximum permitted values.
$widget$ function used to construct a shiny interface for modifying values.

Usage

x$print()

x$show()

x$repr()

x$validate(tbl)

x$get()

x$set(tbl)

x$reset()

x$render(...)

Arguments

tbl data.frame containing new parameter values with row names indicating the labels and a column called "values" containing the new parameter values.

... arguments passed to function in widget field.

Details

print print the object.
show show the object.
repr character representation of object.
validate check if a proposed new set of parameters are valid.
get return a data.frame containing the parameter values.
set update the parameter values using a data.frame.
reset update the parameter values to be the default values.
render create a shiny widget to modify parameter values.

See Also

ScalarParameter-class, Parameter-class.
Description

Create parameters that consist of multiple numbers. If an attempt is made to create a parameter with conflicting settings then an error will be thrown.

Usage

```r
proportion_parameter_array(name, value, label)
```

```r
binary_parameter_array(name, value, label)
```

```r
integer_parameter_array(
  name, 
  value, 
  label, 
  lower_limit = rep(as.integer(-.Machine$integer.max), length(value)),
  upper_limit = rep(as.integer(.Machine$integer.max), length(value))
)
```

```r
numeric_parameter_array(
  name, 
  value, 
  label, 
  lower_limit = rep(.Machine$double.xmin, length(value)),
  upper_limit = rep(.Machine$double.xmax, length(value))
)
```

Arguments

- **name** character name of parameter.
- **value** vector of values.
- **label** character vector of labels for each value.
- **lower_limit** vector of values denoting the minimum acceptable value for each element in value. Defaults to the smallest possible number on the system.
- **upper_limit** vector of values denoting the maximum acceptable value for each element in value. Defaults to the largest possible number on the system.

Details

Below is a list of parameter generating functions and a brief description of each.

- **proportion_parameter_array** a parameter that consists of multiple numeric values that are between zero and one.
**binary_parameter_array** a parameter that consists of multiple integer values that are either zero or one.

**integer_parameter_array** a parameter that consists of multiple integer values.

**numeric_parameter_array** a parameter that consists of multiple numeric values.

**Value**

An `ArrayParameter-class` object.

**Examples**

```r
# proportion parameter array
p1 <- proportion_parameter_array('prop_array', c(0.1, 0.2, 0.3),
                                 letters[1:3])
print(p1) # print it
p1$get() # get value
p1$id # get id
invalid <- data.frame(value = 1:3, row.names=letters[1:3]) # invalid values
p1$validate(invalid) # check invalid input is invalid
valid <- data.frame(value = c(0.4, 0.5, 0.6), row.names=letters[1:3]) # valid
p1$validate(valid) # check valid input is valid
p1$set(valid) # change value to valid input
print(p1)

# binary parameter array
p2 <- binary_parameter_array('bin_array', c(0L, 1L, 0L), letters[1:3])
print(p2) # print it
p2$get() # get value
p2$id # get id
invalid <- data.frame(value = 1:3, row.names=letters[1:3]) # invalid values
p2$validate(invalid) # check invalid input is invalid
valid <- data.frame(value = c(0L, 0L, 0L), row.names=letters[1:3]) # valid
p2$validate(valid) # check valid input is valid
p2$set(valid) # change value to valid input
print(p2)

# integer parameter array
p3 <- integer_parameter_array('int_array', c(1:3), letters[1:3])
print(p3) # print it
p3$get() # get value
p3$id # get id
invalid <- data.frame(value = rnorm(3), row.names=letters[1:3]) # invalid
p3$validate(invalid) # check invalid input is invalid
valid <- data.frame(value = 5:7, row.names=letters[1:3]) # valid
p3$validate(valid) # check valid input is valid
p3$set(valid) # change value to valid input
print(p3)

# numeric parameter array
p4 <- numeric_parameter_array('dbl_array', c(0.1, 4, -5), letters[1:3])
print(p4) # print it
p4$get() # get value
```
p4$id # get id
invalid <- data.frame(value = c(NA, 1, 2), row.names=letters[1:3]) # invalid
p4$validate(invalid) # check invalid input is invalid
valid <- data.frame(value = c(1, 2, 3), row.names=letters[1:3]) # valid
p4$validate(valid) # check valid input is valid
p4$set(valid) # change value to valid input
print(p4)

# numeric parameter array with lower bounds
p5 <- numeric_parameter_array('b dbl_array', c(0.1, 4, -5), letters[1:3],
   lower_limit=c(0, 1, 2))
print(p5) # print it
p5$get() # get value
p5$id # get id
invalid <- data.frame(value = c(-1, 5, 5), row.names=letters[1:3]) # invalid
p5$validate(invalid) # check invalid input is invalid
valid <- data.frame(value = c(0, 1, 2), row.names=letters[1:3]) # valid
p5$validate(valid) # check valid input is valid
p5$set(valid) # change value to valid input
print(p5)

---

**as.Id**

---

**Coerce object to another object**

**Description**

Coerce an object.

**Usage**

as.Id(x, ...)

## S3 method for class 'character'
as.Id(x, ...)

## S3 method for class 'Parameters'
as.list(x, ...)

## S3 method for class 'Zones'
as.list(x, ...)

**Arguments**

x # Object.
...

**Value**

An Object.
as.list.OptimizationProblem

Convert OptimizationProblem to list

Description
Convert OptimizationProblem to list

Usage
## S3 method for class 'OptimizationProblem'
as.list(x, ...)

Arguments
 x OptimizationProblem-class object.
...

Value
list object.

binary_stack

Description
Convert a RasterLayer-class object containing categorical identifiers into a RasterStack-class object where each layer corresponds to a different identifier and values indicate the presence/absence of that category in the input object.

Usage
binary_stack(x)

Arguments
 x Raster-class object containing a single layer.

Details
This function is provided to help manage data that encompass multiple management zones. For instance, this function may be helpful for preparing raster data for add_locked_in_constraints and add_locked_out_constraints since they require binary RasterStack-class objects as input arguments.
boundary_matrix

Value

RasterStack-class object.

See Also

category_layer.

Examples

# create raster with categorical identifiers
x <- raster(matrix(c(1, 2, 3, 1, NA, 1), nrow = 3))

# convert to binary stack
y <- binary_stack(x)

# plot categorical raster and binary stack representation
plot(stack(x, y), main = c("x", "y[[1]]", "y[[2]]", "y[[3]]"), nr = 1)

boundary_matrix

Description

Generate a matrix describing the amount of shared boundary length between different planning units, and the amount of exposed edge length each planning unit exhibits.

Usage

boundary_matrix(x, str_tree)

## S3 method for class 'Raster'
boundary_matrix(x, str_tree = FALSE)

## S3 method for class 'SpatialPolygons'
boundary_matrix(x, str_tree = FALSE)

## S3 method for class 'SpatialLines'
boundary_matrix(x, str_tree = FALSE)

## S3 method for class 'SpatialPoints'
boundary_matrix(x, str_tree = FALSE)

## S3 method for class 'sf'
boundary_matrix(x, str_tree = FALSE)

## Default S3 method:
boundary_matrix(x, str_tree = FALSE)
Arguments

x  **Raster-class, SpatialLines-class, SpatialPolygons-class, sf** object representing planning units. If x is a Raster-class object then it must have only one layer.

str_tree  logical should a GEOS STRtree be used to pre-process data? If TRUE, then the experimental gUnarySTRtreeQuery function will be used to pre-compute which planning units are adjacent to each other and potentially reduce the processing time required to generate the boundary matrices. This argument is only used when the planning unit data are vector-based polygons (i.e. SpatialPolygonsDataFrame objects). **Note that using TRUE may crash Mac OSX systems.** The default argument is FALSE.

Details

This function returns a dsCMatrix-class symmetric sparse matrix. Cells on the off-diagonal indicate the length of the shared boundary between two different planning units. Cells on the diagonal indicate length of a given planning unit’s edges that have no neighbors (e.g. for edges of planning units found along the coastline). **This function assumes the data are in a coordinate system where Euclidean distances accurately describe the proximity between two points on the earth.** Thus spatial data in a longitude/latitude coordinate system (aka WGS84) should be reprojected to another coordinate system before using this function. Note that for Raster-class objects boundaries are missing for cells that have NA values in all cells.

Value

**Matrix**{dsCMatrix-class} object.

Examples

```r
# load data
data(sim_pu_raster, sim_pu_polygons)

# subset data to reduce processing time
r <- crop(sim_pu_raster, c(0, 0.3, 0, 0.3))
ply <- sim_pu_polygons[c(1:2, 10:12, 20:22), ]
ply2 <- st_as_sf(ply)

# create boundary matrix using raster data
bm_raster <- boundary_matrix(r)

# create boundary matrix using polygon (Spatial) data
bm_ply1 <- boundary_matrix(ply)

# create boundary matrix using polygon (sf) data
bm_ply2 <- boundary_matrix(ply2)

# create boundary matrix with polygon (Spatial) data and GEOS STR query trees
# to speed up processing
bm_ply3 <- boundary_matrix(ply, TRUE)
```
# plot raster and boundary matrix
par(mfrow = c(1, 2))
plot(r, main = "raster", axes = FALSE, box = FALSE)
plot(raster(as.matrix(bm_raster)), main = "boundary matrix",
     axes = FALSE, box = FALSE)

# plot polygons and boundary matrices
par(mfrow = c(1, 3))
plot(r, main = "polygons (Spatial)", axes = FALSE, box = FALSE)
plot(raster(as.matrix(bm_ply1)), main = "boundary matrix", axes = FALSE,
      box = FALSE)
plot(r, main = "polygons (sf)", axes = FALSE, box = FALSE)
plot(raster(as.matrix(bm_ply2)), main = "boundary matrix", axes = FALSE,
      box = FALSE)
plot(raster(as.matrix(bm_ply3)), main = "boundary matrix (Spatial, STR)",
     axes = FALSE, box = FALSE)

---

### branch_matrix

**Branch matrix**

Phylogenetic trees depict the evolutionary relationships between different species. Each branch in a phylogenetic tree represents a period of evolutionary history. Species that are connected to the same branch both share that same period of evolutionary history. This function creates a matrix that shows which species are connected with branch. In other words, it creates a matrix that shows which periods of evolutionary history each species have experienced.

#### Usage

```r
branch_matrix(x)
```

#### Arguments

- `x`  
  
  *phylo* tree object.

#### Value

`dgCMatrix-class` sparse matrix object. Each row corresponds to a different species. Each column corresponds to a different branch. Species that inherit from a given branch are denoted with a one.
### Examples

```r
# load data
data(sim_phylogeny)

# generate species by branch matrix
m <- branch_matrix(sim_phylogeny)

# plot data
par(mfrow = c(1,2))
plot(sim_phylogeny, main = "phylogeny")
plot(raster(as.matrix(m)), main = "branch matrix", axes = FALSE,
     box = FALSE)
```

---

### category_layer

**Category layer**

**Description**
Convert a `RasterStack-class` object where each layer corresponds to a different identifier and values indicate the presence/absence of that category into a `RasterLayer-class` object containing categorical identifiers.

**Usage**

`category_layer(x)`

**Arguments**

- `x` : `Raster-class` object containing a multiple layers. Note that pixels must be 0, 1 or NA values.

**Details**
This function is provided to help manage data that encompass multiple management zones. For instance, this function may be helpful for interpreting solutions for problems associated with multiple zones that have binary decisions.

**Value**

`RasterLayer-class` object.

**See Also**

`binary_stack`.
category_vector

Examples

# create a binary raster stack
x <- stack(raster(matrix(c(1, 0, 0, 1, NA, 0), nrow = 3)),
           raster(matrix(c(0, 1, 0, 0, NA, 0), nrow = 3)),
           raster(matrix(c(0, 0, 1, 0, NA, 1), nrow = 3)))

# convert to binary stack
y <- category_layer(x)

# plot categorical raster and binary stack representation
plot(stack(x, y), main = c("x[[1]]", "x[[2]]", "x[[3]]", "y"), nr = 1)

category_vector  
Category vector

Description

Convert an object containing binary (integer) fields (columns) into a integer vector indicating
the column index where each row is 1.

Usage

category_vector(x)

## S3 method for class 'data.frame'
category_vector(x)

## S3 method for class 'sf'
category_vector(x)

## S3 method for class 'Spatial'
category_vector(x)

## S3 method for class 'matrix'
category_vector(x)

Arguments

x  
matrix, data.frame, Spatial-class, or sf object.

Details

This function is conceptually similar to max.col except that rows with no values equal to 1 values
are assigned a value of zero. Also, note that in the argument to x, each row must contain only a
single value equal to 1.
**Value**

integer vector

**See Also**

max.col

**Examples**

```r
# create matrix with logical fields
x <- matrix(c(1, 0, 0, NA, 0, 1, 0, NA, 0, 0, 0, NA), ncol = 3)

# print matrix
print(x)

# convert to category vector
y <- category_vector(x)

# print category vector
print(y)
```

### Description

This prototype represents a collection of `ConservationModifier-class` objects.

**Fields**

- `$...` `ConservationModifier-class` objects stored in the collection.

**Usage**

```r
x$print()
x$show()
x$repr()
x$ids()
x$length()
x$add
x$remove(id)
x$get_parameter(id)
x$set_parameter(id,value)
x$render_parameter(id)
x$render_all_parameters()
```
Arguments

**id**  id object.
**value**  any object.

Details

**print**  print the object.
**show**  show the object.
**repr**  character representation of object.
**ids**  character ids for objects inside collection.
**length**  integer number of objects inside collection.
**find**  character id for object inside collection which contains the input id.
**find_parameter**  character id for object inside collection which contains the input character object as a parameter.
**add**  add `ConservationModifier-class` object.
**remove**  remove an item from the collection.
**get_parameter**  retrieve the value of a parameter in the object using an id object.
**set_parameter**  change the value of a parameter in the object to a new object.
**render_parameter**  generate a shiny widget to modify the value of a parameter (specified by argument id).
**render_all_parameters**  generate a div containing all the parameters' widgets.

See Also

`Constraint-class`, `Penalty-class`.

---

**compile**  Compile a problem

**Description**

Compile a conservation planning problem into an (potentially mixed) integer linear programming problem.

**Usage**

```r
compile(x, ...)
```

```r
## S3 method for class 'ConservationProblem'
compile(x, compressed_formulation = NA, ...)
```
connectivity_matrix

Arguments

- **x**: ConservationProblem-class object.
- ... not used.
- **compressed_formulation**: logical should the conservation problem compiled into a compressed version of a planning problem? If TRUE then the problem is expressed using the compressed formulation. If FALSE then the problem is expressed using the expanded formulation. If NA, then the compressed is used unless one of the constraints requires the expanded formulation. This argument defaults to NA.

Details

This function might be useful for those interested in understanding how their conservation planning problem is expressed as a mathematical problem. However, if the problem just needs to be solved, then the solve function should just be used.

Please note that in nearly all cases, the default argument to formulation should be used. The only situation where manually setting the argument to formulation is desirable is during testing. Manually setting the argument to formulation will at best have no effect on the problem. At worst, it may result in an error, a misspecified problem, or unnecessarily long solve times.

Value

OptimizationProblem-class object.

Examples

```r
# build minimal conservation problem
p <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1)

# compile the conservation problem into an optimization problem
o <- compile(p)

# print the optimization problem
print(o)
```

Description

Create a matrix showing the connectivity between planning units. Connectivity is calculated as the average conductance of two planning units multiplied by the amount of shared boundary between the two planning units. Thus planning units that each have higher a conductance and share a greater boundary are associated with greater connectivity.
Usage

connectivity_matrix(x, y, ...)

## S4 method for signature 'Spatial,Raster'
connectivity_matrix(x, y, ...)

## S4 method for signature 'Spatial,character'
connectivity_matrix(x, y, ...)

## S4 method for signature 'sf,character'
connectivity_matrix(x, y, ...)

## S4 method for signature 'sf,Raster'
connectivity_matrix(x, y, ...)

## S4 method for signature 'Raster,Raster'
connectivity_matrix(x, y, ...)

Arguments

- **x** `Raster-class, SpatialPolygonsDataFrame-class, SpatialLinesDataFrame-class, or sf` object representing planning units. If `x` is a `Raster-class` object then it must contain a single layer.

- **y** `Raster-class` object showing the conductance of different areas across the study area, or a `character` object denoting a column name in the attribute table of `x` that contains the conductance values. Note that argument to `y` can only be a `character` object if the argument to `x` is a `Spatial-class` or `sf` object. Also, note that if the argument to `x` is a `Raster-class` object then argument to `y` must have the same spatial properties as it (i.e. coordinate system, extent, resolution).

- **...** additional arguments passed to `fast_extract` for extracting and calculating the conductance values for each planning unit. These arguments are only used if argument to `x` is a link[sp]{Spatial-class} or `sf` object and argument to `y` is a `Raster-class` object.

Details

Shared boundary calculations are performed using `boundary_matrix`.

Value

dsCMatrix-class sparse symmetric matrix. Each row and column represents a planning unit. Cells values indicate the connectivity between different pairs of planning units. To reduce computational burden, cells among the matrix diagonal are set to zero. Furthermore, if the argument to `x` is a `Raster-class` object, then cells with NA values are set to zero too.

Examples

```r
# load data
```
ConservationModifier-class

Conservation problem modifier prototype

Description

This super-prototype is used to represent prototypes that in turn are used to modify a ConservationProblem-class object. Specifically, the Constraint-class, Decision-class, Objective-class, and Target-class prototypes inherit from this class. Only experts should interact with this class directly because changes to these class will have profound and far reaching effects.
Fields

$name character name of object.

$parameters list object used to customize the modifier.

$data list object with data.

$compressed_formulation logical can this constraint be applied to the compressed version of the conservation planning problem? Defaults to TRUE.

Usage

x$print()

x$show()

x$repr()

x$get_data(name)

x$set_data(name,value)

x$calculate(cp)

x$output()

x$apply(op,cp)

x$get_parameter(id)

x$get_all_parameters()

x$set_parameter(id,value)

x$render_parameter(id)

x$render_all_parameter()

Arguments

name character name for object

value any object

id id or name of parameter

cp ConservationProblem-class object

op OptimizationProblem-class object

Details

print print the object.

show show the object.

repr return character representation of the object.

get_data return an object stored in the data field with the corresponding name. If the object is not present in the data field, a waiver object is returned.

set_data store an object stored in the data field with the corresponding name. If an object with that name already exists then the object is overwritten.
**ConservationProblem-class**

**calculate** function used to perform preliminary calculations and store the data so that they can be reused later without performing the same calculations multiple times. Data can be stored in the data slot of the input ConservationModifier or ConservationProblem objects.

**output** function used to generate an output from the object. This method is only used for Target-class objects.

**apply** function used to apply the modifier to an OptimizationProblem-class object. This is used by Constraint-class, Decision-class, and Objective-class objects.

**get_parameter** retrieve the value of a parameter.

**get_all_parameters** generate list containing all the parameters.

**set_parameter** change the value of a parameter to new value.

**render_parameter** generate a shiny widget to modify the value of a parameter (specified by argument id).

**render_all_parameters** generate a div containing all the parameters' widgets.

---

**ConservationProblem-class**

*Conservation problem class*

---

**Description**

This class is used to represent conservation planning problems. A conservation planning problem has spatially explicit planning units. A prioritization involves making a decision on each planning unit (e.g. is the planning unit going to be turned into a protected area?). Each planning unit is associated with a cost that represents the cost incurred by applying the decision to the planning unit. The problem also has a set of representation targets for each feature. Further, it also has constraints used to ensure that the solution meets additional objectives (e.g. certain areas are locked into the solution). Finally, a conservation planning problem—unlike an optimization problem—also requires a method to solve the problem. **This class represents a planning problem, to actually build and then solve a planning problem, use the problem function. Only experts should use this class directly.**

**Fields**

- **$data** list object containing data.
- **$objective** Objective-class object used to represent how the targets relate to the solution.
- **$decisions** Decision-class object used to represent the type of decision made on planning units.
- **$targets** Target-class object used to represent representation targets for features.
- **$penalties** Collection-class object used to represent additional penalties that the problem is subject to.
- **$constraints** Collection-class object used to represent additional constraints that the problem is subject to.
- **$portfolio** Portfolio-class object used to represent the method for generating a portfolio of solutions.
- **$solver** Solver-class object used to solve the problem.
Usage

x$print()
x$show()
x$repr()
x$get_data(name)
x$set_data(name,value)
x$number_of_total_units()
x$number_of_planning_units()
x$planning_unit_indices()
x$planning_unit_indices_with_finite_costs()
x$planning_unit_costs()
x$number_of_features()
x$feature_names()
x$feature_abundances_in_planning_units()
x$feature_abundances_in_total_units()
x$feature_targets()
x$number_of_zones()
x$zone_names()
x$add_objective(obj)
x$add_decisions(dec)
x$add_portfolio(pol)
x$add_solver(sol)
x$add_constraint(con)
x$add_targets(targ)
x$get_constraint_parameter(id)
x$set_constraint_parameter(id,value)
x$render_constraint_parameter(id)
x$render_all_constraint_parameters()
x$get_objective_parameter(id)
x$set_objective_parameter(id,value)
x$render_objective_parameter(id)
x$render_all_objective_parameters()
x$get_solver_parameter(id)
x$set_solver_parameter(id,value)
x$render_solver_parameter(id)
x$render_all_solver_parameters()
x$get_portfolio_parameter(id)
$set_portfolio_parameter(id, value)
$render_portfolio_parameter(id)
$render_all_portfolio_parameters()
$get_penalty_parameter(id)
$set_penalty_parameter(id, value)
$render_penalty_parameter(id)
$render_all_penalty_parameters()

Arguments

- **name** character name for object.
- **value** an object.
- **obj** Objective-class object.
- **dec** Decision-class object.
- **con** Constraint-class object.
- **pol** Portfolio-class object.
- **sol** Solver-class object.
- **targ** Target-class object.
- **cost** RasterLayer-class, SpatialPolygonsDataFrame-class, or SpatialLinesDataFrame-class object showing spatial representation of the planning units and their cost.
- **features** Zones-class or data.frame object containing feature data.
- **id** Id object that refers to a specific parameter.
- **value** object that the parameter value should become.

Details

- **print** print the object.
- **show** show the object.
- **repr** return character representation of the object.
- **get_data** return an object stored in the data field with the corresponding name. If the object is not present in the data field, a waiver object is returned.
- **set_data** store an object stored in the data field with the corresponding name. If an object with that name already exists then the object is overwritten.
- **number_of_planning_units** integer number of planning units.
- **planning_unit_indices** integer indices of the planning units in the planning unit data.
- **planning_unit_indices_with_finite_costs** list of integer indices of planning units in each zone that have finite cost data.
- **number_of_total_units** integer number of units in the cost data including units that have N cost data.
- **planning_unit_costs** matrix cost of allocating each planning unit to each zone. Each column corresponds to a different zone and each row corresponds to a different planning unit.
ConservationProblem-class

**number_of_features**  integer number of features.

**feature_names**  character names of features in problem.

**feature_abundances_in_planning_units**  matrix total abundance of each feature in planning units available in each zone. Each column corresponds to a different zone and each row corresponds to a different feature.

**feature_abundances_in_total_units**  matrix total abundance of each feature in each zone. Each column corresponds to a different zone and each row corresponds to a different feature.

**feature_targets**  tibble with feature targets.

**number_of_zones**  integer number of zones.

**zone_names**  character names of zones in problem.

**add_objective**  return a new ConservationProblem-class with the objective added to it.

**add_decisions**  return a new ConservationProblem-class object with the decision added to it.

**add_portfolio**  return a new ConservationProblem-class object with the portfolio method added to it.

**add_solver**  return a new ConservationProblem-class object with the solver added to it.

**add_constraint**  return a new ConservationProblem-class object with the constraint added to it.

**add_targets**  return a copy with the targets added to the problem.

**get_constraint_parameter**  get the value of a parameter (specified by argument id) used in one of the constraints in the object.

**set_constraint_parameter**  set the value of a parameter (specified by argument id) used in one of the constraints in the object to value.

**render_constraint_parameter**  generate a shiny widget to modify the value of a parameter (specified by argument id).

**render_all_constraint_parameters**  generate a shiny div containing all the parameters’ widgets.

**get_objective_parameter**  get the value of a parameter (specified by argument id) used in the object’s objective.

**set_objective_parameter**  set the value of a parameter (specified by argument id) used in the object’s objective to value.

**render_objective_parameter**  generate a shiny widget to modify the value of a parameter (specified by argument id).

**render_all_objective_parameters**  generate a shiny div containing all the parameters’ widgets.

**get_solver_parameter**  get the value of a parameter (specified by argument id) used in the object’s solver.

**set_solver_parameter**  set the value of a parameter (specified by argument id) used in the object’s solver to value.

**render_solver_parameter**  generate a shiny widget to modify the value of a parameter (specified by argument id).

**render_all_solver_parameters**  generate a shiny div containing all the parameters’ widgets.

**get_portfolio_parameter**  get the value of a parameter (specified by argument id) used in the object’s portfolio.
set_portfolio_parameter set the value of a parameter (specified by argument id) used in objects’ solver to value.

render_portfolio_parameter generate a shiny widget to modify the value of a parameter (specified by argument id).

render_all_portfolio_parameters generate a shiny div containing all the parameters’ widgets.

---

### Description

This prototype is used to represent the constraints used when making a prioritization. **This prototype represents a recipe, to actually add constraints to a planning problem, see the help page on constraints. Only experts should use this class directly.** This prototype inherits from the ConservationModifier-class.

### See Also

ConservationModifier-class.

---

### constraints

**Conservation problem constraints**

### Description

A constraint can be added to a conservation planning problem to ensure that solutions exhibit a specific characteristic.

### Details

Constraints can be used to ensure that solutions exhibit a range of different characteristics. For instance, they can be used to lock in or lock out certain planning units from the solution, such as protected areas or degraded land (respectively). Additionally, similar to the penalties functions, some of the constraint functions can be used to increase connectivity in a solution. The key difference between a penalty and a constraint, however, is that constraints work by invalidating solutions that do not exhibit a specific characteristic, whereas penalty functions work by than penalizing solutions which do not meet a specific characteristic. Thus constraints do not affect the objective function. The following constraints are available.

The following constraints can be added to a conservation planning problem:

- **add_locked_in_constraints** Add constraints to ensure that certain planning units are selected in the solution.
- **add_locked_out_constraints** Add constraints to ensure that certain planning units are not selected in the solution.
add_neighbor_constraints Add constraints to ensure that all selected planning units have at least a certain number of neighbors.

add_contiguity_constraints Add constraints to ensure that all selected planning units are spatially connected to each other and form a single contiguous unit.

add_feature_contiguity_constraints Add constraints to ensure that each feature is represented in a contiguous unit of dispersible habitat. These constraints are a more advanced version of those implemented in the add_contiguity_constraints function, because they ensure that each feature is represented in a contiguous unit and not that the entire solution should form a contiguous unit.

add_mandatory_allocation_constraints Add constraints to ensure that every planning unit is allocated to a management zone in the solution. This function can only be used with problems that contain multiple zones.

See Also
decisions, objectives, penalties, portfolios, problem, solvers, targets.

Examples

# load data
data(sim_pu_raster, sim_features, sim_locked_in_raster, sim_locked_out_raster)

# create minimal problem with only targets and no additional constraints
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions()

# create problem with locked in constraints
p2 <- p1 %>% add_locked_in_constraints(sim_locked_in_raster)

# create problem with locked out constraints
p3 <- p1 %>% add_locked_out_constraints(sim_locked_out_raster)

# create problem with neighbor constraints
p4 <- p1 %>% add_neighbor_constraints(2)

# create problem with contiguity constraints
p5 <- p1 %>% add_contiguity_constraints()

# create problem with feature contiguity constraints
p6 <- p1 %>% add_feature_contiguity_constraints()

# solve problems
s <- stack(lapply(list(p1, p2, p3, p4, p5, p6), solve))

# plot solutions
plot(s, box = FALSE, axes = FALSE, nr = 2,
     main = c("minimal problem", "locked in", "locked out", "neighbor", "contiguity", "feature contiguity"))
Description

This prototype used to represent the type of decision that is made when prioritizing planning units. This prototype represents a recipe to make a decision, to actually specify the type of decision in a planning problem, see the help page on decisions. Only experts should use this class directly. This class inherits from the ConservationModifier-class.

See Also

ConservationModifier-class.

decisions

Specify the type of decisions

Description

Conservation planning problems involve making decisions on how different planning units will be managed. These decisions might involve turning an entire planning unit into a protected area, turning part of a planning unit into a protected area, or allocating a planning unit to a specific management zone. If no decision is explicitly added to a problem, then binary decisions will be used by default.

Details

Only a single type of decision can be added to a conservation planning problem. If multiple decisions are added to problem, then the last one to be added will be used.

The following decisions can be added to a conservation planning problem:

- **add_binary_decisions** Add a binary decision to a conservation planning problem. This is the classic decision of either prioritizing or not prioritizing a planning unit. Typically, this decision has the assumed action of buying the planning unit to include in a protected area network. If no decision is added to a problem object then this decision class will be used by default.

- **add_proportion_decisions** Add a proportion decision to a conservation planning problem. This is a relaxed decision where a part of a planning unit can be prioritized, as opposed to the default of the entire planning unit. Typically, this decision has the assumed action of buying a fraction of a planning unit to include in a protected area network.

- **add_semicontinuous_decisions** Add a semi-continuous decision to a conservation planning problem. This decision is similar to add_proportion_decision except that it has an upper bound parameter. By default, the decision can range from prioritizing none (0 %) to all (100 %) of a planning unit. However, a upper bound can be specified to ensure that at most only a fraction (e.g. 80 %) of a planning unit can be preserved. This type of decision may be useful when it is not practical to conserve the entire area encompassed by any single planning unit.
**distribute_load**

Distribute load

### Description

Utility function for distributing computations among a pool of workers for parallel processing.

### Usage

```r
distribute_load(x, n = 1)
```

### Arguments

- `x` integer number of item to process.
- `n` integer number of threads.
**Details**

This function returns a list containing an element for each worker. Each element contains an integer vector specifying the indices that the worker should process.

**Value**

list object.

**Examples**

```r
# imagine that we have 10 jobs that need processing. For simplicity,
# our jobs will involve adding 1 to each element in 1:10.
values <- 1:10

# we could complete this processing using the following vectorized code
result <- 1 + 1:10
print(result)

# however, if our jobs were complex then we would be better off using
# functionals
result <- lapply(1:10, function(x) x + 1)
print(result)

# we could do one better, and use the "plyr" package to handle the
# processing
result <- plyr::llply(1:10, function(x) x + 1)
print(result)

# we could also use the parallel processing options available through "plyr"
# to use more computation resources to complete the jobs (note that since
# these jobs are very quick to process this is actually slower).
cl <- parallel::makeCluster(2, "PSOCK")
doParallel::registerDoParallel(cl)
result <- plyr::llply(1:10, function(x) x + 1, .parallel = TRUE)
cl <- parallel::stopCluster(cl)
print(result)

# however this approach iterates over each element individually, we could
# use the distribute_load function to split the N jobs up into K super
# jobs, and evaluate each super job using vectorized code.
x <- 1:10
cl <- parallel::makeCluster(2, "PSOCK")
parallel::clusterExport(cl, 'x', envir = environment())
doParallel::registerDoParallel(cl)
l <- distribute_load(length(x), n = 2)
result <- plyr::llply(l, function(i) x[i] + 1, .parallel = TRUE)
cl <- parallel::stopCluster(cl)
print(result)
```
Description

Extract data from a Raster-class object.

Usage

fast_extract(x, y, ...) 

## S4 method for signature 'Raster,SpatialPolygons'
fast_extract(x, y, fun = "mean", ...) 

## S4 method for signature 'Raster,SpatialPoints'
fast_extract(x, y, fun = "mean", ...) 

## S4 method for signature 'Raster,SpatialLines'
fast_extract(x, y, fun = "mean", ...) 

## S4 method for signature 'Raster,sfc'
fast_extract(x, y, fun = "mean", ...) 

## S4 method for signature 'Raster,sf'
fast_extract(x, y, fun = "mean", ...) 

Arguments

x Raster-class object.
y Spatial-class or sf object.
... not used.
fun character name of statistic to summarize data. Defaults to "mean". Available options include "sum" or "mean". Defaults to "mean".

Details

This function is simply a wrapper that uses extract to extract data for SpatialPoints-class and SpatialLines-class and non-polygonal sf data, and exact_extract for SpatialPolygons-class and polygonal sf data.

Value

matrix containing the summary amount of each feature within each planning unit. Rows correspond to different spatial features in the argument to y and columns correspond to different raster layers in the argument to x.
feature_abundances

See Also

extract, exact_extract.

Examples

# load data
data(sim_pu_sf, sim_features)

# extract data
result <- fast_extract(sim_features, sim_pu_sf)

# show result
print(head(result))

Description

Calculate the total abundance of each feature found in the planning units of a conservation planning problem.

Usage

feature_abundances(x, na.rm)

## S3 method for class 'ConservationProblem'
feature_abundances(x, na.rm = FALSE)

Arguments

x ConservationProblem-class object.

na.rm logical should planning units with NA cost data be excluded from the abundance calculations? The default argument is FALSE.

Details

Planning units can have cost data with finite values (e.g. 0.1, 3, 100) and NA values. This functionality is provided so that locations which are not available for protected area acquisition can be included when calculating targets for conservation features (e.g. when targets are specified using add_relative_targets). If the total amount of each feature in all the planning units is required—including the planning units with NA cost data—then the the na.rm argument should be set to FALSE. However, if the planning units with NA cost data should be excluded—for instance, to calculate the highest feasible targets for each feature—then the na.rm argument should be set to TRUE.
Value

tibble containing the total amount ("absolute_abundance") and proportion ("relative_abundance") of the distribution of each feature in the planning units. Here, each row contains data that pertain to a specific feature in a specific management zone (if multiple zones are present). This object contains the following columns:

**feature** character name of the feature.

**zone** character name of the zone (not included when the argument to x contains only one management zone).

**absolute_abundance** numeric amount of each feature in the planning units. If the problem contains multiple zones, then this column shows how well each feature is represented in a each zone.

**relative_abundance** numeric proportion of the feature’s distribution in the planning units. If the argument to na.rm is FALSE, then this column will only contain values equal to one. Otherwise, if the argument to na.rm is TRUE and planning units with NA cost data contain non-zero amounts of each feature, then this column will contain values between zero and one.

See Also

problem, feature_representation.

Examples

```r
# load data
data(sim_pu_raster, sim_features)

# create a simple conservation planning data set so we can see exactly
# how the feature abundances are calculated
pu <- data.frame(id = seq_len(10), cost = c(0.2, NA, runif(8)),
                 spp1 = runif(10), spp2 = c(rpois(9, 4), NA))

# create problem
p1 <- problem(pu, c("spp1", "spp2"), cost_column = "cost")

# calculate feature abundances; including planning units with NA costs
a1 <- feature_abundances(p1, na.rm = FALSE) # (default)
print(a1)

# calculate feature abundances; excluding planning units with NA costs
a2 <- feature_abundances(p1, na.rm = TRUE)
print(a2)

# verify correctness of feature abundance calculations
all.equal(a1$absolute_abundance,
          c(sum(pu$spp1), sum(pu$spp2, na.rm = TRUE)))

all.equal(a1$relative_abundance,
          c(sum(pu$spp1) / sum(pu$spp1),
           sum(pu$spp2, na.rm = TRUE) / sum(pu$spp2, na.rm = TRUE)))
```
```r
call.equal(a2$absolute_abundance, 
c(sum(pu$spp1[lis.na(pu$cost)]), 
  sum(pu$spp2[lis.na(pu$cost)], na.rm = TRUE)))

call.equal(a2$relative_abundance, 
c(sum(pu$spp1[lis.na(pu$cost)])) / sum(pu$spp1, na.rm = TRUE), 
  sum(pu$spp2[lis.na(pu$cost)], na.rm = TRUE) / sum(pu$spp2, 
  na.rm = TRUE)))

# initialize conservation problem with raster data
p3 <- problem(sim_pu_raster, sim_features)

# calculate feature abundances; including planning units with \code{NA} costs
a3 <- feature_abundances(p3, na.rm = FALSE) # (default)
print(a3)

# create problem using total amounts of features in all the planning units
# (including units with NA cost data)
p4 <- p3 %>%
  add_min_set_objective() %>%
  add_relative_targets(a3$relative_abundance) %>%
  add_binary_decisions()

# attempt to solve the problem, but we will see that this problem is
# infeasible because the targets cannot be met using only the planning units
# with finite cost data
s4 <- try(solve(p4))

# calculate feature abundances; excluding planning units with \code{NA} costs
a5 <- feature_abundances(p3, na.rm = TRUE)
print(a5)

# create problem using total amounts of features in the planning units with
# finite cost data
p5 <- p3 %>%
  add_min_set_objective() %>%
  add_relative_targets(a5$relative_abundance) %>%
  add_binary_decisions()

# solve the problem
s5 <- solve(p5)

# plot the solution
# this solution contains all the planning units with finite cost data (i.e.
# cost data that do not have NA values)
plot(s5)
```

<table>
<thead>
<tr>
<th>feature_names</th>
<th>Feature names</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**feature_representation**

**Description**

Extract the names of the features in an object.

**Usage**

```r
feature_names(x)
```

## S4 method for signature 'ConservationProblem'

```r
feature_names(x)
```

## S4 method for signature 'ZonesRaster'

```r
feature_names(x)
```

## S4 method for signature 'ZonesCharacter'

```r
feature_names(x)
```

**Arguments**

- `x`  
  `ConservationProblem-class` or `Zones`

**Value**

character feature names.

**Examples**

```r
# load data
data(sim_pu_raster, sim_features)

# create problem
p <- problem(sim_pu_raster, sim_features) %>%
    add_min_set_objective() %>%
    add_relative_targets(0.2) %>%
    add_binary_decisions()

# print feature names
print(feature_names(p))
```

---

**feature_representation**

*Feature representation*

**Description**

Calculate how well features are represented in a solution.
Usage

feature_representation(x, solution)

## S4 method for signature 'ConservationProblem,numeric'
feature_representation(x, solution)

## S4 method for signature 'ConservationProblem, matrix'
feature_representation(x, solution)

## S4 method for signature 'ConservationProblem, data.frame'
feature_representation(x, solution)

## S4 method for signature 'ConservationProblem, Spatial'
feature_representation(x, solution)

## S4 method for signature 'ConservationProblem, sf'
feature_representation(x, solution)

## S4 method for signature 'ConservationProblem, Raster'
feature_representation(x, solution)

Arguments

x ConservationProblem-class object.

solution numeric, matrix, data.frame, Raster-class, Spatial-class, or sf object. See the Details section for more information.

Details

Note that all arguments to solution must correspond to the planning unit data in the argument to x in terms of data representation, dimensionality, and spatial attributes (if applicable). This means that if the planning unit data in x is a numeric vector then the argument to solution must be a numeric vector with the same number of elements, if the planning unit data in x is a RasterLayer-class then the argument to solution must also be a RasterLayer-class with the same number of rows and columns and the same resolution, extent, and coordinate reference system, if the planning unit data in x is a Spatial-class or sf object then the argument to solution must also be a Spatial-class or sf object, respectively, and have the same number of spatial features (e.g. polygons) and have the same coordinate reference system, if the planning units in x are a data.frame then the argument to solution must also be a data.frame with each column correspond to a different zone and each row correspond to a different planning unit, and values correspond to the allocations (e.g. values of zero or one).

Solutions must have planning unit statuses set to missing (NA) values for planning units that have missing (NA) cost data. For problems with multiple zones, this means that planning units must have missing (NA) allocation values in zones where they have missing (NA) cost data. In other words, planning units that have missing (NA) cost values in x should always have a missing (NA) value the argument to solution. If an argument is supplied to solution where this is not the case, then an error will be thrown. Please note that earlier versions of the prioritizr (prior to 4.0.4.1) required
that such planning units always have zero values, but this has been changed to make the handling of missing values more consistent throughout the package.

Additionally, note that when calculating the proportion of each feature represented in the solution, the denominator is calculated using all planning units—including any planning units with NA cost values in the argument to x. This is exactly the same equation used when calculating relative targets for problems (e.g. add_relative_targets).

Value

tibble object containing the amount ("absolute_held") and proportion ("relative_held") of the distribution of each feature held in the solution. Here, each row contains data that pertain to a specific feature in a specific management zone (if multiple zones are present). This object contains the following columns:

feature character name of the feature.
zone character name of the zone (not included when the argument to x contains only one management zone).
absolute_held numeric total amount of each feature secured in the solution. If the problem contains multiple zones, then this column shows how well each feature is represented in each zone.
relative_held numeric proportion of the feature’s distribution held in the solution. If the problem contains multiple zones, then this column shows how well each feature is represented in each zone.

See Also

problem, feature_abundances.

Examples

# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_raster, sim_pu_polygons, sim_pu_zones_sf, sim_features, sim_pu_zones_stack, sim_features_zones)

# create a simple conservation planning data set so we can see exactly how feature representation is calculated
pu <- data.frame(id = seq_len(10), cost = c(0.2, NA, runif(8)),
                 spp1 = runif(10), spp2 = c(rpois(9, 4), NA))

# create problem
pl <- problem(pu, c("spp1", "spp2"), cost_column = "cost") %>%
      add_min_set_objective() %>%
      add_relative_targets(0.1) %>%
      add_binary_decisions()

# create a solution
s1 <- data.frame(solution = c(1, NA, rep(c(1, 0), 4)))
print(s1)

# calculate feature representation
r1 <- feature_representation(p1, s1)
print(r1)

# verify that feature representation calculations are correct
all.equal(r1$absolute_held, c(sum(pu$spp1 * s1[[1]], na.rm = TRUE),
                   sum(pu$spp2 * s1[[1]], na.rm = TRUE)))
all.equal(r1$relative_held, c(sum(pu$spp1 * s1[[1]], na.rm = TRUE) /
                            sum(pu$spp1),
                   sum(pu$spp2 * s1[[1]], na.rm = TRUE) /
                            sum(pu$spp2, na.rm = TRUE)))

# solve the problem using an exact algorithm solver
s1_2 <- solve(p1)
print(s1_2)

# calculate feature representation in this solution
r1_2 <- feature_representation(p1, s1_2[, "solution_1", drop = FALSE])
print(r1_2)

# build minimal conservation problem with raster data
p2 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions()

# solve the problem
s2 <- solve(p2)

# print solution
print(s2)

# calculate feature representation in the solution
r2 <- feature_representation(p2, s2)
print(r2)

# plot solution
plot(s2, main = "solution", axes = FALSE, box = FALSE)

# build minimal conservation problem with polygon (Spatial) data
p3 <- problem(sim_pu_polygons, sim_features, cost_column = "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions()

# solve the problem
s3 <- solve(p3)

# print first six rows of the attribute table
print(head(s3))
# calculate feature representation in the solution
r3 <- feature_representation(p3, s3[, "solution_1"])
print(r3)

# plot solution
spplot(s3, zcol = "solution_1", main = "solution", axes = FALSE, box = FALSE)

# build multi-zone conservation problem with raster data
p4 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5,
                              ncol = 3)) %>%
  add_binary_decisions()

# solve the problem
s4 <- solve(p4)

# print solution
print(s4)

# calculate feature representation in the solution
r4 <- feature_representation(p4, s4)
print(r4)

# plot solution
plot(category_layer(s4), main = "solution", axes = FALSE, box = FALSE)

# build multi-zone conservation problem with polygon (sf) data
p5 <- problem(sim_pu_zones_sf, sim_features_zones,
              cost_column = c("cost_1", "cost_2", "cost_3")) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5,
                              ncol = 3)) %>%
  add_binary_decisions()

# solve the problem
s5 <- solve(p5)

# print first six rows of the attribute table
print(head(s5))

# calculate feature representation in the solution
r5 <- feature_representation(p5, s5[, c("solution_1_zone_1",
                                       "solution_1_zone_2",
                                       "solution_1_zone_3")])
print(r5)

# create new column representing the zone id that each planning unit
# was allocated to in the solution
s5$solution <- category_vector(s5[, c("solution_1_zone_1",
                                      "solution_1_zone_2",
                                      "solution_1_zone_3")],
                               col_names = TRUE)
ferrier_score

Ferrier irreplaceability score

Description

Calculate irreplaceability scores for planning units selected in a solution using the method outlined in Ferrier et al. (2000). Specifically, the scores are implemented following the CLUZ decision support tool (Smith 2019). Here, scores are calculated separately for each feature within each planning unit. Additionally, a total irreplaceability score is also calculated as the sum of the irreplaceability scores for each planning unit. Note that this function only works for problems with a minimum set objective and a single zone. It will throw an error for other types of problems.

Usage

ferrier_score(x, solution)

## S4 method for signature 'ConservationProblem,numeric'
ferrier_score(x, solution)

## S4 method for signature 'ConservationProblem,matrix'
ferrier_score(x, solution)

## S4 method for signature 'ConservationProblem,data.frame'
ferrier_score(x, solution)

## S4 method for signature 'ConservationProblem,Spatial'
ferrier_score(x, solution)

## S4 method for signature 'ConservationProblem,Raster'
ferrier_score(x, solution)

Arguments

x ConservationProblem-class object.
solution numeric, matrix, data.frame, Raster-class, or Spatial-class object. See the Details section for more information.
Details
The argument to solution must correspond to the planning unit data in the argument to x in terms of data representation, dimensionality, and spatial attributes (if applicable). This means that if the planning unit data in x is a numeric vector then the argument to solution must be a numeric vector with the same number of elements, if the planning unit data in x is a RasterLayer-class then the argument to solution must also be a RasterLayer-class with the same number of rows and columns and the same resolution, extent, and coordinate reference system, if the planning unit data in x is a Spatial-class object then the argument to solution must also be a Spatial-class object and have the same number of spatial features (e.g. polygons) and have the same coordinate reference system, if the planning units in x are a data.frame then the argument to solution must also be a data.frame with each column correspond to a different zone and each row correspond to a different planning unit, and values correspond to the allocations (e.g. values of zero or one). Furthermore, solutions must have planning unit statuses set to missing (NA) values for planning units that have missing (NA) cost data. If an argument is supplied to solution where this is not the case, then an error will be thrown.

Value
A matrix, tibble, RasterLayer-class, or Spatial-class object containing the scores for each planning unit selected in the solution.

References
Ferrier S, Pressey RL, and Barrett TW (2000) A new predictor of the irreplaceability of areas for achieving a conservation goal, its application to real-world planning, and a research agenda for further refinement. Biological Conservation, 93: 303–325.


See Also
irreplaceability.

Examples
# seed seed for reproducibility
set.seed(600)

# load data
data(sim_pu_raster, sim_features)

# create minimal problem with binary decisions
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(gap = 0, verbose = FALSE)

# solve problem
s1 <- solve(p1)
# print solution
print(s1)

# plot solution
plot(s1, main = "solution", axes = FALSE, box = FALSE)

# calculate irreplaceability scores using Ferrier et al. 2000 method
fs1 <- ferrier_score(p1, s1)

# print irreplaceability scores,
# each planning unit has an irreplaceability score for each feature
# (as indicated by the column names) and each planning unit also
# has an overall total irreplaceability score (in the "total" column)
print(fs1)

# plot total irreplaceability scores
plot(fs1, axes = FALSE, box = FALSE)

intersecting_units  Find intersecting units

Description
Find which of the units in a spatial data object intersect with the units in another spatial data object.

Usage
intersecting_units(x, y)

## S4 method for signature 'Raster,Raster'
intersecting_units(x, y)

## S4 method for signature 'Spatial,Spatial'
intersecting_units(x, y)

## S4 method for signature 'sf,Spatial'
intersecting_units(x, y)

## S4 method for signature 'Spatial,Raster'
intersecting_units(x, y)

## S4 method for signature 'Spatial,sf'
intersecting_units(x, y)

## S4 method for signature 'Raster,Spatial'
intersecting_units(x, y)
## S4 method for signature 'sf,sf'
intersecting_units(x, y)

## S4 method for signature 'Raster,sf'
intersecting_units(x, y)

## S4 method for signature 'sf,Raster'
intersecting_units(x, y)

## S4 method for signature 'data.frame,ANY'
intersecting_units(x, y)

### Arguments

- **x**: Spatial-class or Raster-class object.
- **y**: Spatial-class or Raster-class object.

### Value

integer indices of the units in x that intersect with y.

### See Also

fast_extract.

### Examples

```r
# create data
r <- raster(matrix(1:9, byrow = TRUE, ncol=3))
r_with_holes <- r
r_with_holes[c(1, 5, 9)] <- NA
ply <- rasterToPolygons(r)
ply_with_holes <- st_as_sf(rasterToPolygons(r_with_holes))

# intersect raster with raster
par(mfrow = c(1, 2))
plot(r, main = "x=Raster")
plot(r_with_holes, main = "y=Raster")
print(intersecting_units(r, r_with_holes))

# intersect raster with polygons (sf)
par(mfrow = c(1, 2))
plot(r, main = "x=Raster")
plot(ply_with_holes, main = "y=sf", key.pos = NULL, reset = FALSE)
print(intersecting_units(r, ply_with_holes))
```
Irreplaceability scores can be used to assess the relative importance of planning units in a solution to a conservation planning problem.

### Details

The following methods are available for calculating irreplaceability scores:

- **replacement_cost** The replacement cost scores (based on Cabeza and Moilanen 2006) quantify the change in the objective function (e.g. additional costs required to meet feature targets) of the optimal solution if a given planning unit in a solution cannot be acquired. They can (i) account for the cost of different planning units, (ii) account for multiple management zones, (iii) apply to any objective function, and (iv) identify truly irreplaceable planning units (denoted with infinite values).

- **ferrier_score** The Ferrier scores (Ferrier et al. 2000) quantify the importance of planning units for meeting feature targets. They can only be applied to conservation problems with a minimum set objective and a single zone (i.e. the classic Marxan-type problem). Furthermore—unlike the replacement cost scores—the Ferrier irreplaceability scores provide a score for each feature within each planning unit, providing insight into why certain planning units are more important than other planning units.

- **rarity_weighted_richness** The rarity weighted richness scores (based on Williams et al. 1996) are simply a measure of biological diversity. They do not account for planning costs, multiple management zones, objective functions, or feature targets (or weightings). They merely describe the spatial patterns of biodiversity, and do not account for many of the factors needed to quantify the importance of a planning unit for achieving conservation goals.
Generally speaking, we recommend using replacement cost scores for small and moderate sized problems (e.g. less than 30,000 planning units) when it is feasible to do so. It can take a very long time to compute replacement cost scores, and so it is simply not feasible to compute these scores for particularly large problems. For moderate and large sized problems (e.g. more than 30,000 planning units), we recommend using the Ferrier irreplaceability scores if possible. As mentioned earlier, the Ferrier irreplaceability scores can only be used for a specific type of conservation problem. For large sized problems (e.g. more than 100,000 planning units), we recommend using the rarity weighted richness scores simply because there is no other choice available. It has been known for decades that such static measures of biodiversity lead to poor conservation plans (Kirkpatrick 1983).

References


Ferrier S, Pressey RL, and Barrett TW (2000) A new predictor of the irreplaceability of areas for achieving a conservation goal, its application to real-world planning, and a research agenda for further refinement. Biological Conservation, 93: 303–325.


See Also

problem.

Examples

```r
# load data
data(sim_pu_raster, sim_pu_polygons, sim_features)

# build minimal conservation problem with raster data
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(gap = 0, verbose = FALSE)

# solve the problem
s1 <- solve(p1)

# plot solution
plot(s1, main = "solution", axes = FALSE, box = FALSE)

# calculate irreplaceability scores using replacement cost scores
irl1 <- replacement_cost(p1, s1)

# calculate irreplaceability scores using Ferrier et al 2000 method,
```
# and extract the total irreplaceability scores
ir2 <- ferrier_score(p1, s1)["total"]

# calculate irreplaceability scores using rarity weighted richness scores
ir3 <- rarity_weighted_richness(p1, s1)

# plot irreplaceability scores
plot(stack(ir1, ir2, ir3), axes = FALSE, box = FALSE,
     main = c("replacement cost", "Ferrier score",
              "rarity weighted richness"))

---

**is.Id**

*Is it?*

**Description**

Test if an object inherits from a class.

**Usage**

```r
is.Id(x)
```

**Arguments**

- `x` Object.

**Value**

logical indicating if it inherits from the class.

---

**loglinear_interpolation**

*Log-linear interpolation*

**Description**

Log-linearly interpolate values between two thresholds.

**Usage**

```r
loglinear_interpolation(
    x, coordinate_one_x, coordinate_one_y, coordinate_two_x, coordinate_two_y
)
```
marxan_boundary_data_to_matrix

Arguments

x numeric x values for which interpolate y values.
coordinate_one_x numeric value for lower x-coordinate.
coordinate_one_y numeric value for lower y-coordinate.
coordinate_two_x numeric value for upper x-coordinate.
coordinate_two_y numeric value for upper y-coordinate.

Details

Values are log-linearly interpolated at the x-coordinates specified in x using the lower and upper coordinate arguments to define the line. Values lesser or greater than these numbers are assigned the minimum and maximum y coordinates.

Value

numeric values.

Examples

# create series of x-values
x <- seq(0, 1000)

# interpolate y-values for the x-values given the two reference points: # (200, 100) and (900, 15)
y <- loglinear_interpolation(x, 200, 100, 900, 15)

# plot the interpolated values
plot(y ~ x)

# add the reference points to the plot (shown in red)
points(x = c(200, 900), y = c(100, 15), pch = 18, col = "red", cex = 2)

marxan_boundary_data_to_matrix

Convert Marxan boundary data to a matrix format

Description

Convert a data.frame object that follows the Marxan format to a matrix format. This function is useful for converting data.frame objects to matrix or array objects that are used by the various penalties and constraints functions. If the boundary data contains data for a single zone, then a matrix object is returned. Otherwise if the boundary data contains data for multiple zones, then an array is returned.
Usage

marxan_boundary_data_to_matrix(x, data)

Arguments

x  ConservationProblem-class object that contains planning unit and zone data to ensure that the argument to data is converted correctly. This argument can be set to NULL if checks are not required (not recommended).

data  data.frame object with the columns "id1", "id2", and "boundary". The columns "zone1" and "zone2" can also be provided to indicate zone data.

Value

array or sparse matrix (dgCMatrix-class) object.

Examples

# create marxan boundary with four planning units and one zone
bldf1 <- expand.grid(id1 = seq_len(4), id2 = seq_len(4))
bldf1$boundary <- 1
bldf1$boundary[bldf1$id1 == bldf1$id2] <- 0.5

# convert to matrix
m1 <- marxan_boundary_data_to_matrix(NULL, bldf1)

# visualize matrix
image(m1)

# create marxan boundary with three planning units and two zones
bldf2 <- expand.grid(id1 = seq_len(3), id2 = seq_len(3),
zone1 = c("z1", "z2"),
zone2 = c("z1", "z2"))
bldf2$boundary <- 1
bldf2$boundary[bldf2$id1 == bldf2$id2 & bldf2$zone1 == bldf2$zone2] <- 0.5
bldf2$boundary[bldf2$id1 == bldf2$id2 & bldf2$zone1 != bldf2$zone2] <- 0

# convert to array
m2 <- marxan_boundary_data_to_matrix(NULL, bldf2)

# print array
print(m2)

marxan_problem  Marxan conservation problem

Description

Create a conservation planning problem following the mathematical formulations used in Marxan (detailed in Beyer et al. 2016).
Usage

marxan_problem(x, ...)

## Default S3 method:
marxan_problem(x, ...)

## S3 method for class 'data.frame'
marxan_problem(x, spec, puvspr, bound = NULL, blm = 0, ...)

## S3 method for class 'character'
marxan_problem(x, ...)

Arguments

x character file path for a Marxan input file (typically called "input.dat"),
or data.frame containing planning unit data (typically called "pu.dat"). If
the argument to x is a data.frame, then each row corresponds to a different
planning unit, and it must have the following columns:

"id" integer unique identifier for each planning unit. These identifiers are
used in the argument to puvspr.
"cost" numeric cost of each planning unit.
"status" integer indicating if each planning unit should not be locked in
the solution (0) or if it should be locked in (2) or locked out (3) of the
solution. Although Marxan allows planning units to be selected in the initial
solution (using values of 1), these values have no effect here. This column
is optional.

... not used.

spec data.frame containing information on the features. The argument to spec must
follow the conventions used by Marxan for the species data file
(conventionally called "spec.dat"). Each row corresponds to a different feature and each column
corresponds to different information about the features. It must contain
the columns listed below. Note that the argument to spec must contain at least
one column named "prop" or "amount"—but not both columns with both of
these names—to specify the target for each feature.

"id" integer unique identifier for each feature. These identifiers are used in
the argument to puvspr.
"name" character name for each feature.
"prop" numeric relative target for each feature (optional).
"amount" numeric absolute target for each feature (optional).

puvspr data.frame containing information on the amount of each feature in each planning unit. The argument to puvspr must follow the conventions used in the Marxan input data file (conventionally called "puvspr.dat"). It must contain the following columns:

"pu" integer planning unit identifier.
"species" integer feature identifier.
"amount" numeric amount of the feature in the planning unit.

bound NULL object indicating that no boundary data is required for the conservation planning problem, or a data.frame containing information on the planning units' boundaries. The argument to bound must follow the conventions used in the Marxan input data file (conventionally called "bound.dat"). It must contain the following columns:

"id1" integer planning unit identifier.
"id2" integer planning unit identifier.
"boundary" numeric length of shared boundary between the planning units identified in the previous two columns.

blm numeric boundary length modifier. This argument only has an effect when argument to x is a data.frame. The default argument is zero.

Details
This function is provided as a convenient wrapper for solving Marxan problems using prioritizr. Although this function could accommodate asymmetric connectivity in earlier versions of the prioritizr package, this functionality is no longer available. Please see the add_connectivity_penalties function for adding asymmetric connectivity penalties to a conservation planning problem.

Value
ConservationProblem-class object.

References

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

Examples
# create Marxan problem using Marxan input file
input_file <- system.file("extdata/input.dat", package = "prioritizr")
p1 <- marxan_problem(input_file)

# solve problem
s1 <- solve(p1)

# print solution
head(s1)
# create Marxan problem using data.frames that have been loaded into R
## load in planning unit data
pu_path <- system.file("extdata/input/pu.dat", package = "prioritizr")
pu_dat <- data.table::fread(pu_path, data.table = FALSE)
head(pu_dat)

## load in feature data
spec_path <- system.file("extdata/input/spec.dat", package = "prioritizr")
spec_dat <- data.table::fread(spec_path, data.table = FALSE)
head(spec_dat)

## load in planning unit vs feature data
puvspr_path <- system.file("extdata/input/puvspr.dat", package = "prioritizr")
puvspr_dat <- data.table::fread(puvspr_path, data.table = FALSE)
head(puvspr_dat)

## load in the boundary data
bound_path <- system.file("extdata/input/bound.dat", package = "prioritizr")
bound_dat <- data.table::fread(bound_path, data.table = FALSE)
head(bound_dat)

# create problem without the boundary data
p2 <- marxan_problem(pu_dat, spec_dat, puvspr_dat)

# solve problem
s2 <- solve(p2)

# print solution
head(s2)

# create problem with the boundary data and a boundary length modifier
# set to 5
p3 <- marxan_problem(pu_dat, spec_dat, puvspr_dat, bound_dat, 5)

# solve problem
s3 <- solve(p3)

# print solution
head(s3)

---

matrix_parameters  Matrix parameters

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Create a parameter that represents a matrix object.</td>
</tr>
</tbody>
</table>
Usage

```r
numeric_matrix_parameter(
  name,
  value,
  lower_limit = .Machine$double.xmin,
  upper_limit = .Machine$double.xmax,
  symmetric = FALSE
)
```

```r
binary_matrix_parameter(name, value, symmetric = FALSE)
```

Arguments

- **name**: character name of parameter.
- **value**: matrix object.
- **lower_limit**: numeric values denoting the minimum acceptable value in the matrix. Defaults to the smallest possible number on the system.
- **upper_limit**: numeric values denoting the maximum acceptable value in the matrix. Defaults to the smallest possible number on the system.
- **symmetric**: logical must the matrix be symmetric? Defaults to FALSE.

Value

*MiscParameter-class* object.

Examples

```r
# create matrix
m <- matrix(runif(9), ncol = 3)
colnames(m) <- letters[1:3]ownames(m) <- letters[1:3]

# create a numeric matrix parameter
p1 <- numeric_matrix_parameter("m", m)
print(p1) # print it
p1$get() # get value
p1$id # get id
p1$validate(m[, -1]) # check if parameter can be updated
p1$set(m + 1) # set parameter to new values
p1$print() # print it again

# create a binary matrix parameter
m <- matrix(round(runif(9)), ncol = 3)
colnames(m) <- letters[1:3]ownames(m) <- letters[1:3]

# create a binary matrix parameter
p2 <- binary_matrix_parameter("m", m)
print(p2) # print it
```
MiscParameter-class

p2$get() # get value
p2$id # get id
p2$validate(m[, -1]) # check if parameter can be updated
p2$set(m + 1) # set parameter to new values
p2$print() # print it again

 MiscParameter-class Miscellaneous parameter prototype

Description

This prototype is used to represent a parameter that can be any object. Only experts should interact directly with this prototype.

Fields

$id character identifier for parameter.
$name character name of parameter.
$value tibble object.
$validator list object containing a function that is used to validate changes to the parameter.
$widget list object containing a function used to construct a shiny interface for modifying values.

Usage

x$print()
x$show()
x$validate(x)
x$get()
x$set(x)
x$reset()
x$render(...)

Arguments

x object used to set a new parameter value.
... arguments passed to $widget.
Details

**print**  print the object.

**show**  show the object.

**validate**  check if a proposed new parameter is valid.

**get**  extract the parameter value.

**set**  update the parameter value.

**reset**  update the parameter value to be the default value.

**render**  create a shiny widget to modify parameter values.

See Also

Parameter-class.

---

misc_parameter  

*Miscellaneous parameter*

Description

Create a parameter that consists of a miscellaneous object.

Usage

misc_parameter(name, value, validator, widget)

Arguments

- **name**  character name of parameter.
- **value**  object.
- **validator**  function to validate changes to the parameter. This function must have a single argument and return either TRUE or FALSE depending on if the argument is valid candidate for the parameter.
- **widget**  function to render a shiny widget. This function should must have a single argument that accepts a valid object and return a shiny.tag or shiny.tag.list object.

Value

MiscParameter-class object.
Examples

```r
# load data
data(iris, mtcars)

# create table parameter can that can be updated to any other object
p1 <- misc_parameter("tbl", iris,
    function(x) TRUE,
    function(id, x) structure(id, .Class = "shiny.tag"))
print(p1) # print it
p1$get() # get value
p1$id # get id
p1$validate(mtcars) # check if parameter can be updated
p1$set(mtcars) # set parameter to mtcars
p1$print() # print it again

# create table parameter with validation function that requires
# all values in the first column to be less then 200 and that the
# parameter have the same column names as the iris data set
p2 <- misc_parameter("tbl2", iris,
    function(x) all(names(x) %in% names(iris)) &&
        all(x[1] < 200),
    function(id, x) structure(id, .Class = "shiny.tag"))
print(p2) # print it
p2$get() # get value
p2$id # get id
p2$validate(mtcars) # check if parameter can be updated
iris2 <- iris; iris2[1,1] <- 300 # create updated iris data set
p2$validate(iris2) # check if parameter can be updated
iris3 <- iris; iris3[1,1] <- 100 # create updated iris data set
p2$set(iris3) # set parameter to iris3
p2$print() # print it again
```

---

### new_id

<table>
<thead>
<tr>
<th>Identifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>new_id</td>
</tr>
</tbody>
</table>

**Description**

Generate a new unique identifier.

**Usage**

```r
new_id()
```

**Details**

Identifiers are made using the `UUIDgenerate`. 
new_optimization_problem

**Value**

Id object.

**See Also**

UUIDgenerate.

**Examples**

```r
# create new id
i <- new_id()

# print id
print(i)

# convert to character
as.character(i)

# check if it is an Id object
is.Id(i)
```

---

**new_optimization_problem**

*Optimization problem*

---

**Description**

Generate a new empty `OptimizationProblem-class` object.

**Usage**

`new_optimization_problem()`

**Value**

`OptimizationProblem-class` object.

**See Also**

`OptimizationProblem-methods`

**Examples**

```r
# create empty OptimizationProblem object
x <- new_optimization_problem()

# print new object
print(x)
```
**Description**

Create a waiver object.

**Usage**

`new_waiver()`

**Details**

This object is used to represent that the user has not manually specified a setting, and so defaults should be used. By explicitly using a `new_waiver()`, this means that NULL objects can be a valid setting. The use of a "waiver" object was inspired by the ggplot2 package.

**Value**

object of class Waiver.

**Examples**

```r
# create new waiver object
w <- new_waiver()

# print object
print(w)

# is it a waiver object?
is.Waiver(w)
```

---

**Description**

Extract the number of features in an object.
Usage

number_of_features(x)

## S4 method for signature 'ConservationProblem'
number_of_features(x)

## S4 method for signature 'OptimizationProblem'
number_of_features(x)

## S4 method for signature 'ZonesRaster'
number_of_features(x)

## S4 method for signature 'ZonesCharacter'
number_of_features(x)

Arguments

x ConservationProblem-class, OptimizationProblem-class or Zones object.

Value

integer number of features.

Examples

# load data
data(sim_pu_raster, sim_features)

# create problem
p <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions()

# print number of features
print(number_of_features(p))

Description

Extract the number of planning units in an object.
Usage

number_of_planning_units(x)

## S4 method for signature 'ConservationProblem'
number_of_planning_units(x)

## S4 method for signature 'OptimizationProblem'
number_of_planning_units(x)

Arguments

x ConservationProblem-class or OptimizationProblem-class object.

Value

integer number of planning units.

Examples

# load data
data(sim_pu_raster, sim_features)

# create problem
p <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions()

# print number of planning units
print(number_of_planning_units(p))

number_of_total_units  Number of total units

Description

Extract the number of total units in an object.

Usage

number_of_total_units(x)

## S4 method for signature 'ConservationProblem'
number_of_total_units(x)

Arguments

x ConservationProblem-class or OptimizationProblem-class object.
**Value**

integer number of total units.

**Examples**

```r
# load data
data(sim_pu_raster, sim_pu_zones_stack, sim_features, sim_features_zones)

# create problem with one zone
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions()

# print number of planning units
print(number_of_planning_units(p1))

# print number of total units
print(number_of_total_units(p1))

# create problem with multiple zones
p2 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(0.2, ncol = 3, nrow = 5)) %>%
  add_binary_decisions()

# print number of planning units
print(number_of_planning_units(p2))

# print number of total units
print(number_of_total_units(p2))
```

---

**number_of_zones**

<table>
<thead>
<tr>
<th>number_of_zones</th>
<th>Number of zones</th>
</tr>
</thead>
</table>

**Description**

Extract the number of zones in an object.

**Usage**

```r
number_of_zones(x)
```

## S4 method for signature 'ConservationProblem'

```r
number_of_zones(x)
```

## S4 method for signature 'OptimizationProblem'

```r
number_of_zones(x)
```
## S4 method for signature 'ZonesRaster'
number_of_zones(x)

## S4 method for signature 'ZonesCharacter'
number_of_zones(x)

### Arguments

- `x`: `ConservationProblem-class`, `OptimizationProblem-class`, or `Zones` object.

### Value

integer number of zones.

### Examples

```r
# load data
data(sim_pu_zones_stack, sim_features_zones)

# print number of zones in a Zones object
print(number_of_zones(sim_features_zones))

# create problem with multiple zones
p <- problem(sim_pu_zones_stack, sim_features_zones) %>%
    add_min_set_objective() %>%
    add_relative_targets(matrix(0.2, ncol = 3, nrow = 5)) %>%
    add_binary_decisions()

# print number of zones in the problem
print(number_of_zones(p))
```

---

### Objective-class

#### Objective prototype

This prototype is used to represent an objective that can be added to a `ConservationProblem-class` object. **This prototype represents a recipe to make an objective, to actually add an objective to a planning problem**: see `objectives`. Only experts should use this class directly.
## Problem objective

An objective is used to specify the overall goal of a conservation planning problem. All conservation planning problems involve minimizing or maximizing some kind of objective. For instance, the planner may require a solution that conserves enough habitat for each species while minimizing the overall cost of the reserve network. Alternatively, the planner may require a solution that maximizes the number of conserved species while ensuring that the cost of the reserve network does not exceed the budget.

### Details

Please note that failing to specify an objective before attempting to solve a problem will return an error.

The following objectives can be added to a conservation planning problem:

- **add_min_set_objective**: Minimize the cost of the solution whilst ensuring that all targets are met. This objective is similar to that used in Marxan.
- **add_max_cover_objective**: Represent at least one instance of as many features as possible within a given budget.
- **add_max_features_objective**: Fulfill as many targets as possible while ensuring that the cost of the solution does not exceed a budget.
- **add_min_shortfall_objective**: Minimize the shortfall for as many targets as possible while ensuring that the cost of the solution does not exceed a budget.
- **add_max_phylo_div_objective**: Maximize the phylogenetic diversity of the features represented in the solution subject to a budget.
- **add_max_phylo_end_objective**: Maximize the phylogenetic endemism of the features represented in the solution subject to a budget.
- **add_max_utility_objective**: Secure as much of the features as possible without exceeding a budget.

### See Also

[constraints](#), [decisions](#), [penalties](#), [portfolios](#), [problem](#), [solvers](#), [targets](#).

### Examples

```r
# load data
data(sim_pu_raster, sim_features, sim_phylogeny)

# create base problem
p <- problem(sim_pu_raster, sim_features) %>%
    add_relative_targets(0.1)
```
# create problem with added minimum set objective
p1 <- p %>% add_min_set_objective()

# create problem with added maximum coverage objective
# note that this objective does not use targets
p2 <- p %>% add_max_cover_objective(500)

# create problem with added maximum feature representation objective
p3 <- p %>% add_max_features_objective(1900)
# create problem with added minimum shortfall objective
p4 <- p %>% add_min_shortfall_objective(1900)

# create problem with added maximum phylogenetic diversity objective
p5 <- p %>% add_max_phylo_div_objective(1900, sim_phylogeny)

# create problem with added maximum phylogenetic diversity objective
p6 <- p %>% add_max_phylo_end_objective(1900, sim_phylogeny)

# create problem with added maximum utility objective
# note that this objective does not use targets
p7 <- p %>% add_max_utility_objective(1900)

# solve problems
s <- stack(solve(p1), solve(p2), solve(p3), solve(p4), solve(p5), solve(p6), solve(p7))

# plot solutions
plot(s, axes = FALSE, box = FALSE,
     main = c("minimum set", "maximum coverage", "maximum features",
              "minimum shortfall", "maximum phylogenetic diversity",
              "maximum phylogenetic endemism", "maximum utility"))

---

OptimizationProblem-class

*Optimization problem class*

**Description**

The OptimizationProblem class is used to represent an optimization problem. Data are stored in memory and accessed using an external pointer. **Only experts should interact with this class directly.**

**Fields**

$ptr externalptr object.
Usage

- `x$print()`
- `x$show()`
- `x$repr()`
- `x$ncol()`
- `x$nrow()`
- `x$ncell()`
- `x$modelsense()`
- `x$vtype()`
- `x$obj()`
- `x$A()`
- `x$rhs()`
- `x$sense()`
- `x$lb()`
- `x$ub()`
- `x$number_of_planning_units()`
- `x$number_of_features()`
- `x$number_of_zones()`
- `x$row_ids()`
- `x$col_ids()`
- `x$compressed_formulation()`

Arguments

- `ptr` externalptr object.

Details

- `print` print the object.
- `show` show the object.
- `repr` character representation of object.
- `ncol` integer number of columns (variables) in model matrix.
- `nrow` integer number of rows (constraints) in model matrix.
- `ncell` integer number of cells in model matrix.
- `modelsense` character model sense.
- `vtype` character vector of variable types.
- `obj` numeric vector of objective function.
- `A` dgCMatrix-class model matrix
- `rhs` numeric vector of right-hand-side constraints.
sense character vector of constraint senses.
lb numeric vector of lower bounds for each decision variable.
ub numeric vector of upper bounds for each decision variable.
number_of_features integer number of features in the problem.
number_of_planning_units integer number of planning units in the problem.
number_of_zones integer number of zones in the problem.
col_ids character names describing each decision variable (column) in the model matrix.
row_ids character names describing each constraint (row) in the model matrix.
compressed_formulation is the optimization problem formulated using a compressed version of the rij matrix?
shuffle_columns randomly shuffle the columns in the problem. This should almost never be called manually and only should only be called after the optimization problem has been fully constructed.

---

OptimizationProblem-methods

Description

These functions are used to access data from an OptimizationProblem-class object.

Usage

nrow(x)

## S4 method for signature 'OptimizationProblem'
nrow(x)

ncol(x)

## S4 method for signature 'OptimizationProblem'
ncol(x)

ncell(x)

## S4 method for signature 'OptimizationProblem'
ncell(x)

modelsense(x)

## S4 method for signature 'OptimizationProblem'
modelsense(x)
vtype(x)
## S4 method for signature 'OptimizationProblem'
vtype(x)

obj(x)
## S4 method for signature 'OptimizationProblem'
obj(x)

A(x)
## S4 method for signature 'OptimizationProblem'
A(x)

rhs(x)
## S4 method for signature 'OptimizationProblem'
rhs(x)

sense(x)
## S4 method for signature 'OptimizationProblem'
sense(x)

lb(x)
## S4 method for signature 'OptimizationProblem'
lb(x)

ub(x)
## S4 method for signature 'OptimizationProblem'
ub(x)

col_ids(x)
## S4 method for signature 'OptimizationProblem'
col_ids(x)

row_ids(x)
## S4 method for signature 'OptimizationProblem'
row_ids(x)

compressed_formulation(x)
## S4 method for signature 'OptimizationProblem'
compressed_formulation(x)

Arguments

x OptimizationProblem-class object.

Details

The functions return the following data:

- **nrow** integer number of rows (constraints).
- **ncol** integer number of columns (decision variables).
- **ncell** integer number of cells.
- **modelsense** character describing if the problem is to be maximized ("max") or minimized ("min").
- **vtype** character describing the type of each decision variable: binary ("B"), semi-continuous ("S"), or continuous ("C")
- **obj** numeric vector specifying the objective function.
- **A** dgCMatrix-class matrix object defining the problem matrix.
- **rhs** numeric vector with right-hand-side linear constraints
- **sense** character vector with the senses of the linear constraints ("<", ">", "=").
- **lb** numeric lower bound for each decision variable. Missing data values (NA) indicate no lower bound for a given variable.
- **ub** numeric upper bounds for each decision variable. Missing data values (NA) indicate no upper bound for a given variable.
- **number_of_planning_units** integer number of planning units in the problem.
- **number_of_features** integer number of features the problem.

Value

dgCMatrix-class, numeric vector, numeric vector, or scalar integer depending on the method used.

Description

This class is used to represent a parameter that has multiple values. Each value has a different label to differentiate values. **Only experts should interact directly with this class.**
Fields

$\text{id}$  identifier for parameter.
$\text{name}$  character name of parameter.
$\text{value}$  numeric vector of values.
$\text{default}$  numeric vector of default values.
$\text{class}$  character name of the class that the values inherit from (e.g. "integer").
$\text{lower_limit}$  numeric vector specifying the minimum permitted value for each element in \text{value}.
$\text{upper_limit}$  numeric vector specifying the maximum permitted value for each element in \text{value}.
$\text{widget}$  function used to construct a \text{shiny} interface for modifying values.

Usage

x$\text{print()}$
x$\text{show()}$
x$\text{reset()}$

Details

\text{print}  print the object.
\text{show}  show the object.
\text{reset}  change the parameter values to be the default values.

See Also

\text{ScalarParameter-class}.

Description

Create a new collection of Parameter objects.

Usage

parameters(...)

Arguments

...  \text{Parameter-class} objects.

Value

\text{Parameters-class} object.
Parameters-class

See Also

array_parameters, scalar_parameters.

Examples

# create two Parameter objects
p1 <- binary_parameter("parameter one", 1)
print(p1)

p2 <- numeric_parameter("parameter two", 5)
print(p2)

# store Parameter objects in a Parameters object
p <- parameters(p1, p2)
print(p)

Parameters-class

<table>
<thead>
<tr>
<th>Parameters class</th>
</tr>
</thead>
</table>

Description

This class represents a collection of Parameter-class objects. It provides methods for accessing, updating, and rendering the parameters stored inside it.

Fields

$parameters list object containing Parameter-class objects.

Usage

x$print()
x$show()
x$repr()
x$names()
x$ids()
x$length()
x$get(id)
x$set(id,value)
x$add(p)
x$render(id)
x$render_all()
Arguments

- **id**: Id object.
- **p**: Parameter-class object.
- **value**: any object.

Details

- **print**: print the object.
- **show**: show the object.
- **repr**: character representation of object.
- **names**: return character names of parameters.
- **ids**: return character parameter unique identifiers.
- **length**: return integer number of parameters in object.
- **get**: retrieve the value of a parameter in the object using an Id object.
- **set**: change the value of a parameter in the object to a new object.
- **render**: generate a shiny widget to modify the the value of a parameter (specified by argument Id).
- **render_all**: generate a div containing all the parameters' widgets.

---

**Conservation problem penalties**

Description

A penalty can be applied to a conservation planning problem to penalize solutions according to a specific metric. Penalties—unlike constraints—act as an explicit trade-off with the objective being minimized or maximized (e.g. solution cost when used with add_min_set_objective).

Details

Both penalties and constraints can be used to modify a problem and identify solutions that exhibit specific characteristics. Constraints work by invalidating solutions that do not exhibit specific characteristics. On the other hand, penalties work by specifying trade-offs against the main problem objective and are mediated by a penalty factor.

The following penalties can be added to a conservation planning problem:

- **add_boundary_penalties**: Add penalties to a conservation problem to favor solutions that have planning units clumped together into contiguous areas.
- **add_connectivity_penalties**: Add penalties to a conservation problem to favor solutions that select planning units with high connectivity between them.

See Also

constraints, decisions, objectives portfolios, problem, solvers, targets.
Examples

```r
# load data
data(sim_pu_points, sim_features)

# create basic problem
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_default_solver()

# create problem with boundary penalties
p2 <- p1 %>% add_boundary_penalties(5, 1)

# create connectivity matrix based on spatial proximity
scm <- as.data.frame(sim_pu_raster, xy = TRUE, na.rm = FALSE)
scm <- 1 / (as.matrix(dist(scm)) + 1)

# remove weak and moderate connections between planning units to reduce run time
scm[scm < 0.85] <- 0

# create problem with connectivity penalties
p3 <- p1 %>% add_connectivity_penalties(25, data = scm)

# solve problems
s <- stack(solve(p1), solve(p2), solve(p3))

# plot solutions
plot(s, axes = FALSE, box = FALSE,
     main = c("basic solution", "boundary penalties",
              "connectivity penalties"))
```

## Description

This prototype is used to represent penalties that are added to the objective function when making a conservation problem. **This prototype represents a recipe, to actually add penalties to a planning problem, see the help page on penalties. Only experts should use this class directly.** This prototype inherits from the `ConservationModifier-class`.

## See Also

`ConservationModifier-class`. 
Description

This prototype is used to represent methods for generating portfolios of optimization problems. This class represents a recipe to create portfolio generating method and is only recommended for use by expert users. To customize the method used to generate portfolios, please see the help page on portfolios.

Fields

$name character name of portfolio method.
$parameters Parameters object with parameters used to customize the the portfolio.
$run function used to generate a portfolio.

Usage

x$print()
x$show()
 x$repr()
 x$run(op,sol)

Arguments

x Solver-class object.
op OptimizationProblem-class object.

Details

print print the object.
show show the object.
repr character representation of object.
run solve an OptimizationProblem-class object using this object and a Solver-class object.
Description

Conservation planners often desire a portfolio of solutions to present to decision makers. This is because conservation planners often do not have access to "perfect" information, such as cost data that accurately reflects stakeholder preferences, and so having multiple near-optimal solutions can be useful.

Details

All methods for generating portfolios will return solutions that are within the specified optimality gap.

The following portfolios can be added to a conservation planning problem:

- **add_default_portfolio** Generate a single solution.
- **add_extra_portfolio** Generate a portfolio of solutions by storing feasible solutions found during the optimization process. This method is useful for quickly obtaining multiple solutions, but does not provide any guarantees on the number of solutions, or the quality of solutions. Note that it requires the *Gurobi* solver.
- **add_top_portfolio** Generate a portfolio of solutions by finding a pre-specified number of solutions that are closest to optimality (i.e the top solutions). This is useful for examining differences among near-optimal solutions. It can also be used to generate multiple solutions and, in turn, to calculate selection frequencies for small problems. Note that it requires the *Gurobi* solver.
- **add_gap_portfolio** Generate a portfolio of solutions by finding a certain number of solutions that are all within a pre-specified optimality gap. This method is useful for generating multiple solutions that can be used to calculate selection frequencies for moderate and large-sized problems (similar to *Marxan*). Note that it requires the *Gurobi* solver.
- **add_cuts_portfolio** Generate a portfolio of distinct solutions within a pre-specified optimality gap using Bender’s cuts. This is recommended as a replacement for **add_top_portfolio** when the *Gurobi* software is not available.
- **add_shuffle_portfolio** Generate a portfolio of solutions by randomly reordering the data prior to attempting to solve the problem. This is recommended as a replacement for **add_gap_portfolio** when the *Gurobi* software is not available.

See Also

- constraints, decisions, objectives penalties, problem, solvers, targets.
Examples

```r
# load data
data(sim_pu_raster, sim_features)

# create problem
p <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(gap = 0.02, verbose = FALSE)

# create problem with cuts portfolio with 4 solutions
p1 <- p %>% add_cuts_portfolio(4)

# create problem with shuffle portfolio with 4 solutions
p2 <- p %>% add_shuffle_portfolio(4)

# create problem with extra portfolio
p3 <- p %>% add_extra_portfolio()

# create problem with top portfolio with 4 solutions
p4 <- p %>% add_top_portfolio(4)

# create problem with gap portfolio with 4 solutions within 50% of optimality
p5 <- p %>% add_gap_portfolio(4, 0.5)

# solve problems and create solution portfolios
s <- list(solve(p1), solve(p2), solve(p3), solve(p4), solve(p5))

# plot solutions from extra portfolio
plot(stack(s[[1]]), axes = FALSE, box = FALSE)

# plot solutions from top portfolio
plot(stack(s[[2]]), axes = FALSE, box = FALSE)

# plot solutions from gap portfolio
plot(stack(s[[3]]), axes = FALSE, box = FALSE)

# plot solutions from cuts portfolio
plot(stack(s[[4]]), axes = FALSE, box = FALSE)

# plot solutions from shuffle portfolio
plot(stack(s[[5]]), axes = FALSE, box = FALSE)
```

Create a new pproto object

ppproto
predefined_optimization_problem

Description

Construct a new object with pproto. This object system is inspired from the ggproto system used in the ggplot2 package.

Usage

ppproto(`_class` = NULL, `_inherit` = NULL, ...)

Arguments

_class Class name to assign to the object. This is stored as the class attribute of the object. This is optional: if NULL (the default), no class name will be added to the object.

_inherit pproto object to inherit from. If NULL, don’t inherit from any object.

... A list of members to add to the new pproto object.

Examples

Adder <- pproto("Adder",
  x = 0,
  add = function(self, n) {
    self$x <- self$x + n
    self$x
  }
)

Adder$add(10)
Adder$add(10)

Abacus <- pproto("Abacus", Adder,
  subtract = function(self, n) {
    self$x <- self$x - n
    self$x
  }
)

Abacus$add(10)
Abacus$subtract(10)

---

predefined_optimization_problem

Predefined optimization problem

Description

Create a new OptimizationProblem-class object.
Usage

predefined_optimization_problem(x)

Arguments

x  list object containing data to construct the problem.

Details

The argument to x must be a list that contains the following elements:

- **modelsense** character model sense.
- **number_of_features** integer number of features in problem.
- **number_of_planning_units** integer number of planning units.
- **A_i** integer row indices for problem matrix.
- **A_j** integer column indices for problem matrix.
- **A_x** numeric values for problem matrix.
- **obj** numeric objective function values.
- **lb** numeric lower bound for decision values.
- **ub** numeric upper bound for decision values.
- **rhs** numeric right-hand side values.
- **sense** numeric constraint senses.
- **vtype** character variable types. These are used to specify that the decision variables are binary ("B") or continuous ("C").
- **row_ids** character identifiers for the rows in the problem matrix.
- **col_ids** character identifiers for the columns in the problem matrix.

Examples

```r
# create list with problem data
l <- list(modelsense = "min", number_of_features = 2,
    number_of_planning_units = 3, number_of_zones = 1,
    A_i = c(0L, 1L, 0L, 1L, 0L, 1L),
    A_j = c(0L, 0L, 1L, 1L, 2L, 2L),
    A_x = c(2, 10, 1, 10, 1, 10),
    obj = c(1, 2, 2),
    lb = c(0, 1, 0),
    ub = c(0, 1, 0),
    sense = c("=", ">="),
    vtype = c("B", "B", "B"),
    row_ids = c("spp_target", "spp_target"),
    col_ids = c("pu", "pu", "pu"))

# create OptimizationProblem object
x <- predefined_optimization_problem(l)

# print new object
print(x)
```
**Description**

Check a conservation planning problem for potential issues before trying to solve it. Specifically, problems are checked for (i) values that are likely to result in "strange" solutions and (ii) values that are likely to cause numerical instability issues and lead to unreasonably long run times when solving it. Although these checks are provided to help diagnose potential issues, please be aware that some detected issues may be false positives. Please note that these checks will not be able to verify if a problem has a feasible solution or not.

**Usage**

```r
presolve_check(x)
```

## S3 method for class 'ConservationProblem'

```r
presolve_check(x)
```

## S3 method for class 'OptimizationProblem'

```r
presolve_check(x)
```

**Arguments**

- `x` ConservationProblem-class or an OptimizationProblem-class object.

**Details**

This function checks for issues that are likely to result in "strange" solutions. Specifically, it checks if (i) all planning units are locked in, (ii) all planning units are locked out, and (iii) all planning units have negative cost values (after applying penalties if any were specified). Although such conservation planning problems are mathematically valid, they are generally the result of a coding mistake when building the problem (e.g. using an absurdly high penalty value or using the wrong dataset to lock in planning units). Thus such issues, if they are indeed issues and not false positives, can be fixed by carefully checking the code, data, and parameters used to build the conservation planning problem.

This function then checks for values that may lead to numerical instability issues when solving the problem. Specifically, it checks if the range of values in certain components of the optimization problem are over a certain threshold (i.e. $1 \times 10^9$) or if the values themselves exceed a certain threshold (i.e. $1 \times 10^{10}$). In most cases, such issues will simply cause an exact algorithm solver to take a very long time to generate a solution. In rare cases, such issues can cause incorrect calculations which can lead to exact algorithm solvers returning infeasible solutions (e.g. a solution to the minimum set problem where not all targets are met) or solutions that exceed the specified optimality gap (e.g. a suboptimal solution when a zero optimality gap is specified).

What can you do if a conservation planning problem fails to pass these checks? Well, this function will have thrown some warning messages describing the source of these issues, so read them carefully. For instance, a common issue is when a relatively large penalty value is specified for boundary
(add_boundary_penalties) or connectivity penalties (add_connectivity_penalties). This can be fixed by trying a smaller penalty value. In such cases, the original penalty value supplied was so high that the optimal solution would just have selected every single planning unit in the solution—and this may not be especially helpful anyway (see below for example). Another common issue is that the planning unit cost values are too large. For example, if you express the costs of the planning units in terms of USD then you might have some planning units that cost over one billion dollars in large-scale planning exercises. This can be fixed by rescaling the values so that they are smaller (e.g. multiplying the values by a number smaller than one, or expressing them as a fraction of the maximum cost). Let’s consider another common issue, let’s pretend that you used habitat suitability models to predict the amount of suitable habitat in each planning unit for each feature. If you calculated the amount of suitable habitat in each planning unit in square meters then this could lead to very large numbers. You could fix this by converting the units from square meters to square kilometers or thousands of square kilometers. Alternatively, you could calculate the percentage of each planning unit that is occupied by suitable habitat, which will yield values between zero and one hundred.

But what can you do if you can’t fix these issues by simply changing the penalty values or rescaling data? You will need to apply some creative thinking. Let’s run through a couple of scenarios. Let’s pretend that you have a few planning units that cost a billion times more than any other planning unit so you can’t fix this by rescaling the cost values. In this case, it’s extremely unlikely that these planning units will be selected in the optimal solution so just set the costs to zero and lock them out. If this procedure yields a problem with no feasible solution, because one (or several) of the planning units that you manually locked out contains critical habitat for a feature, then find out which planning unit(s) is causing this infeasibility and set its cost to zero. After solving the problem, you will need to manually recalculate the cost of the solutions but at least now you can be confident that you have the optimal solution. Now let’s pretend that you are using the maximum features objective (i.e. add_max_features_objective) and assigned some really high weights to the targets for some features to ensure that their targets were met in the optimal solution. If you set the weights for these features to one billion then you will probably run into numerical instability issues. Instead, you can calculate minimum weight needed to guarantee that these features will be represented in the optimal solution and use this value instead of one billion. This minimum weight value can be calculated as the sum of the weight values for the other features and adding a small number to it (e.g. 1). Finally, if you’re running out of ideas for addressing numerical stability issues you have one remaining option: you can use the numeric_focus argument in the add_gurobi_solver function to tell the solver to pay extra attention to numerical instability issues. This is not a free lunch, however, because telling the solver to pay extra attention to numerical issues can substantially increase run time. So, if you have problems that are already taking an unreasonable time to solve, then this will not help at all.

Value

Logical value indicating if all checks are passed successfully.

See Also

Examples

# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_raster, sim_features)

# create minimal problem with no issues
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions()

# run presolve checks
# note that no warning is thrown which suggests that we should not
# encounter any numerical stability issues when trying to solve the problem
print(presolve_check(p1))

# create a minimal problem, containing cost values that are really
# high so that they could cause numerical instability issues when trying
# to solve it
sim_pu_raster2 <- sim_pu_raster
sim_pu_raster2[1] <- 1e+15
p2 <- problem(sim_pu_raster2, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions()

# run presolve checks
# note that a warning is thrown which suggests that we might encounter
# some issues, such as long solve time or suboptimal solutions, when
# trying to solve the problem
print(presolve_check(p2))

# create a minimal problem with connectivity penalties values that have
# a really high penalty value that is likely to cause numerical instability
# issues when trying to solve the it
cm <- adjacency_matrix(sim_pu_raster)
p3 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_connectivity_penalties(1e+15, data = cm) %>%
  add_binary_decisions()

# run presolve checks
# note that a warning is thrown which suggests that we might encounter
# some numerical instability issues when trying to solve the problem
print(presolve_check(p3))

# let's forcibly solve the problem using Gurobi and tell it to
# be extra careful about numerical instability problems
s3 <- p3 %>%
add_gurobi_solver(numeric_focus = TRUE) %>%
solve(force = TRUE)

# plot solution
# we can see that all planning units were selected because the connectivity
# penalty is so high that cost becomes irrelevant, so we should try using
# a much lower penalty value
plot(s3, main = "solution", axes = FALSE, box = FALSE)

print

Description
Display information about an object.

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

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

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

## S4 method for signature 'Id'
print(x)

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

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

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

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

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

## S4 method for signature 'tbl_df'
print(x)
**Arguments**

- `x`  
  Any object.

- `...`
  not used.

**Value**

None.

**See Also**

`print`.

**Examples**

```r
a <- 1:4
print(a)
```

---

**Description**

The `prioritizr` R package uses integer linear programming (ILP) techniques to provide a flexible interface for building and solving conservation planning problems (Rodrigues et al. 2000; Billionnet 2013). It supports a broad range of objectives, constraints, and penalties that can be used to custom-tailor conservation planning problems to the specific needs of a conservation planning exercise. Once built, conservation planning problems can be solved using a variety of commercial and open-source exact algorithm solvers. In contrast to the algorithms conventionally used to solve conservation problems, such as heuristics or simulated annealing (Ball et al. 2009), the exact algorithms used here are guaranteed to find optimal solutions. Furthermore, conservation problems can be constructed to optimize the spatial allocation of different management actions or zones, meaning that conservation practitioners can identify solutions that benefit multiple stakeholders. Finally, this package has the functionality to read input data formatted for the Marxan conservation planning program (Ball et al. 2009), and find much cheaper solutions in a much shorter period of time than Marxan (Beyer et al. 2016). See the online code repository for more information.

**Details**

This package contains several vignettes that are designed to showcase its functionality. To view them, type of the command `vignette("name", package = "prioritizr")` where "name" is the name of the desired vignette (e.g. "gurobi_installation").

- `prioritizr` provides background information on systematic conservation planning and a comprehensive overview of the package and its usage.

- `gurobi_installation` contains detailed instructions for installing and setting up the Gurobi software suite for use with the package.
**publication_record** lists of scientific publications that have used the package for developing prioritzations.

**zones** describes how problems can be constructed with multiple management actions or zones.

**tasmania** provides a tutorial using Tasmania, Australia as a case-study. This tutorial uses vector-based planning unit data and is written for individuals familiar with the Marxan decision support tool.

**saltspring** provides a tutorial using Salt Spring Island, Canada as a case-study. This tutorial uses raster-based planning unit data.

References


---

**problem**  
*Conservation planning problem*

Description

Create a systematic conservation planning problem. This function is used to specify the basic data used in a spatial prioritization problem: the spatial distribution of the planning units and their costs, as well as the features (e.g. species, ecosystems) that need to be conserved. After constructing this ConservationProblem-class object, it can be customized to meet specific goals using objectives, targets, constraints, and penalties. After building the problem, the solve function can be used to identify solutions.

Usage

```r
problem(x, features, ...)  
## S4 method for signature 'Raster,Raster'
problem(x, features, run_checks, ...)  
## S4 method for signature 'Raster,ZonesRaster'
problem(x, features, run_checks, ...)  
## S4 method for signature 'Spatial,Raster'
problem(x, features, cost_column, run_checks, ...)
```
Arguments

- **x**
  - Raster-class, sf, SpatialPolygonsDataFrame-class, SpatialLinesDataFrame-class, SpatialPointsDataFrame-class, data.frame object, numeric vector, or matrix specifying the planning units to use in the reserve design exercise and their corresponding cost. It may be desirable to exclude some planning units from the analysis, for example those outside the study area. To exclude planning units, set the cost for those raster cells to NA, or use the `add_locked_out_constraint` function.

- **features**
  - The feature data can be specified in a variety of ways. The specific formats that can be used depend on the cost data format (i.e. argument to x) and whether
the problem should have a single zone or multiple zones. If the problem should have a single zone, then the feature data can be specified following:

- \( x = \text{RasterLayer-class}, \text{or } x = \text{Spatial-class}, \text{or } x = \text{sf}; y = \text{Raster-class} \) object showing the distribution of conservation features. Missing values (i.e. NA values) can be used to indicate the absence of a feature in a particular cell instead of explicitly setting these cells to zero. Note that this argument type for features can only be used to specify data for problems involving a single zone.

- \( x = \text{Spatial-class}, x = \text{sf}, \text{or } x = \text{data.frame}; y = \text{character} \) vector with column names that correspond to the abundance or occurrence of different features in each planning unit. Note that this argument type can only be used to create problems involving a single zone.

- \( x = \text{Spatial-class}, x = \text{sf}, x = \text{data.frame}, x = \text{numeric vector}, \text{or } x = \text{matrix}; y = \text{data.frame} \) object containing the names of the features. Note that if this type of argument is supplied to features then the argument \( r_{ij} \) or \( r_{ij, \text{matrix}} \) must also be supplied. This type of argument should follow the conventions used by Marxan, wherein each row corresponds to a different feature. It must also contain the following columns:
  - "id" integer unique identifier for each feature. These identifiers are used in the argument to \( r_{ij} \).
  - "name" character name for each feature.
  - "prop" numeric relative target for each feature (optional).
  - "amount" numeric absolute target for each feature (optional).

If the problem should have multiple zones, then the feature data can be specified following:

- \( x = \text{RasterStack-class}, x = \text{RasterBrick-class}, x = \text{Spatial-class}, \text{or } x = \text{sf}; y = \text{ZonesRaster} \) object showing the distribution of conservation features in multiple zones. As above, missing values (i.e. NA values) can be used to indicate the absence of a feature in a particular cell instead of explicitly setting these cells to zero.

- \( x = \text{Spatial-class}, x = \text{sf}, \text{or } x = \text{data.frame}; y = \text{ZonesCharacter} \) object with column names that correspond to the abundance or occurrence of different features in each planning unit in different zones.

... not used.

**run_checks** logical flag indicating whether checks should be run to ensure the integrity of the input data. These checks are run by default; however, for large data sets they may increase run time. If it is taking a prohibitively long time to create the prioritization problem, it is suggested to try setting run_checks to FALSE.

**cost_column** character name or integer indicating the column(s) with the cost data. This argument must be supplied when the argument to \( x \) is a Spatial-class or data.frame object. This argument should contain the name of each column containing cost data for each management zone when creating problems with multiple zones. To create a problem with a single zone, then set the argument to cost_column as a single column name.
rij data.frame containing information on the amount of each feature in each planning unit assuming each management zone. Similar to data.frame arguments for features, the data.frame objects must follow the conventions used by Marxan. Note that the "zone" column is not needed for problems involving a single management zone. Specifically, the argument should contain the following columns:
"pu" integer planning unit identifier.
"species" integer feature identifier.
"zone" integer zone identifier (optional for problems involving a single zone).
"amount" numeric amount of the feature in the planning unit.

zones data.frame containing information on the zones. This argument is only used when argument to x and y are both data.frame objects and the problem being built contains multiple zones. Following conventions used in MarZone, this argument should contain the following columns: columns:
"id" integer zone identifier.
"name" character zone name.

rij_matrix list of matrix or dgCMatrix-class objects specifying the amount of each feature (rows) within each planning unit (columns) for each zone. The list elements denote different zones, matrix rows denote features, and matrix columns denote planning units. For convenience, the argument to rij_matrix can be a single matrix or dgCMatrix-class when specifying a problem with a single management zone. This argument is only used when the argument to x is a numeric or matrix object.

Details

A reserve design exercise starts by dividing the study region into planning units (typically square or hexagonal cells) and, for each planning unit, assigning values that quantify socioeconomic cost and conservation benefit for a set of conservation features. The cost can be the acquisition cost of the land, the cost of management, the opportunity cost of foregone commercial activities (e.g. from logging or agriculture), or simply the area. The conservation features are typically species (e.g. Clouded Leopard) or habitats (e.g. mangroves or cloud forest). The benefit that each feature derives from a planning unit can take a variety of forms, but is typically either occupancy (i.e. presence or absence) or area of occurrence within each planning unit. Finally, in some types of reserve design models, representation targets must be set for each conservation feature, such as 20 extent of cloud forest or 10,000 km^2 of Clouded Leopard habitat (see targets).

The goal of the reserve design exercise is then to optimize the trade-off between conservation benefit and socioeconomic cost, i.e. to get the most benefit for your limited conservation funds. In general, the goal of an optimization problem is to minimize an objective function over a set of decision variables, subject to a series of constraints. The decision variables are what we control, usually there is one binary variable for each planning unit specifying whether or not to protect that unit (but other approaches are available, see decisions). The constraints can be thought of as rules that need to be followed, for example, that the reserve must stay within a certain budget or meet the representation targets.

Integer linear programming (ILP) is the subset of optimization algorithms used in this package to solve reserve design problems. The general form of an integer programming problem can be expressed in matrix notation using the following equation.
Minimize $c^T x$ subject to $A x \geq b$ or $A x \leq b$

Here, $x$ is a vector of decision variables, $c$ and $b$ are vectors of known coefficients, and $A$ is the constraint matrix. The final term specifies a series of structural constraints where relational operators for the constraint can be either $\geq$, $=$, or $\leq$ the coefficients. For example, in the minimum set cover problem, $c$ would be a vector of costs for each planning unit, $b$ a vector of targets for each conservation feature, the relational operator would be $\geq$ for all features, and $A$ would be the representation matrix with $A_{ij} = r_{ij}$, the representation level of feature $i$ in planning unit $j$.

Please note that this function internally computes the amount of each feature in each planning unit when this data is not supplied (using the $rij_matrix$ parameter). As a consequence, it can take a while to initialize large-scale conservation planning problems that involve millions of planning units.

**Value**

A ConservationProblem-class object containing the basic data used to build a prioritization problem.

**See Also**

constraints, decisions, objectives.penalties, portfolios, solvers, targets, feature_representation, irreplaceability.

**Examples**

```r
# load data
data(sim_pu_raster, sim_pu_polygons, sim_pu_lines, sim_pu_points,
sim_pu_sf, sim_features)

# create problem using raster planning unit data
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions()

# create problem using polygon (Spatial) planning unit data
p2 <- problem(sim_pu_polygons, sim_features, "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions()

# create problem using line (Spatial) planning unit data
p3 <- problem(sim_pu_lines, sim_features, "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions()

# create problem using point (Spatial) planning unit data
```r
p4 <- problem(sim_pu_points, sim_features, "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions()

# create problem using polygon (sf) planning unit data
p5 <- problem(sim_pu_sf, sim_features, "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions()

# add columns to polygon planning unit data representing the abundance
# of species inside them
sim_pu_polygons$spp_1 <- rpois(length(sim_pu_polygons), 5)
sim_pu_polygons$spp_2 <- rpois(length(sim_pu_polygons), 8)
sim_pu_polygons$spp_3 <- rpois(length(sim_pu_polygons), 2)

# create problem using pre-processed data when feature abundances are
# stored in the columns of an attribute table for a spatial vector data set
p6 <- problem(sim_pu_polygons, features = c("spp_1", "spp_2", "spp_3"),
              "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions()

# alternatively one can supply pre-processed aspatial data
costs <- sim_pu_polygons$cost
features <- data.frame(id = seq_len(nlayers(sim_features)),
                        name = names(sim_features))
rij_mat <- rij_matrix(sim_pu_polygons, sim_features)
p7 <- problem(costs, features, rij_matrix = rij_mat) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions()

# solve problems
s1 <- solve(p1)
s2 <- solve(p2)
s3 <- solve(p3)
s4 <- solve(p4)
s5 <- solve(p5)
s6 <- solve(p6)
s7 <- solve(p7)

# plot solutions for problems associated with spatial data
par(mfrow = c(3, 2), mar = c(0, 0, 4.1, 0))
plot(s1, main = "raster data", axes = FALSE, box = FALSE)
plot(s2, main = "polygon data")
plot(s2[s2$solution_1 == 1, ], col = "darkgreen", add = TRUE)
plot(s3, main = "line data")
lines(s3[s3$solution_1 == 1, ], col = "darkgreen", lwd = 2)
```
plot(s4, main = "point data", pch = 19)
points(s4[s4$solution_1 == 1, ], col = "darkgreen", cex = 2, pch = 19)

plot(s5, main = "sf (polygon) data", pch = 19)
points(s5[s5$solution_1 == 1, ], col = "darkgreen", cex = 2, pch = 19)

plot(s6, main = "preprocessed data", pch = 19)
plot(s6[s6$solution_1 == 1, ], col = "darkgreen", add = TRUE)

# show solutions for problems associated with aspatial data
str(s7)

# create some problems with multiple zones

# first, create a matrix containing the targets for multi-zone problems
# here each row corresponds to a different feature, each
# column corresponds to a different zone, and values correspond
# to the total (absolute) amount of a given feature that needs to be secured
# in a given zone
targets <- matrix(rpois(15, 1),
nrow = number_of_features(sim_features_zones),
ncol = number_of_zones(sim_features_zones),
dimnames = list(feature_names(sim_features_zones),
                zone_names(sim_features_zones)))

# print targets
print(targets)

# create a multi-zone problem with raster data
p8 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
    add_min_set_objective() %>%
    add_absolute_targets(targets) %>%
    add_binary_decisions()

# solve problem
s8 <- solve(p8)

# plot solution
# here, each layer/panel corresponds to a different zone and pixel values
# indicate if a given planning unit has been allocated to a given zone
par(mfrow = c(1, 1))
plot(s8, main = c("zone 1", "zone 2", "zone 3"), axes = FALSE, box = FALSE)

# alternatively, the category_layer function can be used to create
# a new raster object containing the zone ids for each planning unit
# in the solution (note this only works for problems with binary decisions)
par(mfrow = c(1, 1))
plot(category_layer(s8), axes = FALSE, box = FALSE)

# create a multi-zone problem with polygon data
p9 <- problem(sim_pu_zones_polygons, sim_features_zones,
              cost_column = c("cost_1", "cost_2", "cost_3")) %>%
# solve problem
s9 <- solve(p9)

# create column containing the zone id for which each planning unit was allocated to in the solution
s9$solution <- category_vector(s9$data[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")])

s9$solution <- factor(s9$solution)

# plot solution
spplot(s9, zcol = "solution", main = "solution", axes = FALSE, box = FALSE)

# create a multi-zone problem with polygon planning unit data
# and where fields (columns) in the attribute table correspond to feature abundances
# first fields need to be added to the planning unit data
# which indicate the amount of each feature in each zone
# to do this, the fields will be populated with random counts
sim_pu_zones_polygons$spp1_z1 <- rpois(nrow(sim_pu_zones_polygons), 1)
sim_pu_zones_polygons$spp2_z1 <- rpois(nrow(sim_pu_zones_polygons), 1)
sim_pu_zones_polygons$spp3_z1 <- rpois(nrow(sim_pu_zones_polygons), 1)
sim_pu_zones_polygons$spp1_z2 <- rpois(nrow(sim_pu_zones_polygons), 1)
sim_pu_zones_polygons$spp2_z2 <- rpois(nrow(sim_pu_zones_polygons), 1)
sim_pu_zones_polygons$spp3_z2 <- rpois(nrow(sim_pu_zones_polygons), 1)

# create problem with polygon planning unit data and use field names to indicate feature data
# additionally, to make this example slightly more interesting, the problem will have proportion-type decisions such that a proportion of each planning unit can be allocated to each of the two management zones
p10 <- problem(sim_pu_zones_polygons,
    zones(c("spp1_z1", "spp2_z1", "spp3_z1"),
          c("spp1_z2", "spp2_z2", "spp3_z2"),
          zone_names = c("z1", "z2")),
    cost_column = c("cost_1", "cost_2")) %>%
    add_min_set_objective() %>%
    add_absolute_targets(targets[1:3, 1:2]) %>%
    add_proportion_decisions()

# solve problem
s10 <- solve(p10)

# plot solution
spplot(s10, zcol = c("solution_1_z1", "solution_1_z2"), main = "solution", axes = FALSE, box = FALSE)
proximity_matrix  Proximity matrix

Description
Create a matrix showing which planning units are within a certain spatial proximity to each other.

Usage
proximity_matrix(x, distance)

## S3 method for class 'Raster'
proximity_matrix(x, distance)

## S3 method for class 'SpatialPolygons'
proximity_matrix(x, distance)

## S3 method for class 'SpatialLines'
proximity_matrix(x, distance)

## S3 method for class 'SpatialPoints'
proximity_matrix(x, distance)

## S3 method for class 'sf'
proximity_matrix(x, distance)

## Default S3 method:
proximity_matrix(x, distance)

Arguments
x  Raster-class, Spatial-class, or sf object representing planning units.
distance  numeric distance threshold. Planning units that are further apart from each other than this threshold are not treated as being within proximity of each other.

Details
Proximity calculations are performed using st_is_within_distance.

Value
dsCMatrix-class sparse symmetric matrix. Each row and column represents a planning unit. Cells values indicate if the pair-wise distances between different planning units are within the distance threshold or not (using ones and zeros). To reduce computational burden, cells among the matrix diagonal are set to zero. Furthermore, if the argument to x is a Raster-class object, then cells with NA values are set to zero too.
Examples

# load data
data(sim_pu_raster, sim_pu_sf, sim_pu_lines, sim_pu_points)

# create proximity matrix using raster data
## crop raster to 9 cells to provide a small example
r <- crop(sim_pu_raster, c(0, 0.3, 0, 0.3))

## make proximity matrix using a distance threshold of 2
cm_raster <- proximity_matrix(r, distance = 2)

# create proximity matrix using polygon (sf) data
## subset 9 polygons to provide a small example
ply <- sim_pu_sf[c(1:2, 10:12, 20:22), ]

## make proximity matrix using a distance threshold of 2
cm_ply <- proximity_matrix(ply, distance = 2)

# create proximity matrix using line (Spatial) data
## subset 9 lines to provide a small example
lns <- sim_pu_lines[c(1:2, 10:12, 20:22), ]

## make proximity matrix
cm_lns <- proximity_matrix(lns, distance = 2)

## create proximity matrix using point (Spatial) data
## subset 9 points to provide a small example
pts <- sim_pu_points[c(1:2, 10:12, 20:22), ]

## make proximity matrix
cm_pts <- proximity_matrix(pts, distance = 2)

# plot data and the proximity matrices
par(mfrow = c(4,2))

## plot raster and proximity matrix
plot(r, main = "raster", axes = FALSE, box = FALSE)
plot(raster(as.matrix(cm_raster)), main = "proximity matrix", axes = FALSE, box = FALSE)

## plot polygons and proximity matrix
plot(r, main = "polygons (sf)", axes = FALSE, box = FALSE)
plot(raster(as.matrix(cm_ply)), main = "proximity matrix", axes = FALSE, box = FALSE)

## plot lines and proximity matrix
plot(r, main = "lines (Spatial)", axes = FALSE, box = FALSE)
plot(raster(as.matrix(cm_lns)), main = "proximity matrix", axes = FALSE, box = FALSE)

## plot points and proximity matrix
plot(r, main = "points (Spatial)", axes = FALSE, box = FALSE)
plot(raster(as.matrix(cm_pts)), main = "proximity matrix", axes = FALSE, box = FALSE)

rarity_weighted_richness

Rarity weighted richness

Description
Calculate irreplaceability scores for planning units selected in a solution using rarity weighted richness (based on Williams et al. 1996). Please note that this method is only recommended for large-scaled conservation planning exercises (i.e. more than 100,000 planning units) where irreplaceability scores cannot be calculated using the replacement cost method (replacement_cost) in a feasible period of time. This is because rarity weighted richness scores cannot (i) account for the cost of different planning units, (ii) account for multiple management zones, and (iii) identify truly irreplaceable planning units—unlike the replacement cost metric which does not suffer any of these limitations.

Usage

rarity_weighted_richness(x, solution, ...)

## S4 method for signature 'ConservationProblem,numeric'
rarity_weighted_richness(x, solution, rescale, ...)

## S4 method for signature 'ConservationProblem,matrix'
rarity_weighted_richness(x, solution, rescale, ...)

## S4 method for signature 'ConservationProblem,data.frame'
rarity_weighted_richness(x, solution, rescale, ...)

## S4 method for signature 'ConservationProblem,Spatial'
rarity_weighted_richness(x, solution, rescale, ...)

## S4 method for signature 'ConservationProblem,sf'
rarity_weighted_richness(x, solution, rescale, ...)

## S4 method for signature 'ConservationProblem,Raster'
rarity_weighted_richness(x, solution, rescale, ...)

Arguments

x ConservationProblem-class object.
solution numeric, matrix, data.frame, Raster-class, Spatial-class, or sf object. See the Details section for more information.
rarity_weighted_richness

... not used.
rescale logical flag indicating if replacement cost values—excepting infinite (Inf) and zero values—should be rescaled to range between 0.01 and 1. Defaults to TRUE.

Details

Rarity weighted richness scores are calculated using the following terms. Let \( I \) denote the set of planning units (indexed by \( i \)), let \( J \) denote the set of conservation features (indexed by \( j \)), let \( r_{ij} \) denote the amount of feature \( j \) associated with planning unit \( i \), and let \( M_j \) denote the maximum value of feature \( j \) in \( r_{ij} \) in all planning units \( i \in I \). To calculate the rarity weighted richness (RWR) for planning unit \( k \):

\[
RWR_k = \sum_j \frac{r_{kj}}{M_j} \sum_i r_{ij}
\]

The argument to solution must correspond to the planning unit data in the argument to \( x \) in terms of data representation, dimensionality, and spatial attributes (if applicable). This means that if the planning unit data in \( x \) is a numeric vector then the argument to solution must be a numeric vector with the same number of elements; if the planning unit data in \( x \) is a RasterLayer-class then the argument to solution must also be a RasterLayer-class with the same number of rows and columns and the same resolution, extent, and coordinate reference system; if the planning unit data in \( x \) is a Spatial-class object then the argument to solution must also be a Spatial-class object and have the same number of spatial features (e.g. polygons) and have the same coordinate reference system; if the planning unit data in \( x \) is a sf object then the argument to solution must also be a sf object and have the same number of spatial features (e.g. polygons) and have the same coordinate reference system; if the planning units in \( x \) are a data.frame then the argument to solution must also be a data.frame with each column correspond to a different zone and each row correspond to a different planning unit, and values correspond to the allocations (e.g. values of zero or one).

Solutions must have planning unit statuses set to missing (NA) values for planning units that have missing (NA) cost data. For problems with multiple zones, this means that planning units must have missing (NA) allocation values in zones where they have missing (NA) cost data. In other words, planning units that have missing (NA) cost values in \( x \) should always have a missing (NA) value the argument to solution. If an argument is supplied to solution where this is not the case, then an error will be thrown.

Value

A numeric, matrix, RasterLayer-class, Spatial-class, or sf object containing the rarity weighted richness scores for each planning unit in the solution.

References

replacement_cost

See Also

irreplaceability.

Examples

# seed seed for reproducibility
set.seed(600)

# load data
data(sim_pu_raster, sim_features)

# create minimal problem with binary decisions
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(gap = 0, verbose = FALSE)

# solve problem
s1 <- solve(p1)

# print solution
print(s1)

# plot solution
plot(s1, main = "solution", axes = FALSE, box = FALSE)

# calculate irreplaceability scores
rwr1 <- rarity_weighted_richness(p1, s1)

# print irreplaceability scores
print(rwr1)

# plot irreplaceability scores
plot(rwr1, main = "rarity weighted richness", axes = FALSE, box = FALSE)

replacement_cost

Description

Calculate irreplaceability scores for planning units selected in a solution based on the replacement cost method (Cabeza and Moilanen 2006).
Usage

replacement_cost(x, solution, ...)

## S4 method for signature 'ConservationProblem,numeric'
replacement_cost(x, solution, rescale, run_checks, force, threads, ...)

## S4 method for signature 'ConservationProblem,matrix'
replacement_cost(x, solution, rescale, run_checks, force, threads, ...)

## S4 method for signature 'ConservationProblem,data.frame'
replacement_cost(x, solution, rescale, run_checks, force, threads, ...)

## S4 method for signature 'ConservationProblem,Spatial'
replacement_cost(x, solution, rescale, run_checks, force, threads, ...)

## S4 method for signature 'ConservationProblem,sf'
replacement_cost(x, solution, rescale, run_checks, force, threads, ...)

## S4 method for signature 'ConservationProblem,Raster'
replacement_cost(x, solution, rescale, run_checks, force, threads, ...)

Arguments

x ConservationProblem-class object.
solution numeric, matrix, data.frame, Raster-class, Spatial-class, or sf object. See the Details section for more information.
...
not used.
rescale logical flag indicating if replacement cost values—excepting infinite (Inf) and zero values—should be rescaled to range between 0.01 and 1. Defaults to TRUE.
run_checks logical flag indicating whether presolve checks should be run prior solving the problem. These checks are performed using the presolve_check function. Defaults to TRUE. Skipping these checks may reduce run time for large problems.
force logical flag indicating if an attempt to should be made to solve the problem even if potential issues were detected during the presolve checks. Defaults to FALSE.
threads integer number of threads to use for the optimization algorithm. The default value of 1 will result in only one thread being used.

Details

Using this method, the score for each planning unit is calculated as the difference in the objective value of a solution when each planning unit is locked out and the optimization processes rerun with all other selected planning units locked in. In other words, the replacement cost metric corresponds to change in solution quality incurred if a given planning unit cannot be acquired when implementing the solution and the next best planning unit (or set of planning units) will need to be considered instead. Thus planning units with a higher score are more irreplaceable. For example, when using the minimum set objective function (add_min_set_objective), the replacement cost
scores correspond to the additional costs needed to meet targets when each planning unit is locked out. When using the maximum utility objective function (\texttt{add_max_utility_objective}), the replacement cost scores correspond to the reduction in the utility when each planning unit is locked out. Infinite values mean that no feasible solution exists when planning units are locked out—they are absolutely essential for obtaining a solution (e.g. they contain rare species that are not found in any other planning units or were locked in). Zeros values mean that planning units can swapped with other planning units and this will have no effect on the performance of the solution at all (e.g. because they were only selected due to spatial fragmentation penalties). Since these calculations can take a long time to complete, we recommend calculating these scores without additional penalties (e.g. \texttt{add_boundary_penalties}) or constraints (e.g. \texttt{link(add_contiguity_constraints)}). They can be sped up further by using proportion-type decisions when calculating the scores (see below for an example).

The argument to \texttt{solution} must correspond to the planning unit data in the argument to \texttt{x} in terms of data representation, dimensionality, and spatial attributes (if applicable). This means that if the planning unit data in \texttt{x} is a numeric vector then the argument to \texttt{solution} must be a numeric vector with the same number of elements; if the planning unit data in \texttt{x} is a \texttt{RasterLayer-class} then the argument to \texttt{solution} must also be a \texttt{RasterLayer-class} with the same number of rows and columns and the same resolution, extent, and coordinate reference system; if the planning unit data in \texttt{x} is a \texttt{Spatial-class} object then the argument to \texttt{solution} must also be a \texttt{Spatial-class} object and have the same number of spatial features (e.g. polygons) and have the same coordinate reference system; if the planning unit data in \texttt{x} is a \texttt{sf} object then the argument to \texttt{solution} must also be a \texttt{sf} object and have the same number of spatial features (e.g. polygons) and have the same coordinate reference system; if the planning unit data in \texttt{x} is a \texttt{data.frame} then the argument to \texttt{solution} must also be a \texttt{data.frame} with each column correspond to a different zone and each row correspond to a different planning unit, and values correspond to the allocations (e.g. values of zero or one).

Solutions must have planning unit statuses set to missing (\texttt{NA}) values for planning units that have missing (\texttt{NA}) cost data. For problems with multiple zones, this means that planning units must have missing (\texttt{NA}) allocation values in zones where they have missing (\texttt{NA}) cost data. In other words, planning units that have missing (\texttt{NA}) cost values in \texttt{x} should always have a missing (\texttt{NA}) value the argument to \texttt{solution}. If an argument is supplied to \texttt{solution} where this is not the case, then an error will be thrown.

**Value**

A numeric, matrix, \texttt{RasterLayer-class}, \texttt{Spatial-class}, or \texttt{sf} object containing the replacement costs for each planning unit in the solution.

**References**


**See Also**

\texttt{irreplaceability}.
Examples

# seed seed for reproducibility
set.seed(600)

# load data
data(sim_pu_raster, sim_features, sim_pu_zones_stack, sim_features_zones)

# create minimal problem with binary decisions
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(gap = 0, verbose = FALSE)

# solve problem
s1 <- solve(p1)

# print solution
print(s1)

# plot solution
plot(s1, main = "solution", axes = FALSE, box = FALSE)

# calculate irreplaceability scores
rc1 <- replacement_cost(p1, s1)

# print irreplaceability scores
print(rc1)

# plot irreplacability scores
plot(rc1, main = "replacement cost", axes = FALSE, box = FALSE)

# since replacement cost scores can take a long time to calculate with
# binary decisions, we can calculate them using proportion-type
# decision variables. Note we are still calculating the scores for our
# previous solution (s1), we are just using a different optimization
# problem when calculating the scores.

p2 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_proportion_decisions() %>%
  add_default_solver(gap = 0, verbose = FALSE)

# calculate irreplaceability scores using proportion type decisions
rc2 <- replacement_cost(p2, s1)

# print irreplaceability scores based on proportion type decisions
print(rc2)

# plot irreplacability scores based on proportion type decisions
# we can see that the irreplaceability values in rc1 and rc2 are similar,
# and this confirms that the proportion type decisions are a good
# approximation
plot(rc2, main = "replacement cost", axes = FALSE, box = FALSE)

# build multi-zone conservation problem with binary decisions
p3 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5,
    ncol = 3)) %>%
  add_binary_decisions() %>%
  add_default_solver(gap = 0, verbose = FALSE)

# solve the problem
s3 <- solve(p3)

# print solution
print(s3)

# plot solution
# each panel corresponds to a different zone, and data show the
# status of each planning unit in a given zone
plot(s3, main = paste0("zone ", seq_len(nlayers(s3))), axes = FALSE,
     box = FALSE)

# calculate irreplaceability scores
rc3 <- replacement_cost(p3, s3)

# plot irreplaceability
# each panel corresponds to a different zone, and data show the
# irreplaceability of each planning unit in a given zone
plot(rc3, main = paste0("zone ", seq_len(nlayers(s3))), axes = FALSE,
     box = FALSE)

---

**rij_matrix**

*Feature by planning unit matrix*

**Description**

Generate a matrix showing the amount of each feature in each planning unit (also known as an *rij* matrix).

**Usage**

rij_matrix(x, y, ...)

## S4 method for signature 'Raster,Raster'
rij_matrix

rij_matrix(x, y, ...)
## S4 method for signature 'Spatial,Raster'
rij_matrix(x, y, fun, ...)
## S4 method for signature 'sf,Raster'
rij_matrix(x, y, fun, ...)

Arguments

x Raster-class, Spatial-class, or sf object representing the planning units.
y Raster-class object representing the features.
... not used.
fun character for summarizing values inside each planning unit. This parameter is only used when the argument to x is a Spatial-class or sf object. Defaults to "sum".

Details

Generally, processing vector (i.e. Spatial-class or sf) data takes much longer to process than Raster-class data, so it is recommended to use Raster-class data for planning units where possible.

Value
dgCMatrix-class sparse matrix object. The sparse matrix represents the spatial intersection between the planning units and the features. Rows correspond to planning units, and columns correspond to features. Values correspond to the amount of the feature in the planning unit. For example, the amount of the third species in the second planning unit would be stored in the third column and second row.

Examples

# load data
data(sim_pu_raster, sim_pu_polygons, sim_pu_sf, sim_pu_zones_stack)

# create rij matrix using raster layer planning units
rij_raster <- rij_matrix(sim_pu_raster, sim_features)
print(rij_raster)

# create rij matrix using polygon (Spatial) planning units
rij_polygons <- rij_matrix(sim_pu_polygons, sim_features)
print(rij_polygons)

# create rij matrix using polygon (sf) planning units
rij_sf <- rij_matrix(sim_pu_sf, sim_features)
print(rij_sf)

# create rij matrix using raster stack planning units
rij_zones_raster <- rij_matrix(sim_pu_zones_stack, sim_features)
run_calculations

print(rij_zones_raster)

run_calculations  Run calculations

Description

Execute preliminary calculations in a conservation problem and store the results for later use. This function is useful when creating slightly different versions of the same conservation planning problem that involve the same pre-processing steps (e.g. calculating boundary data), because means that the same calculations will not be run multiple times.

Usage

run_calculations(x)

Arguments

x  ConservationProblem-class object

Details

This function is used for the effect of modifying the input ConservationProblem-class object. As such, it does not return anything. To use this function with pipe operators, use the %T>% operator and not the %>% operator.

Value

Invisible TRUE indicating success.

Examples

# Let us imagine a scenario where we wanted to understand the effect of setting different targets on our solution.

# create a conservation problem with no targets
p <- problem(sim_pu_raster, sim_features) %>%
    add_min_set_objective() %>%
    add_boundary_penalties(10, 0.5)

# create a copies of p and add targets
p1 <- p %>% add_relative_targets(0.1)
p2 <- p %>% add_relative_targets(0.2)
p3 <- p %>% add_relative_targets(0.3)

# now solve each of the different problems and record the time spent solving them
s1 <- system.time({solve(p1); solve(p2); solve(p3)})
# This approach is inefficient. Since these problems all share the same
# planning units it is actually performing the same calculations three times.
# To avoid this, we can use the "run_calculations" function before creating
# the copies. Normally, R runs the calculations just before solving the
# problem

# recreate a conservation problem with no targets and tell R run the
# preliminary calculations. Note how we use the \%T\% operator here.
p <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_boundary_penalties(10, 0.5) %>%
  run_calculations()

# create a copies of p and add targets just like before
p1 <- p %>% add_relative_targets(0.1)
p2 <- p %>% add_relative_targets(0.2)
p3 <- p %>% add_relative_targets(0.3)

# solve each of the different problems and record the time spent
# solving them
s2 <- system.time({solve(p1); solve(p2); solve(p3)})

# now lets compare the times
print(s1) # time spent without running preliminary calculations
print(s2) # time spent after running preliminary calculations

# As we can see, we can save a lot of time by running the preliminary
# calculations before making copies of the problem with slightly
# different constraints.

---

ScalarParameter-class  Scalar parameter prototype

**Description**

This prototype is used to represent a parameter has a single value. **Only experts should interact directly with this prototype.**

**Fields**

- `$id` character identifier for parameter.
- `$name` character name of parameter.
- `$value` numeric scalar value.
- `$default` numeric scalar default value.
- `$class` character name of the class that `$value` should inherit from (e.g. integer).
- `$lower_limit` numeric scalar value that is the minimum value that `$value` is permitted to be.
- `$upper_limit` numeric scalar value that is the maximum value that `$value` is permitted to be.
- `$widget` function used to construct a shiny interface for modifying values.
Usage

x$print()
x$show()
x$validate(x)
x$get()
x$set(x)
x$reset()
x$render(...)

Arguments

x  object used to set a new parameter value.
...
arguments passed to $widget.

Details

print  print the object.
show  show the object.
validate  check if a proposed new set of parameters are valid.
get  extract the parameter value.
set  update the parameter value.
reset  update the parameter value to be the default value.
render  create a shiny widget to modify parameter values.

See Also

Parameter-class, ArrayParameter-class.

scalar_parameters  Scalar parameters

Description

These functions are used to create parameters that consist of a single number. Parameters have a name, a value, a defined range of acceptable values, a default value, a class, and a shiny widget for modifying them. If values are supplied to a parameter that are unacceptable then an error is thrown.
Usage

proportion_parameter(name, value)

binary_parameter(name, value)

type name parameter

integer_parameter(
  name,
  value,
  lower_limit = as.integer(-.Machine$integer.max),
  upper_limit = as.integer(.Machine$integer.max)
)

numeric_parameter(
  name,
  value,
  lower_limit = .Machine$double.xmin,
  upper_limit = .Machine$double.xmax
)

Arguments

name character
  name of parameter.

value integer or double
  value depending on the parameter.

lower_limit integer or double
  representing the smallest acceptable value for value.
  Defaults to the smallest possible number on the system.

upper_limit integer or double
  representing the largest acceptable value for value.
  Defaults to the largest possible number on the system.

Details

Below is a list of parameter generating functions and a brief description of each.

proportion_parameter A parameter that is a double and bounded between zero and one.

integer_parameter A parameter that is an integer.

numeric_parameter A parameter that is a double.

binary_parameter A parameter that is restricted to integer values of zero or one.

Value

ScalarParameter-class object.

Examples

# proportion parameter
p1 <- proportion_parameter('prop', 0.5) # create new object
print(p1) # print it
p1$get() # get value
p1$id # get id
p1$validate(5) # check if 5 is a validate input
p1$validate(0.1) # check if 0.1 is a validate input
p1$set(0.1) # change value to 0.1
print(p1)

# binary parameter
p2 <- binary_parameter('bin', 0) # create new object
print(p2) # print it
p2$get() # get value
p2$id # get id
p2$validate(5) # check if 5 is a validate input
p2$validate(1L) # check if 1L is a validate input
p2$set(1L) # change value to 1L
print(p1) # print it again

# integer parameter
p3 <- integer_parameter('int', 5L) # create new object
print(p3) # print it
p3$get() # get value
p3$id # get id
p3$validate(5.6) # check if 5.6 is a validate input
p3$validate(2L) # check if 2L is a validate input
p3$set(2L) # change value to 2L
print(p3) # print it again

# numeric parameter
p4 <- numeric_parameter('dbl', -7.6) # create new object
print(p4) # print it
p4$get() # get value
p4$id # get id
p4$validate(NA) # check if NA is a validate input
p4$validate(8.9) # check if 8.9 is a validate input
p4$set(8.9) # change value to 8.9
print(p4) # print it again

# numeric parameter with lower bounds
p5 <- numeric_parameter('bdbl', 6, lower_limit=0) # create new object
print(p5) # print it
p5$get() # get value
p5$id # get id
p5$validate(-10) # check if -10 is a validate input
p5$validate(90) # check if 90 is a validate input
p5$set(90) # change value to 8.9
print(p5) # print it again

---

**Description**

Display information about an object.
simulate_cost

Usage

```r
## S4 method for signature 'ConservationModifier'
show(x)

## S4 method for signature 'ConservationProblem'
show(x)

## S4 method for signature 'Id'
show(x)

## S4 method for signature 'OptimizationProblem'
show(x)

## S4 method for signature 'Parameter'
show(x)

## S4 method for signature 'Solver'
show(x)
```

Arguments

- `x` Any object.

Value

None.

See Also

- `show`

simulate_cost | Simulate cost data

Description

This function generates cost layers using random field models. By default, it returns spatially autocorrelated integer values.

Usage

```r
simulate_cost(
x,
n = 1,
model = RandomFields::RPoisson(RandomFields::RMtruncsupport(radius = raster::xres(x) * 10, RandomFields::RMgauss())),
transform = identity,
...
)
```
simulate_data

Arguments

- **x**: RasterLayer-class object to use as
- **n**: integer number of species to simulate.
- **model**: RP model object to use for simulating data.
- **transform**: function to transform values output from the random fields simulation.
- **...**: additional arguments passed to RFsimulate.

Value

RasterStack-class object.

See Also

simulate_data.

Examples

```r
# create raster
r <- raster(ncol=10, nrow=10, xmn=0, xmx=1, ymn=0, ymx=1)
values(r) <- 1

# simulate data
cost <- simulate_cost(r)

# plot simulated species
plot(cost, main = "simulated cost data")
```

Description

Simulate spatially auto-correlated data.

Usage

simulate_data(x, n, model, transform = identity, ...)

Arguments

- **x**: RasterLayer-class object to use as
- **n**: integer number of species to simulate.
- **model**: RP model object to use for simulating data.
- **transform**: function to transform values output from the random fields simulation.
- **...**: additional arguments passed to RFsimulate.
simulate_species

Value

*RasterStack-class* object with a layer for each species.

See Also

*RFsimulate, simulate_cost, simulate_species.*

Examples

```r
# create raster
r <- raster(ncol=10, nrow=10, xmn=0, xmx=1, ymn=0, ymx=1)
values(r) <- 1

# simulate data using a Gaussian field
d <- simulate_data(r, n = 1, model = RandomFields::RMgauss())

# plot simulated data
plot(d, main = "random Gaussian field")
```

### simulate_species

*Simulate species habitat suitability data*

Description

Generates a random set of species using random field models. By default, the output will contain values between zero and one.

Usage

```r
simulate_species(
  x,
  n = 1,
  model = RandomFields::RMgauss(),
  transform = stats::plogis,
  ...
)
```

Arguments

- `x` *RasterLayer-class* object to use as
- `n` integer number of species to simulate.
- `model` *RP* model object to use for simulating data.
- `transform` function to transform values output from the random fields simulation.
- `...` additional arguments passed to *RFsimulate.*
Value

*RasterStack-class* object.

See Also

simulate_data.

Examples

```r
# create raster
r <- raster(ncol=10, nrow=10, xmn=0, xmx=1, ymn=0, ymx=1)
values(r) <- 1

# simulate 4 species
spp <- simulate_species(r, 4)

# plot simulated species
plot(spp, main = "simulated species distributions")
```

---

### `sim_data`  
*Simulated conservation planning data*

Description

Simulated data for making spatial prioritizations.

Usage

```r
data(simPu_polygons)
data(simPu_zones_polygons)
data(simPu_points)
data(simPu_lines)
data(simPu_sf)
data(simPu_zones_sf)
data(sim_locked_in_raster)
data(sim_locked_out_raster)
```
sim_data

data(sim_pu_zones_stack)
data(sim_features)
data(sim_features_zones)
data(sim_phylogeny)
sim_features
sim_features_zones
sim_pu_polygons
sim_pu_zones_polygons
sim_pu_sf
sim_pu_zones_sf
sim_pu_lines
sim_pu_points
sim_pu_raster
sim_pu_zones_stack
sim_phylogeny
sim_locked_in_raster
sim_locked_out_raster

Format

sim_pu_polygons SpatialPolygonsDataFrame-class object.
sim_pu_zones_polygons SpatialPolygonsDataFrame-class object.
sim_pu_sf sf object.
sim_pu_zones_sf sf object.
sim_pu_lines SpatialLinesDataFrame-class object.
sim_pu_points SpatialPointsDataFrame-class object.
sim_pu_raster RasterLayer-class object.
sim_pu_zones_stack RasterStack-class object.
sim_locked_in_raster RasterLayer-class object.
**sim_locked_out_raster**  
*RasterLayer-class* object.

**sim_features**  
*RasterStack-class* object.

**sim_features_zones**  
*ZonesRaster* object.

**sim_phylogeny**  
*phylo* object.

An object of class *RasterStack* of dimension 10 x 10 x 5.

An object of class *ZonesRaster* (inherits from *Zones*) of length 3.

An object of class *SpatialPolygonsDataFrame* with 90 rows and 3 columns.

An object of class *SpatialPolygonsDataFrame* with 90 rows and 6 columns.

An object of class *sf* (inherits from *data.frame*) with 90 rows and 4 columns.

An object of class *sf* (inherits from *data.frame*) with 90 rows and 7 columns.

An object of class *SpatialLinesDataFrame* with 90 rows and 3 columns.

An object of class *SpatialPointsDataFrame* with 90 rows and 3 columns.

An object of class *RasterLayer* of dimension 10 x 10 x 1.

An object of class *RasterStack* of dimension 10 x 10 x 3.

An object of class *phylo* of length 4.

An object of class *RasterLayer* of dimension 10 x 10 x 1.

An object of class *RasterLayer* of dimension 10 x 10 x 1.

---

**Details**

**sim_pu_raster** Planning units are represented as raster data. Pixel values indicate planning unit cost and NA values indicate that a pixel is not a planning unit.

**sim_pu_zones_stack** Planning units are represented as raster stack data. Each layer indicates the cost for a different management zone. Pixels with NA values in a given zone indicate that a planning unit cannot be allocated to that zone in a solution. Additionally, pixels with NA values in all layers are not a planning unit.

**sim_locked_in_raster** Planning units are represented as raster data. Pixel values are binary and indicate if planning units should be locked in to the solution.

**sim_locked_out_raster** Planning units are represented as raster data. Pixel values are binary and indicate if planning units should be locked out from the solution.

**sim_pu_polygons** Planning units represented as polygon data. The attribute table contains fields (columns) indicating the expenditure required for prioritizing each planning unit ("cost" field), if the planning units should be selected in the solution ("locked_in" field), and if the planning units should never be selected in the solution ("locked_out" field).

**sim_pu_points** Planning units represented as point data. The attribute table follows the same conventions as for **sim_pu_polygons**.

**sim_pu_lines** Planning units represented as line data. The attribute table follows the same conventions as for **sim_pu_polygons**.

**sim_pu_sf** Planning units represented as polygon data using the *sf* package. The attribute table follows the same conventions as for **sim_pu_polygons**.
**Examples**

```r
# load data
data(sim_pu_polygons, sim_pu_lines, sim_pu_points, sim_pu_raster,
     sim_locked_in_raster, sim_locked_out_raster, sim_phylogeny,
     sim_features, sim_pu_sf)

# plot example Spatial-class planning unit data
par(mfrow = c(2, 3))
plot(sim_pu_raster, main = "planning units (raster)"
plot(sim_locked_in_raster, main = "locked in units (raster)"
plot(sim_locked_out_raster, main = "locked out units (raster)"
plot(sim_pu_polygons, main = "planning units (polygons)"
plot(sim_pu_lines, main = "planning units (lines)"
plot(sim_pu_points, main = "planning units (points)"

# plot example sf-class planning unit data
plot(sim_pu_sf)

# plot example phylogeny data
par(mfrow = c(1, 1))
aplot.phylo(sim_phylogeny, main = "simulated phylogeny"

# plot example feature data
par(mfrow = c(1, 1))
plot(sim_features)

# plot example management zone cost data
par(mfrow = c(1, 1))
plot(sim_pu_zones_stack)

# plot example feature data for each management zone
plot(do.call(stack, sim_features_zones),
     main = paste0("Species ",
             rep(seq_len(number_of_zones(sim_features_zones)),
             number_of_features(sim_features_zones)),
             " (zone ",
```
solve

Description

Solve a conservation planning problem.

Usage

## S4 method for signature 'OptimizationProblem,Solver'
solve(a, b, ...)

## S4 method for signature 'ConservationProblem,missing'
solve(a, b, ..., run_checks = TRUE, force = FALSE)

Arguments

a ConservationProblem-class or an OptimizationProblem-class object.
b Solver-class object. Not used if a is an ConservationProblem-class object.
... arguments passed to compile.
run_checks logical flag indicating whether presolve checks should be run prior solving the problem. These checks are performed using the presolve_check function. Defaults to TRUE. Skipping these checks may reduce run time for large problems.
force logical flag indicating if an attempt should be made to solve the problem even if potential issues were detected during the presolve checks. Defaults to FALSE.

Details

The object returned from this function depends on the argument to a. If the argument to a is an OptimizationProblem-class object, then the solution is returned as a logical vector showing the status of each planning unit in each zone. On the other hand, if the argument to a is an ConservationProblem-class object, then the type of object returned depends on the number of solutions generated and the type data used to represent planning unit costs in the argument to a.

numeric vector containing the solution. Here, each element corresponds to a different planning unit. If multiple solutions are generated, then the solution is returned as a list of numeric vectors.

matrix containing numeric values for the solution. Here, rows correspond to different planning units, and fields (columns) correspond to different management zones. If multiple solutions are generated, then the solution is returned as a list of matrix objects.
solve

**Raster-class** object containing the solution in pixel values. If the argument to \( x \) contains a single management zone, then a **RasterLayer** object will be returned. Otherwise, if the argument to \( x \) contains multiple zones, then a **RasterStack-class** object will be returned containing a different layer for each management zone. If multiple solutions are generated, then the solution is returned as a list of Raster objects.

**Spatial-class**, **sf**, or data.frame containing the solution in fields (columns). Here, each row corresponds to a different planning unit. If the argument to \( x \) contains a single zone, the fields containing solutions are named "solution_XXX" where "XXX" corresponds to the solution number. If the argument to \( x \) contains multiple zones, the fields containing solutions are named "solution_XXX_YYY" where "XXX" corresponds to the solution and "YYY" is the name of the management zone.

Since this function returns an object that specifies how much of each planning unit is allocated to each management zone, it may be useful to use the **category_layer** function to reformat the output for problems containing multiple zones.

**Value**

A numeric, matrix, **RasterLayer-class**, **Spatial-class**, or **sf** object containing the solution to the problem. Additionally, the returned object will have the following additional attributes: "objective" containing the solution’s objective, "runtime" denoting the number of seconds that elapsed while solving the problem, and "status" describing the status of the solution (e.g. "OPTIMAL" indicates that the optimal solution was found).

**See Also**

* feature_representation, problem, solvers, category_layer, presolve_check *

**Examples**

```r
# set seed for reproducibility
set.seed(500)

# load data
data(sim_pu_raster, sim_pu_polygons, sim_pu_sf, sim_features,
sim_pu_zones_stack, sim_pu_zones_sf, sim_features_zones)

# build minimal conservation problem with raster data
p1 <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions()

# solve the problem
s1 <- solve(p1)

# print solution
print(s1)

# print attributes describing the optimization process and the solution
print(attr(s1, "objective"))
```

```
```r
# calculate feature representation in the solution
r1 <- feature_representation(p1, s1)
print(r1)

# plot solution
plot(s1, main = "solution", axes = FALSE, box = FALSE)

# build minimal conservation problem with polygon (Spatial) data
p2 <- problem(sim_pu_polygons, sim_features, cost_column = "cost") %>%
    add_min_set_objective() %>%
    add_relative_targets(0.1) %>%
    add_binary_decisions()

# solve the problem
s2 <- solve(p2)

# print first six rows of the attribute table
print(head(s2))

# calculate feature representation in the solution
r2 <- feature_representation(p2, s2[, "solution_1"])
print(r2)

# plot solution
spplot(s2, zcol = "solution_1", main = "solution", axes = FALSE, box = FALSE)

# build minimal conservation problem with polygon (sf) data
p3 <- problem(sim_pu_sf, sim_features, cost_column = "cost") %>%
    add_min_set_objective() %>%
    add_relative_targets(0.1) %>%
    add_binary_decisions()

# solve the problem
s3 <- solve(p3)

# print first six rows of the attribute table
print(head(s3))

# calculate feature representation in the solution
r3 <- feature_representation(p3, s3[, "solution_1"])
print(r3)

# plot solution
plot(s3[, "solution_1"])

# build multi-zone conservation problem with raster data
p4 <- problem(sim_pu_zones_stack, sim_features_zones) %>%
    add_min_set_objective() %>%
```
add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5, 
   ncol = 3)) %>%
add_binary_decisions()

# solve the problem
s4 <- solve(p4)

# print solution
print(s4)

# calculate feature representation in the solution
r4 <- feature_representation(p4, s4)
print(r4)

# plot solution
plot(category_layer(s4), main = "solution", axes = FALSE, box = FALSE)

# build multi-zone conservation problem with polygon (sf) data
p5 <- problem(sim_pu_zones_sf, sim_features_zones,
   cost_column = c("cost_1", "cost_2", "cost_3")) %>%
   add_min_set_objective() %>%
   add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5, 
      ncol = 3)) %>%
   add_binary_decisions()

# solve the problem
s5 <- solve(p5)

# print first six rows of the attribute table
print(head(s5))

# calculate feature representation in the solution
r5 <- feature_representation(p5, s5[, c("solution_1_zone_1", 
      "solution_1_zone_2", 
      "solution_1_zone_3")])
print(r5)

# create new column representing the zone id that each planning unit
# was allocated to in the solution
s5$solution <- category_vector(s5[, c("solution_1_zone_1", 
      "solution_1_zone_2", 
      "solution_1_zone_3")])

s5$solution <- factor(s5$solution)

# plot solution
plot(s5[, "solution"], )
Description

This prototype is used to generate objects that represent methods for solving optimization problems. This class represents a recipe to create solver and is only recommended for use by expert users. To customize the method used to solve optimization problems, please see the help page on solvers.

Fields

$\text{name}$ character name of solver.
$\text{data}$ list object optimization problem data.
$\text{parameters}$ Parameters object with parameters used to customize the solver.
$\text{solve}$ function used to solve a OptimizationProblem-class object.

Usage

x$\text{print}()$
x$\text{show}()$
x$\text{repr}()$
x$\text{get\_data(name)}$
x$\text{set\_data(name,value)}$
x$\text{set\_variable\_ub(index,value)}$
x$\text{set\_variable\_lb(index,value)}$
x$\text{calculate(op)}$
x$\text{run}()$
x$\text{solve(op)}$

Arguments

x Solver-class object.
op OptimizationProblem-class object.

Details

print print the object.
show show the object.
repr character representation of object.
get\_data return an object stored in the data field with the corresponding name. If the object is not present in the data field, a waiver object is returned.
set\_data store an object stored in the data field with the corresponding name. If an object with that name already exists then the object is overwritten.
set\_variable\_ub set the upper bounds on decision variables in a pre-calculated optimization problem stored in the solver.
set_variable_lb  set the lower bounds on decision variables in a pre-calculated optimization problem stored in the solver.

calculate  ingest a general purpose OptimizationProblem-class object and convert it to the correct format for the solver.

run  run the solver and output a solution

solve  solve an OptimizationProblem-class using this object.

<table>
<thead>
<tr>
<th>solvers</th>
<th>Problem solvers</th>
</tr>
</thead>
</table>

Description

Specify the software and configuration used to solve a conservation planning problem. By default, the best available software currently installed on the system will be used.

Details

The following solvers can be used to find solutions for a conservation planning problem:

add_default_solver  This solver uses the best software currently installed on the system.

add_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.

add_rsymphony_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.

add_lpsymphony_solver  The lpsymphony package provides a different interface to the COIN-OR software suite. Unlike the Rsymphony package, the lpsymphony package is distributed through Bioconductor. The lpsymphony package may be easier to install on Windows or Max OSX systems than the Rsymphony package.

See Also

constraints, decisions, objectives penalties, portfolios, problem, targets.

Examples

# load data
data(sim_pu_raster, sim_features)

# create basic problem
p <- problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions()

# create vector to store plot titles
titles <- c()

# create empty stack to store solutions
s <- stack()

# create problem with added rsymphony solver and limit the time spent
# searching for the optimal solution to 2 seconds
if (require("Rsymphony")) {
  titles <- c(titles, "Rsymphony (2s)")
  p1 <- p %>% add_rsymphony_solver(time_limit = 2)
  s <- addLayer(s, solve(p1))
}

# create problem with added rsymphony solver and limit the time spent
# searching for the optimal solution to 5 seconds
if (require("Rsymphony")) {
  titles <- c(titles, "Rsymphony (5s)")
  p2 <- p %>% add_rsymphony_solver(time_limit = 5)
  s <- addLayer(s, solve(p2))
}

# if the gurobi is installed: create problem with added gurobi solver
if (require("gurobi")) {
  titles <- c(titles, "gurobi (5s)")
  p3 <- p %>% add_gurobi_solver(gap = 0.1, presolve = 2, time_limit = 5)
  s <- addLayer(s, solve(p3))
}

# if the lpsymphony is installed: create problem with added lpsymphony solver
# note that this solver is skipped on Linux systems due to instability
# issues
if (require("lpsymphony") &
  isTRUE(Sys.info()["sysname"] != "Linux")) {
  titles <- c(titles, "lpsymphony")
  p4 <- p %>% add_lpsymphony_solver(gap = 0.1, time_limit = 10)
  s <- addLayer(s, solve(p4))
}

# plot solutions
plot(s, main = titles, axes = FALSE, box = FALSE)
targets

Description

This prototype is used to represent the targets used when making a prioritization. This prototype inherits from the ConservationModifier-class. This class represents a recipe, to actually add targets to a planning problem, see the help page on targets. Only experts should use this class directly.

See Also

ConservationModifier-class.

---

targets  

Description

Targets are used to specify the minimum amount or proportion of a feature’s distribution that needs to be protected in the solution.

Details

Please note that most objectives require targets, and attempting to solve a problem that requires targets will throw an error.

The following functions can be used to specify targets for a conservation planning problem:

- add_relative_targets Set targets as a proportion (between 0 and 1) of the total amount of each feature in the study area.
- add_absolute_targets Set targets that denote the minimum amount of each feature required in the prioritization.
- add_loglinear_targets Set targets as a proportion (between 0 and 1) that are calculated using log-linear interpolation.
- add_manual_targets Set targets manually.

See Also

consstraints, decisions, objectives penalties, portfolios, problem, solvers.

Examples

# load data
data(sim_pu_raster, sim_features)

# create base problem
p <- problem(sim_pu_raster, sim_features) %>%
    add_min_set_objective() %>%
    add_binary_decisions()

# create problem with added relative targets
```r
tibble-methods

Manipulate tibbles

Description

Assorted functions for manipulating tibble objects.

Usage

```r
## S4 method for signature 'tbl_df'
nrow(x)
```

```r
## S4 method for signature 'tbl_df'
col(x)
```

```r
## S4 method for signature 'tbl_df'
as.list(x)
```

Arguments

x tibble object.

Details

The following methods are provided from manipulating tibble objects.

nrow extract integer number of rows.
```
zones

ncol  extract integer number of columns.
as.list convert to a list.
print  print the object.

Examples

# load tibble package
require(tibble)

# make tibble
a <- tibble(value = seq_len(5))

# number of rows
nrow(a)

# number of columns
ncol(a)

# convert to list
as.list(a)

zones  Management zones

Description

Organize biodiversity data into the expected amount of different features under different management zones.

Usage

colonize(..., zone_names = NULL, feature_names = NULL)

Arguments

...  raster or character objects that pertain to the biodiversity data. See Details for more information.
zone_names character names of the management zones. Defaults to NULL which results in sequential integers.
feature_names character names of the features zones. Defaults to NULL which results in sequential integers.
Details

This function is used to store and organize data for use in a conservation planning problem that has multiple management zones. In all cases, the data for each zone is input as a separate argument. The correct arguments depend on the type of planning unit data used when building the conservation planning problem.

**Raster-class**, **Spatial-class** Raster-class data denoting the amount of each feature present assuming each management zone. Data for each zone are specified in separate arguments, and the data for each feature in a given zone are specified in separate layers in a stack object. Note that all layers for a given zone must have NA values in exactly the same cells.

**Spatial**, data.frame character vector with column names that correspond to the abundance or occurrence of different features in each planning unit for each zone. Note that these columns must not contain any NA values.

**Spatial**, data.frame or matrix data.frame denoting the amount of each feature in each zone. Following conventions used in Marxan, data.frame objects should be supplied with the columns:

- "pu" integer planning unit identifier.
- "species" integer feature identifier.
- "amount" numeric amount of the feature in the planning unit for a given zone.

Note that data for each zone are specified in a separate argument, and the data contained in a single data.frame object correspond to a single zone. Also, note that data are not required for all combinations of planning units, features, and zones. The amounts of features in planning units assuming different management zones that are missing from the table are treated as zero.

Value

**Zones-class** object.

See Also

**problem**.

Examples

```r
# load planning unit data
data(sim_pu_raster)

zone_1 <- simulate_species(sim_pu_raster, 3)
zone_2 <- simulate_species(sim_pu_raster, 3)

# create zones using two raster stack objects
# each object corresponds to a different zone and each layer corresponds to # a different species
z <- zones(zone_1, zone_2, zone_names = c("zone_1", "zone_2"),
           feature_names = c("feature_1", "feature_2", "feature_3"))
print(z)

# note that the do.call function can also be used to create a Zones object
```
# this method for creating a Zones object can be helpful when there are many
# management zones
l <- list(zone_1, zone_2, zone_names = c("zone_1", "zone_2"),
          feature_names = c("feature_1", "feature_2", "feature_3"))
z <- do.call(zones, l)
print(z)

# create zones using character vectors that represent the names of
# fields (columns) in a data.frame or Spatial object that contain the amount
# of each species expected different management zones
z <- zones(c("spp1_zone1", "spp2_zone1"),
c("spp1_zone2", "spp2_zone2"),
c("spp1_zone3", "spp2_zone3"),
zone_names = c("zone1", "zone2", "zone3"),
feature_names = c("spp1", "spp2"))
print(z)

<table>
<thead>
<tr>
<th>zone_names</th>
<th>Zone names</th>
</tr>
</thead>
</table>

**Description**

Extract the names of zones in an object.

**Usage**

zone_names(x)

## S4 method for signature 'ConservationProblem'
zone_names(x)

## S4 method for signature 'ZonesRaster'
zone_names(x)

## S4 method for signature 'ZonesCharacter'
zone_names(x)

**Arguments**

- **x**  
  ConservationProblem-class or Zones

**Value**

character zone names.
Examples

# load data
data(sim_pu_zones_stack, sim_features_zones)

# print names of zones in a Zones object
print(zone_names(sim_features_zones))

# create problem with multiple zones
p <- problem(sim_pu_zones_stack, sim_features_zones) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(0.2, ncol = 3, nrow = 5)) %>%
  add_binary_decisions()

# print zone names in problem
print(zone_names(p))

---

Pipe operator

Description

This package uses the pipe operator (%>%) to express nested code as a series of imperative procedures.

Arguments

lhs, rhs  An object and a function.

See Also

%>%, tee.

Examples

# set seed for reproducibility
set.seed(500)

# generate 100 random numbers and calculate the mean
mean(runif(100))

# reset the seed
set.seed(500)

# repeat the previous procedure but use the pipe operator instead of nesting
# function calls inside each other.
runicorn(100) %>% mean()
Tee operator

Description
This package uses the "tee" operator (%T>%%) to modify objects.

Arguments
lhs, rhs
An object and a function.

See Also
%T>%, pipe.

Examples
# the tee operator returns the left-hand side of the result and can be
# useful when dealing with mutable objects. In this example we want
# to use the function "f" to modify the object "e" and capture the
# result

# create an empty environment
e <- new.env()

# create a function to modify an environment and return NULL
f <- function(x) {x$a <- 5; return(NULL)}

# if we use the pipe operator we won't capture the result since "f"()
# returns a NULL
e2 <- e %>% f()
print(e2)

# but if we use the tee operator then the result contains a copy of "e"
e3 <- e %T>% f()
print(e3)
Index

*Topic datasets

sim_data, 200

add_absolute_targets, 5, 60, 211
add_absolute_targets, ConservationProblem, character-method

add_absolute_targets, ConservationProblem, matrix-method

add_absolute_targets, ConservationProblem, numeric-method

add_binary_decisions, 8, 27, 57, 90, 120
add_boundary_penalties, 9, 162, 170, 188
add_connectivity_penalties, 11, 14, 142, 162, 170

add_connectivity_penalties, ConservationProblem, ANY, ANY, array-method

add_connectivity_penalties, ConservationProblem, ANY, ANY, data.frame-method

add_connectivity_penalties, ConservationProblem, ANY, ANY, matrix-method

add_connectivity_penalties, ConservationProblem, ANY, ANY, numeric-method

add_cut_portfolio, 25, 165
add_default_decisions, 26
add_default_solver, 27
add_extra_portfolio, 28, 165
add_feature_contiguity_constraints, 29, 119

add_feature_contiguity_constraints, ConservationProblem, ANY, ANY, data.frame-method

add_feature_contiguity_constraints, ConservationProblem, ANY, ANY, matrix-method

add_feature_contiguity_constraints, ConservationProblem, ANY, ANY, numeric-method

add_feature_weights, ConservationProblem, ANY, ANY, data.frame-method

add_feature_weights, ConservationProblem, ANY, ANY, matrix-method

add_gurobi_solver, 27, 28, 37, 39, 94, 170, 209

add_locked_in_constraints, 40, 57, 102

add_locked_in_constraints, ConservationProblem, character-method

add_locked_in_constraints, ConservationProblem, logical-method
add_locked_in_constraints, ConservationProblem, Spatial-method
(add_locked_in_constraints), 40
add_locked_in_constraints, ConservationProblem, sf-method
(add_locked_in_constraints), 40
add_locked_in_constraints, ConservationProblem, Raster-method
(add_locked_in_constraints), 40
add_locked_in_constraints, ConservationProblem, numeric-method
(add_locked_in_constraints), 40
add_locked_in_constraints, ConservationProblem, matrix-method
(add_locked_in_constraints), 40
add_locked_in_constraints, ConservationProblem, logical-method
(add_locked_in_constraints), 40
add_locked_out_constraints, ConservationProblem, matrix-method
(add_locked_out_constraints), 40
add_locked_out_constraints, ConservationProblem, Raster-method
(add_locked_out_constraints), 40
add_locked_out_constraints, ConservationProblem, sf-method
(add_locked_out_constraints), 40
add_locked_out_constraints, ConservationProblem, Spatial-method
(add_locked_out_constraints), 40
add_locked_out_constraints, ConservationProblem, data.frame-method
(add_locked_out_constraints), 40
add_manual_bounded_constraints, ConservationProblem, character-method
(add_manual_bounded_constraints), 40, 45
add_manual_bounded_constraints, ConservationProblem, tbl_df-method
(add_manual_bounded_constraints), 56
add_manual_bounded_constraints, ConservationProblem, data.frame-method
(add_manual_bounded_constraints), 56
add_locked_out_constraints, ConservationProblem, ANY, ANY, matrix-method
(add_locked_out_constraints), 40
add_locked_out_constraints, ConservationProblem, ANY, ANY, array-method
(add_locked_out_constraints), 40
add_locked_out_constraints, ConservationProblem, ANY, ANY, ANY-method
(add_locked_out_constraints), 40
add_relative_targets, ConservationProblem, character-method
(add_relative_targets, ConservationProblem), 59
add_relative_targets, ConservationProblem, numeric-method
(add_relative_targets, ConservationProblem), 59
add_relative_targets, ConservationProblem, data.frame-method
(add_relative_targets, ConservationProblem), 59
add_relative_targets, ConservationProblem, tbl_df-method
(add_relative_targets, ConservationProblem), 59
add_neighbor_constraints, ConservationProblem, ANY, ANY, data-frame-method
(add_neighbor_constraints, ConservationProblem), 81
add_neighbor_constraints, ConservationProblem, ANY, ANY, matrix-method
(add_neighbor_constraints, ConservationProblem), 81
add_neighbor_constraints, ConservationProblem, ANY, ANY, array-method
(add_neighbor_constraints, ConservationProblem), 81
add_neighbor_constraints, ConservationProblem, ANY, ANY, numeric-method
(add_neighbor_constraints, ConservationProblem), 81
add_neighbor_constraints, ConservationProblem, ANY, ANY, character-method
(add_neighbor_constraints, ConservationProblem), 81
add_mandatory_allocation_constraints, ConservationProblem-method
(add_mandatory_allocation_constraints), 54
add_mandatory_allocation_constraints
(add_mandatory_allocation_constraints), 54
add_max_cover_objective
(add_max_cover_objective), 6, 34, 50, 60, 63, 66, 68, 72, 154
add_max_features_objective
(add_max_features_objective), 63, 64, 65, 68, 72, 154, 170
add_max_phylo_end_objective
(add_max_phylo_end_objective), 71, 154
add_max_phylo_objective
(add_max_phylo_objective), 67
add_max_phylo_div_objective
(add_max_phylo_div_objective), 71, 154
add_min_set_objective
(add_min_set_objective), 10, 14, 66, 77, 154, 162, 187
add_min_shortfall_objective
(add_min_shortfall_objective), 79, 154
add_max_phylo_objective
(add_max_phylo_objective), 59
add_min_set_objective
(add_min_set_objective), 59
add_min_shortfall_objective
(add_min_shortfall_objective), 59
add_max_phylo_div_objective
(add_max_phylo_div_objective), 59
add_max_phylo_objective
(add_max_phylo_objective), 59
add_max_features_objective
(add_max_features_objective), 59
add_max_phylo_end_objective
(add_max_phylo_end_objective), 59
add_max_cover_objective
(add_max_cover_objective), 59
add_max_phylo_objective
(add_max_phylo_objective), 59
add_max_phylo_div_objective
(add_max_phylo_div_objective), 59
add_max_features_objective
(add_max_features_objective), 59
add_max_phylo_end_objective
(add_max_phylo_end_objective), 59
add_max_cover_objective
(add_max_cover_objective), 59
add_max_phylo_objective
(add_max_phylo_objective), 59
add_max_phylo_div_objective
(add_max_phylo_div_objective), 59
add_max_features_objective
(add_max_features_objective), 59
add_max_phylo_end_objective
(add_max_phylo_end_objective), 59
add_max_cover_objective
(add_max_cover_objective), 59
INDEX

add_relative_targets-method
(\texttt{add_relative_targets}), 86
add_rsymphony_solver, 27, 89, 209
add_semicontinuous_decisions, 90, 120
add_shuffle_portfolio, 92, 165
add_top_portfolio, 92, 94, 165
adjacency_matrix, 22, 30, 82, 95
adjacent, 96
array_parameters, 99, 161
ArrayParameter (ArrayParameter-class), 97
as (as.Id), 101
as.list, \texttt{tbl_df}-method (\texttt{tibble}-methods), 212
as.list, \texttt{OptimizationProblem}, 102
binary_matrix_parameter
(matrix_parameters), 143
binary_parameter (scalar_parameters), 194
binary_parameter_array
(array_parameters), 99
binary_stack, 102, 106
boundary_matrix, 11, 103, 111
branch_matrix, 69, 73, 105
category_layer, 103, 106, 205
category_vector, 107
col_ids (\texttt{OptimizationProblem}-methods), 157
col_ids, \texttt{OptimizationProblem}-method
(\texttt{OptimizationProblem}-methods), 157
Collection (Collection-class), 108
Collection-class, 108
compile, 109, 204
compressed_formulation
(\texttt{OptimizationProblem}-methods), 157
compressed_formulation, \texttt{OptimizationProblem}-method
(\texttt{OptimizationProblem}-methods), 157
connectivity_matrix, 110
connectivity_matrix, Raster, Raster-method
(connectivity_matrix), 110
connectivity_matrix, sf, Raster-method
(connectivity_matrix, sf), 110
connectivity_matrix, Spatial, character-method
(connectivity_matrix), 110
connectivity_matrix, Spatial, Raster-method
(connectivity_matrix), 110
ConservationModifier
(ConservationModifier-class), 112
ConservationModifier-class, 112
ConservationProblem
(ConservationProblem-class), 114
ConservationProblem-class, 114
Constraint (Constraint-class), 118
Constraint-class, 118
canstraints, 23, 31, 42, 46, 53, 55, 57, 83, 114, 118, 118, 121, 139, 154, 162, 165, 174, 178, 209, 211
data.frame, 98, 175
decision (Decision-class), 120
Decision-class, 120
decisions, 9, 27, 64, 66, 69, 72, 76, 78, 80, 85, 91, 119, 120, 120, 154, 162, 165, 177, 178, 209, 211
distribute_load, 121
div, 109, 114, 162
exact_extract, 123, 124
extract, 123, 124
fast_extract, 111, 123, 135
fast_extract, Raster, sf-method
(fast_extract), 123
fast_extract, Raster, sfc-method
(fast_extract), 123
fast_extract, Raster, SpatialLines-method
(fast_extract), 123
fast_extract, Raster, SpatialPoints-method
(fast_extract), 123
feature_abundances, 49, 86, 124, 129
feature_names, 126
feature_names, ConservationProblem-method
(feature_names), 126
feature_names, ZonesCharacter-method
(feature_names), 126
<table>
<thead>
<tr>
<th>Feature/Method</th>
<th>Page Numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>feature_names, ZonesRaster-method</td>
<td>126</td>
</tr>
<tr>
<td>feature_representation, ConservationProblem, data.frame-method</td>
<td>125, 127, 178, 205</td>
</tr>
<tr>
<td>feature_representation, ConservationProblem, matrix-method</td>
<td>127</td>
</tr>
<tr>
<td>feature_representation, ConservationProblem, numeric-method</td>
<td>127</td>
</tr>
<tr>
<td>feature_representation, ConservationProblem, Raster-method</td>
<td>127</td>
</tr>
<tr>
<td>feature_representation, ConservationProblem, Spatial-method</td>
<td>127</td>
</tr>
<tr>
<td>ferrier_score, ConservationProblem, data.frame-method</td>
<td>132</td>
</tr>
<tr>
<td>ferrier_score, ConservationProblem, matrix-method</td>
<td>132</td>
</tr>
<tr>
<td>ferrier_score, ConservationProblem, numeric-method</td>
<td>132</td>
</tr>
<tr>
<td>ferrier_score, ConservationProblem, Raster-method</td>
<td>132</td>
</tr>
<tr>
<td>ferrier_score, ConservationProblem, Spatial-method</td>
<td>132</td>
</tr>
<tr>
<td>integer_parameter (scalar_parameters)</td>
<td>147</td>
</tr>
<tr>
<td>integer_parameter_array (array_parameters)</td>
<td>194</td>
</tr>
<tr>
<td>intersecting_units, data.frame, ANY-method</td>
<td>42, 46, 134</td>
</tr>
<tr>
<td>intersecting_units, Raster, Raster-method</td>
<td>134</td>
</tr>
<tr>
<td>intersecting_units, Raster, sf-method</td>
<td>134</td>
</tr>
<tr>
<td>intersecting_units, Raster, Spatial-method</td>
<td>134</td>
</tr>
<tr>
<td>intersecting_units, sf, Raster-method</td>
<td>134</td>
</tr>
<tr>
<td>intersecting_units, sf, sf-method</td>
<td>134</td>
</tr>
<tr>
<td>intersecting_units, Spatial-method</td>
<td>134</td>
</tr>
<tr>
<td>intersecting_units, Spatial, Raster-method</td>
<td>134</td>
</tr>
<tr>
<td>intersecting_units, Spatial, sf-method</td>
<td>134</td>
</tr>
<tr>
<td>intersecting_units, Spatial, Spatial-method</td>
<td>134</td>
</tr>
<tr>
<td>is (is.Id)</td>
<td>138</td>
</tr>
<tr>
<td>lb, OptimizationProblem-method</td>
<td>157</td>
</tr>
<tr>
<td>modelsense (OptimizationProblem-methods)</td>
<td>157</td>
</tr>
<tr>
<td>max.col, 107, 108</td>
<td>143</td>
</tr>
<tr>
<td>marxan_boundary_data_to_matrix</td>
<td>139</td>
</tr>
<tr>
<td>marxan_problem</td>
<td>140</td>
</tr>
<tr>
<td>Matrix</td>
<td>104</td>
</tr>
<tr>
<td>matrix, 175, 176</td>
<td>143</td>
</tr>
<tr>
<td>modelsense, OptimizationProblem-method</td>
<td>157</td>
</tr>
<tr>
<td>modelsense, OptimizationProblem-method</td>
<td>157</td>
</tr>
<tr>
<td>MiscParameter (MiscParameter-class)</td>
<td>145</td>
</tr>
<tr>
<td>MiscParameter-class, 145</td>
<td>145</td>
</tr>
<tr>
<td>ncell (OptimizationProblem-methods)</td>
<td>157</td>
</tr>
<tr>
<td>ncol (OptimizationProblem-methods)</td>
<td>157</td>
</tr>
<tr>
<td>nrow (OptimizationProblem-methods)</td>
<td>157</td>
</tr>
<tr>
<td>new_id</td>
<td>147</td>
</tr>
<tr>
<td>new_optimization_problem</td>
<td>148</td>
</tr>
<tr>
<td>new_waiver</td>
<td>149</td>
</tr>
</tbody>
</table>
nrow, OptimizationProblem-method (OptimizationProblem-methods), 157
nrow, tbl_df-method (tibble-methods), 212
number_of_features, ConservationProblem-method (number_of_features), 149
number_of_features, OptimizationProblem-method (number_of_features), 149
number_of_features, ZonesCharacter-method (number_of_features), 149
number_of_features, ZonesRaster-method (number_of_features), 149
number_of_features, ConservationProblem-method (number_of_features), 149
number_of_features, OptimizationProblem-method (number_of_features), 149
number_of_features, ZonesCharacter-method (number_of_features), 149
number_of_features, ZonesRaster-method (number_of_features), 149
number_of_planning_units, ConservationProblem-method (number_of_planning_units), 150
number_of_planning_units, ConservationProblem-method (number_of_planning_units), 150
number_of_planning_units, OptimizationProblem-method (number_of_planning_units), 150
number_of_planning_units, ConservationProblem-method (number_of_planning_units), 150
number_of_planning_units, ConservationProblem-method (number_of_planning_units), 150
number_of_total_units, ConservationProblem-method (number_of_total_units), 151
number_of_total_units, ConservationProblem-method (number_of_total_units), 151
number_of_zones, ConservationProblem-method (number_of_zones), 152
number_of_zones, ConservationProblem-method (number_of_zones), 152
number_of_zones, OptimizationProblem-method (number_of_zones), 152
number_of_zones, ZonesCharacter-method (number_of_zones), 152
number_of_zones, ZonesRaster-method (number_of_zones), 152
numeric, 175
numeric_matrix_parameter (matrix_parameters), 143
numeric_parameter (scalar_parameters), 194
numeric_parameter_array (array_parameters), 99
obj (OptimizationProblem-methods), 157
obj, OptimizationProblem-method (OptimizationProblem-methods), 157
Objective (Objective-class), 153
Objective-class, 153
objectives, 34, 64, 66, 69, 73, 76, 78, 80, 119, 121, 153, 154, 162, 165, 174, 178, 209, 211
OptimizationProblem (OptimizationProblem-class), 155
OptimizationProblem-class, 155
OptimizationProblem-methods, 157
parameters (Parameters-class), 161
parameters, 160
parameters-class, 161
penalties, 12, 16, 83, 114, 118, 119, 121, 139, 154, 162, 163, 165, 174, 178, 209, 211
Penalty (Penalty-class), 163
Penalty-class, 163
phylo, 68, 72, 105, 202
pipe, 192, 217
Optimizer, 152
Portfolio (Portfolio-class), 164
Portfolio-class, 164
portfolios, 25, 26, 28, 29, 93, 94, 119, 121, 154, 162, 164, 165, 178, 209, 211
pproto, 166
predefined_optimization_problem, 167
presolve_check, 169, 187, 204, 205
print, 172, 173
print, Id-method (print), 172
print, tbl_df-method (print), 172
print, ArrayParameter (print), 172
print, ConservationModifier (print), 172
print, ConservationProblem (print), 172
print, Id (print), 172
print, OptimizationProblem (print), 172
print, ScalarParameter (print), 172
print, Solver (print), 172
print, Zones (print), 172
prioritizr, 173
problem, 8, 9, 14, 21, 25, 27–29, 37, 40, 45, 49, 50, 53, 54, 57, 59, 63, 65, 68, 71, 75, 77, 79, 81, 85, 90, 92, 94, 109, 110, 114, 118–121, 125, 129, 136, 137, 140, 154, 162, 165, 169, 170, 174, 204, 205, 209, 211, 214
problem, data.frame, character-method (problem), 174
problem, data.frame, data.frame-method (problem), 174
problem, data.frame, ZonesCharacter-method (problem), 174
INDEX

problem, matrix, data.frame-method
(problem), 174
problem, numeric, data.frame-method
(problem), 174
problem, Raster, Raster-method (problem), 174
problem, Raster, ZonesRaster-method (problem), 174
problem, sf, character-method (problem), 174
problem, sf, Raster-method (problem), 174
problem, sf, ZonesCharacter-method (problem), 174
problem, sf, ZonesRaster-method (problem), 174
problem, Spatial, character-method (problem), 174
problem, Spatial, Raster-method (problem), 174
problem, Spatial, ZonesCharacter-method (problem), 174
problem, Spatial, ZonesRaster-method (problem), 174
proportion parameter
(scalar_parameters), 194
proportion parameter_array
(array_parameters), 99
proximity_matrix, 182
rarity_weighted_richness, 136, 184
rarity_weighted_richness, ConservationProblem, data.frame-method
(rarity_weighted_richness), 184
rarity_weighted_richness, ConservationProblem, matrix-method
(rarity_weighted_richness), 184
rarity_weighted_richness, ConservationProblem, numeric-method
(rarity_weighted_richness), 184
rarity_weighted_richness, ConservationProblem, Raster-method
(rarity_weighted_richness), 184
rarity_weighted_richness, ConservationProblem, sf-method
(rarity_weighted_richness), 184
rarity_weighted_richness, ConservationProblem, Spatial-method
(rarity_weighted_richness), 184
raster, 213
Raster-class, 42, 46, 205, 214
replacement_cost, 136, 184, 186
replacement_cost, ConservationProblem, data.frame-method
(replacement_cost), 186
replacement_cost, ConservationProblem, Raster-method
(replacement_cost), 186
replacement_cost, ConservationProblem, sf-method
(replacement_cost), 186
replacement_cost, ConservationProblem, Spatial-method
(replacement_cost), 186
RFsimulate, 198, 199
rhs (OptimizationProblem-methods), 157
rhs, OptimizationProblem-method
(OptimizationProblem-methods), 157
rij_matrix, 190
rij_matrix, Raster, Raster-method (rij_matrix), 190
rij_matrix, sf, Raster-method (rij_matrix), 190
rij_matrix, Spatial, Raster-method (rij_matrix), 190
row_ids (OptimizationProblem-methods), 157
row_ids, OptimizationProblem-method
(OptimizationProblem-methods), 157
RP, 198, 199
run_calculations, 192
scalar_parameters, 161, 194
ScalarParameter
ScalarParameter-class, 193
matrix (OptimizationProblem-methods), 157
sense, OptimizationProblem-method
sense (OptimizationProblem-methods), 157
shiny, 98, 146, 160, 193, 194
show, ConservationModifier-method
(show), 196
show, ConservationProblem-method
(show), 196
show, Id-method
(show), 196
show, OptimizationProblem-method
(show), 196
show, Parameter-method
(show), 196
show, Solver-method (show), 196
sim_data, 200
sim_features (sim_data), 200
sim_features_zones (sim_data), 200
sim_locked_in_raster (sim_data), 200
sim_locked_out_raster (sim_data), 200
sim_phylogeny (sim_data), 200
sim_pu_lines (sim_data), 200
sim_pu_points (sim_data), 200
sim_pu_raster (sim_data), 200
sim_pu_zones_polygons (sim_data), 200
sim_pu_zones_sf (sim_data), 200
sim_pu_zones_stack (sim_data), 200
simulate_cost, 197, 199
simulate_data, 198, 200
simulate_species, 199, 199
solve, ConservationProblem, missing-method (solve), 204
solve, OptimizationProblem, Solver-method (solve), 204
Solver (Solver-class), 207
solvers, 27, 40, 52, 90, 119, 121, 154, 162, 165, 178, 205, 208, 209, 211
Spatial, 214
Spatial-class, 42, 46, 205, 214
SpatialPolygonsDataFrame, 104
st_intersects, 96
st_is_within_distance, 182
stack, 214
Target (Target-class), 210
Target-class, 210
targets, 6, 50, 60, 78, 87, 119, 121, 154, 162, 165, 174, 177, 178, 209, 211, 211
tee, 216
tee (%T>%), 217
tibble, 54, 57, 59, 117, 125, 129, 133, 145, 212
tibble-methods, 212
ub (OptimizationProblem-methods), 157
ub, OptimizationProblem-method (OptimizationProblem-methods), 157
UUIDgenerate, 147, 148
vtype (OptimizationProblem-methods), 157
vtype, OptimizationProblem-method (OptimizationProblem-methods), 157
zone_names, 215
zone_names, ConservationProblem-method (zone_names), 215
zone_names, OptimizationProblem-method (zone_names), 215
zone_names, ZonesCharacter-method (zone_names), 215
zone_names, ZonesRaster-method (zone_names), 215
Zones, 127, 150, 153, 215
Zones (zones), 213
zones, 213
Zones-class (zones), 213
ZonesCharacter, 176
ZonesCharacter (zones), 213
ZonesRaster, 176, 202
ZonesRaster (zones), 213