

# Package ‘prioritizr’

January 9, 2025

**Type** Package

**Version** 8.0.6

**Title** Systematic Conservation Prioritization in R

**Description** Systematic conservation prioritization using mixed integer linear programming (MILP). It provides a flexible interface for building and solving conservation planning problems. Once built, conservation planning problems can be solved using a variety of commercial and open-source exact algorithm solvers. By using exact algorithm solvers, solutions can be generated that are guaranteed to be optimal (or within a pre-specified optimality gap). 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. To solve large-scale or complex conservation planning problems, users should install the Gurobi optimization software (available from <https://www.gurobi.com/>) and the 'gurobi' R package (see Gurobi Installation Guide vignette for details). Users can also install the IBM CPLEX software (<https://www.ibm.com/products/ilog-cplex-optimization-studio/cplex-optimizer>) and the 'cplexAPI' R package (available at <https://github.com/cran/cplexAPI>). Additionally, the 'rcbc' R package (available at <https://github.com/dirkschumacher/rcbc>) can be used to generate solutions using the CBC optimization software (<https://github.com/coin-or/Cbc>). For further details, see Hanson et al. (2024) [doi:10.1111/cobi.14376](https://doi.org/10.1111/cobi.14376).

**Imports** utils, methods, parallel, R6 (>= 2.5.1), rlang (>= 1.0.6), cli (>= 3.6.0), sf (>= 1.0-12), terra (>= 1.6-53), raster (>= 3.6.11), Matrix (>= 1.3-0), assertthat (>= 0.2.0), slam (>= 0.1-48), igraph (>= 2.0.3), ape (>= 5.6-1), magrittr (>= 2.0.1), exactextractr (>= 0.8.1), tibble (>= 2.0.0), withr (>= 2.3.0)

**Suggests** testthat (>= 3.1.0), knitr (>= 1.36), scales (>= 1.1.1), gurobi (>= 8.0-1), rcbc (>= 0.1.0.9001), cplexAPI (>= 1.4.0), lpsymphony (>= 1.17.0), Rsymphony (>= 0.1-31), highs (>= 0.1-10), rmarkdown (>= 2.11), prioritizrdata (>= 0.2.4), data.table (>= 1.14.2), fields (>= 14.0)

**Depends** R (>= 4.1.0)

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**BugReports** <https://github.com/prioritizr/prioritizr/issues>

**VignetteBuilder** knitr

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**Collate** 'external-classes.R' 'internal.R' 'assertions\_class.R'  
 'assertions\_sf.R' 'assertions\_misc.R' 'assertions\_raster.R'  
 'assertions\_vector.R' 'any\_nonzero.R' 'any\_nonNA.R'  
 'all\_proportion.R' 'all\_positive.R' 'all\_finite.R'  
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 'test-helpers.R' 'write\_problem.R' 'zone\_names.R' 'zzz.R'

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add\_absolute\_targets *Add absolute targets*

## 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

```
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)

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

## Arguments

x [problem\(\)](#) object.

targets object that specifies the targets for each feature. See the Targets format 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.

For problems associated with multiple management zones, [add\\_absolute\\_targets\(\)](#) can be used to set targets that each pertain to a single feature and a single zone. To set targets that 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

An updated [problem\(\)](#) object with the targets added to it.

## Targets format

The targets for a problem can be specified using the following formats.

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

targets as a matrix **object** 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.

targets as a character **vector** containing the column name(s) in the feature data associated with the argument to `x` that contain targets. This format can only be used when the feature data associated with `x` is a `sf::st_sf()` or `data.frame`. For problems that contain a single zone, the argument to `targets` must contain a single column name. Otherwise, for problems that contain multiple zones, the argument to `targets` must contain a column name for each zone.

## See Also

See [targets](#) for an overview of all functions for adding targets.

Other targets: [add\\_loglinear\\_targets\(\)](#), [add\\_manual\\_targets\(\)](#), [add\\_relative\\_targets\(\)](#)

## Examples

```
## Not run:  
# set seed for reproducibility  
set.seed(500)
```

```

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# create minimal problem with no targets
p0 <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# create problem with targets to secure 3 amounts for each feature
p1 <- p0 %>% add_absolute_targets(3)

# create problem with varying targets for each feature
targets <- c(1, 2, 3, 2, 1)
p2 <- p0 %>% add_absolute_targets(targets)

# solve problem
s1 <- c(solve(p1), solve(p2))
names(s1) <- c("equal targets", "varying targets")

# plot solution
plot(s1, axes = FALSE)

# create a problem with multiple management zones
p3 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_min_set_objective() %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# 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_zones_features),
  ncol = number_of_zones(sim_zones_features),
  dimnames = list(
    feature_names(sim_zones_features), zone_names(sim_zones_features)
  )
)
print(p4_targets)

p4 <- p3 %>% add_absolute_targets(p4_targets)

# solve problem
s4 <- solve(p4)

# plot solution (pixel values correspond to zone identifiers)

```



```

plot(category_layer(s4), main = "equal targets", axes = FALSE)

# create a problem with targets that require a varying amount of each
# feature to be represented in each zone
p5_targets <- matrix(
  rpois(15, 1),
  nrow = number_of_features(sim_zones_features),
  ncol = number_of_zones(sim_zones_features),
  dimnames = list(
    feature_names(sim_zones_features),
    zone_names(sim_zones_features)
  )
)
print(p5_targets)

p5 <- p3 %>% add_absolute_targets(p5_targets)

# solve problem
s5 <- solve(p5)

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

## End(Not run)

```

---

add\_asym\_connectivity\_penalties

*Add asymmetric connectivity penalties*

---

## Description

Add penalties to a conservation planning problem to account for asymmetric connectivity between planning units. Asymmetric connectivity data describe connectivity information that is directional. For example, asymmetric connectivity data could describe the strength of rivers flowing between different planning units. Since river flow is directional, the level of connectivity from an upstream planning unit to a downstream planning unit would be higher than that from a downstream planning unit to an upstream planning unit.

## Usage

```

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

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

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

```

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

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

## Arguments

x	<a href="#">problem()</a> 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 <a href="#">add_min_set_objective()</a> ). 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 working with multiple zones and the argument to data is a matrix or Matrix object. If the argument to data is an array or data.frame with data for multiple zones (e.g., using the "zone1" and "zone2" column names), 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 Data format section for more information.

## Details

This function adds penalties to conservation planning problem to penalize solutions that have low connectivity. Specifically, it penalizes solutions that select planning units that share high connectivity values with other planning units that are not selected by the solution (based on Beger *et al.* 2010).

## Value

An updated [problem\(\)](#) object with the penalties added to it.

### Mathematical formulation

The connectivity penalties are implemented 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:

$$\sum_i^I \sum_j^I \sum_z^Z \sum_y^Z (p \times X_{iz} \times D_{ij} \times W_{zy}) - \sum_i^I \sum_j^I \sum_z^Z \sum_y^Z (p \times X_{iz} \times X_{jy} \times D_{ij} \times W_{zy})$$

Otherwise, if the argument to data is supplied as an array object, then the penalties are calculated as:

$$\sum_i^I \sum_j^I \sum_z^Z \sum_y^Z (p \times X_{iz} \times D_{ijzy}) - \sum_i^I \sum_j^I \sum_z^Z \sum_y^Z (p \times X_{iz} \times X_{jy} \times D_{ijzy})$$

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  $-p$ .

### Data format

The argument to data can be specified using several different formats.

**data as a matrix/Matrix object** 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 as a data.frame object** containing columns that are named "id1", "id2", and "boundary". Here, each row denotes the connectivity between a pair of planning units (per values in the "id1" and "id2" columns) following the *Marxan* format. If the argument to x contains multiple zones, then the "zone1" and "zone2" columns can optionally be provided to manually specify the connectivity values between planning units when they are allocated to specific zones. If the "zone1" and "zone2" columns are present, then the argument to zones must be NULL.

**data as an array object** 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.

## References

Beger M, Linke S, Watts M, Game E, Treml E, Ball I, and Possingham, HP (2010) Incorporating asymmetric connectivity into spatial decision making for conservation, *Conservation Letters*, 3: 359–368.

## See Also

See [penalties](#) for an overview of all functions for adding penalties.

Other penalties: [add\\_boundary\\_penalties\(\)](#), [add\\_connectivity\\_penalties\(\)](#), [add\\_feature\\_weights\(\)](#), [add\\_linear\\_penalties\(\)](#)

## Examples

```
## Not run:
# set seed for reproducibility
set.seed(600)

# load data
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# create basic problem
p1 <-
  problem(sim_pu_polygons, sim_features, "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_default_solver(verbose = FALSE)

# 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.
acm1 <- matrix(0, nrow(sim_pu_polygons), nrow(sim_pu_polygons))
acm1 <- as(acm1, "Matrix")
centroids <- sf::st_coordinates(
  suppressWarnings(sf::st_centroid(sim_pu_polygons))
)
adjacent_units <- sf::st_intersects(sim_pu_polygons, sparse = FALSE)
for (i in seq_len(nrow(sim_pu_polygons))) {
  for (j in seq_len(nrow(sim_pu_polygons))) {
    # 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[i, 1] == centroids[j, 1]) {
        if (centroids[i, 2] > centroids[j, 2]) {
          # if i is north of j add 10 units of connectivity
          acm1[i, j] <- acm1[i, j] + 10
        } else if (centroids[i, 2] < centroids[j, 2]) {
```

```

        # if i is south of j add 1 unit of connectivity
        acm1[i, j] <- acm1[i, j] + 1
      }
    }
  }
}

# rescale matrix values to have a maximum value of 1
acm1 <- rescale_matrix(acm1, max = 1)

# visualize asymmetric connectivity matrix
Matrix::image(acm1)

# create penalties
penalties <- c(1, 50)

# create problems using the different penalties
p2 <- list(
  p1,
  p1 %>% add_asym_connectivity_penalties(penalties[1], data = acm1),
  p1 %>% add_asym_connectivity_penalties(penalties[2], data = acm1)
)

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

# create object with all solutions
s2 <- sf::st_sf(
  tibble::tibble(
    p2_1 = s2[[1]]$solution_1,
    p2_2 = s2[[2]]$solution_1,
    p2_3 = s2[[3]]$solution_1
  ),
  geometry = sf::st_geometry(s2[[1]])
)

names(s2)[1:3] <- c("basic problem", paste0("acm1 (", penalties, ")"))

# plot solutions based on different penalty values
plot(s2, cex = 1.5)

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

# crate asymmetric connectivity data by randomly simulating values
acm2 <- matrix(

```

```

runif(ncell(sim_zones_pu_raster) ^ 2),
nrow = ncell(sim_zones_pu_raster)
)

# create multi-zone problems using the penalties
p4 <- list(
  p3,
  p3 %>% add_asym_connectivity_penalties(penalties[1], data = acm2),
  p3 %>% add_asym_connectivity_penalties(penalties[2], data = acm2)
)

# solve problems
s4 <- lapply(p4, solve)
s4 <- lapply(s4, category_layer)
s4 <- terra::rast(s4)
names(s4) <- c("basic problem", paste0("acm2 (", penalties,")"))

# plot solutions
plot(s4, axes = FALSE)

## End(Not run)

```

---

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 [problem\(\)](#) 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). Only a single decision should be added to a [problem\(\)](#) object. Note that if multiple decisions are added to an object, then the last one to be added will be used.

**Value**

An updated `problem()` object with the decisions added to it.

**See Also**

See [decisions](#) for an overview of all functions for adding decisions.

Other decisions: [add\\_proportion\\_decisions\(\)](#), [add\\_semicontinuous\\_decisions\(\)](#)

**Examples**

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_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(verbose = FALSE)

# solve problem
s1 <- solve(p1)

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

# create a matrix with targets for a multi-zone conservation problem
targs <- matrix(runif(15, 0.1, 0.2), nrow = 5, ncol = 3)

# build multi-zone conservation problem with binary decisions
p2 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(targs) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve the problem
s2 <- solve(p2)

# print solution
print(s2)

# plot solution
```

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

## End(Not run)
```

---

```
add_boundary_penalties
      Add boundary penalties
```

---

### Description

Add penalties to a conservation planning problem to favor solutions that spatially clump planning units together based on the overall boundary length (i.e., total perimeter).

### Usage

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

## S4 method for signature 'ConservationProblem,ANY,ANY,ANY,matrix'
add_boundary_penalties(x, penalty, edge_factor, zones, data)

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

### Arguments

x	<code>problem()</code> 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 per <code>add_min_set_objective()</code> ). Higher penalty values prefer solutions with a higher degree of spatial clumping, and smaller penalty values prefer solutions with a smaller degree of clumping. Note that negative penalty values prefer solutions that are more spread out. This parameter is equivalent to the boundary length modifier (BLM) parameter in <i>Marxan</i> .
edge_factor	numeric proportion to scale planning unit edges (borders) that do not have any neighboring planning units. For example, an edge factor of 0.5 is commonly used to avoid overly penalizing planning units along a coastline. 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 combination 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 range 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. If the cells along the matrix diagonal contain markedly smaller values than those found elsewhere in the matrix, then solutions are preferred that surround planning units with those allocated to different zones (i.e., greater spatial fragmentation).

**data** NULL, `data.frame`, `matrix`, or `Matrix` object containing the boundary data. These data describe the total amount of boundary (perimeter) length for each planning unit, and the amount of boundary (perimeter) length shared between different planning units (i.e., planning units that are adjacent to each other). See the Data format 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.

### Value

An updated `problem()` object with the penalties added to it.

### Data format

The argument to `data` can be specified using the following formats. Note that boundary data must always describe symmetric relationships between planning units.

`data` **as a NULL value** indicating that the data should be automatically calculated using the `boundary_matrix()` function. This argument is the default. Note that the boundary data must be supplied using one of the other formats below if the planning unit data in the argument to `x` do not explicitly contain spatial information (e.g., planning unit data are a `data.frame` or `numeric` class).

`data` **as a matrix/Matrix object** 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 denote the total boundary length associated with each planning unit.

`data` **as a data.frame object** with the columns "id1", "id2", and "boundary". The "id1" and "id2" columns contain identifiers (indices) for a pair of planning units, and the "boundary" column contains the amount of shared boundary length between these two planning units. Additionally, if the values in the "id1" and "id2" columns contain the same values, then the value denotes the amount of exposed boundary length (not total boundary). This format follows the standard *Marxan* format for boundary data (i.e., per the "bound.dat" file).

### Mathematical formulation

The boundary penalties are implemented 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`,  $E_z$  represent the argument to `edge_factor`,  $B_{ij}$  represent the matrix argument to `data` (e.g., generated using `boundary_matrix()`), and  $W_{zz}$  represent the matrix argument to `zones`.

$$\sum_i^I \sum_z^Z (p \times W_{zz} B_{ii}) + \sum_i^I \sum_j^I \sum_z^Z \sum_y^Z (-2 \times p \times X_{iz} \times X_{jy} \times W_{zy} \times B_{ij})$$

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  $-p$ .

## References

Ball IR, Possingham HP, and Watts M (2009) *Marxan and relatives: Software for spatial conservation prioritisation* in *Spatial conservation prioritisation: Quantitative methods and computational tools*. Eds Moilanen A, Wilson KA, and Possingham HP. Oxford University Press, Oxford, UK.

Beyer HL, Dujardin Y, Watts ME, and Possingham HP (2016) Solving conservation planning problems with integer linear programming. *Ecological Modelling*, 228: 14–22.

## See Also

See [penalties](#) for an overview of all functions for adding penalties.

Other penalties: [add\\_asym\\_connectivity\\_penalties\(\)](#), [add\\_connectivity\\_penalties\(\)](#), [add\\_feature\\_weights\(\)](#), [add\\_linear\\_penalties\(\)](#)

## Examples

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# 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(verbose = FALSE)

# 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
s1 <- c(solve(p1), solve(p2), solve(p3), solve(p4))
names(s1) <- c("basic solution", "small penalties", "high penalties",
  "precomputed data"
)

# plot solutions
plot(s1, axes = 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_zones_pu_raster, sim_zones_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(0.2, nrow = 5, ncol = 3)) %>%
  add_binary_decisions() %>%
  add_default_solver(time_limit = 10, verbose = FALSE)

# 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 <- list(solve(p5), solve(p6), solve(p7), solve(p8), solve(p9), solve(p10))

#convert to category layers for visualization
s2 <- terra::rast(lapply(s2, category_layer))
names(s2) <- c(
  "basic solution", "within zone clumping (low)",
  "within zone clumping (high)", "between zone clumping",
  "within + between clumping", "negative clumping"
)

# plot solutions
plot(s2, axes = FALSE)

## End(Not run)

```

---

add\_cbc\_solver

*Add a CBC solver*


---

## Description

Specify that the **CBC** (COIN-OR branch and cut) software should be used to solve a conservation planning problem (Forrest & Lougee-Heimer 2005). This function can also be used to customize the behavior of the solver. It requires the **rcbc** package to be installed (only [available on GitHub](#), see below for installation instructions).

## Usage

```

add_cbc_solver(
  x,
  gap = 0.1,
  time_limit = .Machine$integer.max,
  presolve = TRUE,
  threads = 1,
  first_feasible = FALSE,
  start_solution = NULL,
  verbose = TRUE
)

```

## Arguments

x	<code>problem()</code> object.
gap	numeric gap to optimality. This gap is relative and expresses the acceptable deviance from the optimal objective. For example, a value of 0.01 will result in the solver stopping when it has found a solution within 1% of optimality. Additionally, a value of 0 will result in the solver stopping when it has found an optimal solution. The default value is 0.1 (i.e., 10% from optimality).
time_limit	numeric time limit (seconds) for generating solutions. The solver will return the current best solution when this time limit is exceeded. The default value is the largest integer value (i.e., <code>.Machine\$integer.max</code> ), effectively meaning that solver will keep running until a solution within the optimality gap is found.
presolve	logical attempt to simplify the problem before solving it? Defaults to TRUE.
threads	integer number of threads to use for the optimization algorithm. The default value is 1.
first_feasible	logical should the first feasible solution be returned? If <code>first_feasible</code> 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.
start_solution	NULL or object containing the starting solution for the solver. This is can be useful because specifying a starting solution can speed up the optimization process. Defaults to NULL such that no starting solution is used. To specify a starting solution, the argument to <code>start_solution</code> should be in the same format as the planning units (i.e., a NULL, numeric, matrix, data.frame, <code>terra::rast()</code> , or <code>sf::sf()</code> object). See the Start solution format section for more information.
verbose	logical should information be printed while solving optimization problems? Defaults to TRUE.

## Details

*CBC* is an open-source mixed integer programming solver that is part of the Computational Infrastructure for Operations Research (COIN-OR) project. This solver seems to have much better performance than the other open-source solvers (i.e., `add_highs_solver()`, `add_rsymphony_solver()`, `add_lpsymphony_solver()`) (see the *Solver benchmarks* vignette for details). As such, it is strongly recommended to use this solver if the *Gurobi* and *IBM CPLEX* solvers are not available.

## Value

An updated `problem()` object with the solver added to it.

## Installation

The `rbcb` package is required to use this solver. Since the `rbcb` package is not available on the the Comprehensive R Archive Network (CRAN), it must be installed from [its GitHub repository](#). To install the `rbcb` package, please use the following code:

```
if (!require(remotes)) install.packages("remotes")
remotes::install_github("dirkschumacher/rcbc")
```

Note that you may also need to install several dependencies – such as the [Rtools software](#) or system libraries – prior to installing the **rcbc** package. For further details on installing this package, please consult the [online package documentation](#).

### Start solution format

Broadly speaking, the argument to `start_solution` must be in the same format as the planning unit data in the argument to `x`. Further details on the correct format are listed separately for each of the different planning unit data formats:

- x has numeric `planning units`** The argument to `start_solution` must be a numeric vector with each element corresponding to a different planning unit. It should have the same number of planning units as those in the argument to `x`. Additionally, any planning units missing cost (NA) values should also have missing (NA) values in the argument to `start_solution`.
- x has matrix `planning units`** The argument to `start_solution` must be a matrix vector with each row corresponding to a different planning unit, and each column correspond to a different management zone. It should have the same number of planning units and zones as those in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have a missing (NA) values in the argument to `start_solution`.
- x has `terra::rast()` `planning units`** The argument to `start_solution` be a `terra::rast()` object where different grid cells (pixels) correspond to different planning units and layers correspond to a different management zones. It should have the same dimensionality (rows, columns, layers), resolution, extent, and coordinate reference system as the planning units in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `start_solution`.
- x has `data.frame` `planning units`** The argument to `start_solution` must be a `data.frame` with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if a `data.frame` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example with `sf::sf()` data). Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `start_solution`.
- x has `sf::sf()` `planning units`** The argument to `start_solution` must be a `sf::sf()` object with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if the `sf::sf()` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example). Additionally, the argument to `start_solution` must also have the same coordinate reference system as the planning unit data. Furthermore, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `start_solution`.

### References

Forrest J and Lougee-Heimer R (2005) CBC User Guide. In *Emerging theory, Methods, and Applications* (pp. 257–277). INFORMS, Catonsville, MD. [doi:10.1287/educ.1053.0020](https://doi.org/10.1287/educ.1053.0020).

**See Also**

Other solvers: [add\\_cplex\\_solver\(\)](#), [add\\_default\\_solver\(\)](#), [add\\_gurobi\\_solver\(\)](#), [add\\_highs\\_solver\(\)](#), [add\\_ksymphony\\_solver\(\)](#), [add\\_ksymphony\\_solver\(\)](#)

**Examples**

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()

# create problem
p1 <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_cbc_solver(gap = 0, verbose = FALSE)

# generate solution %>%
s1 <- solve(p1)

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

# create a similar problem with boundary length penalties and
# specify the solution from the previous run as a starting solution
p2 <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_boundary_penalties(10) %>%
  add_binary_decisions() %>%
  add_cbc_solver(gap = 0, start_solution = s1, verbose = FALSE)

# generate solution
s2 <- solve(p2)

# plot solution
plot(s2, main = "solution with boundary penalties", axes = FALSE)

## End(Not run)
```

---

add\_connectivity\_penalties

*Add connectivity penalties*

---

## Description

Add penalties to a conservation planning problem to account for symmetric connectivity between planning units. Symmetric connectivity data describe connectivity information that is not directional. For example, symmetric connectivity data could describe which planning units are adjacent to each other (see [adjacency\\_matrix\(\)](#)), or which planning units are within threshold distance of each other (see [proximity\\_matrix\(\)](#)).

## Usage

```
## 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,data.frame'
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,array'
add_connectivity_penalties(x, penalty, zones, data)
```

## Arguments

x	<a href="#">problem()</a> 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 <a href="#">add_min_set_objective()</a> ). 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 working with multiple zones and the argument to data is a matrix or Matrix object. If the argument to data is an array or data.frame with data for multiple zones (e.g., using the "zone1" and "zone2" column names), 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 Data format section for more information.

### Details

This function adds penalties to conservation planning problem to penalize solutions that have low connectivity. Specifically, it favors pair-wise connections between planning units that have high connectivity values (based on Önal and Briers 2002).

### Value

An updated `problem()` object with the penalties added to it.

### Data format

The argument to data can be specified using several different formats.

**data as a matrix/Matrix object** 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 as a data.frame object** containing columns that are named "id1", "id2", and "boundary". Here, each row denotes the connectivity between a pair of planning units (per values in the "id1" and "id2" columns) following the *Marxan* format. If the argument to x contains multiple zones, then the "zone1" and "zone2" columns can optionally be provided to manually specify the connectivity values between planning units when they are allocated to specific zones. If the "zone1" and "zone2" columns are present, then the argument to zones must be NULL.

**data as an array object** 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.

### Mathematical formulation

The connectivity penalties are implemented 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:

$$\sum_i^I \sum_j^I \sum_z^Z \sum_y^Z (-p \times X_{iz} \times X_{jy} \times D_{ij} \times W_{zy})$$

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

$$\sum_i^I \sum_j^I \sum_z^Z \sum_y^Z (-p \times X_{iz} \times X_{jy} \times D_{ijzy})$$

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  $p$ .

## Notes

In previous versions, this function aimed to handle both symmetric and asymmetric connectivity data. This meant that the mathematical formulation used to account for asymmetric connectivity was different to that implemented by the *Marxan* software (see Beger *et al.* for details). To ensure that asymmetric connectivity is handled in a similar manner to the *Marxan* software, the [add\\_asym\\_connectivity\\_penalties\(\)](#) function should now be used for asymmetric connectivity data.

## References

Beger M, Linke S, Watts M, Game E, Treml E, Ball I, and Possingham, HP (2010) Incorporating asymmetric connectivity into spatial decision making for conservation, *Conservation Letters*, 3: 359–368.

Önal H, and Briers RA (2002) Incorporating spatial criteria in optimum reserve network selection. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, 269: 2437–2441.

## See Also

See [penalties](#) for an overview of all functions for adding penalties. Additionally, see [add\\_asym\\_connectivity\\_penalties\(\)](#) to account for asymmetric connectivity between planning units.

Other penalties: [add\\_asym\\_connectivity\\_penalties\(\)](#), [add\\_boundary\\_penalties\(\)](#), [add\\_feature\\_weights\(\)](#), [add\\_linear\\_penalties\(\)](#)

## Examples

```
## Not run:
# set seed for reproducibility
set.seed(600)

# load data
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()
```

```

sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# create basic problem
p1 <-
  problem(sim_pu_polygons, sim_features, "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_default_solver(verbose = FALSE)

# 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)

# rescale matrix values to have a maximum value of 1
b_matrix <- rescale_matrix(b_matrix, max = 1)

# visualize connectivity matrix
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 <- sf::st_coordinates(
  suppressWarnings(sf::st_centroid(sim_pu_polygons))
)
d_matrix <- (1 / (Matrix::Matrix(as.matrix(dist(centroids))) + 1))

# rescale matrix values to have a maximum value of 1
d_matrix <- rescale_matrix(d_matrix, max = 1)

# remove connections between planning units with values below a threshold to
# reduce run-time
d_matrix[d_matrix < 0.8] <- 0

# visualize connectivity matrix
Matrix::image(d_matrix)

# create a symmetric connectivity matrix where the connectivity
# between adjacent two planning units corresponds to their combined
# value in a column of the planning unit data

# for example, this column 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")

# rescale matrix values to have a maximum value of 1
c_matrix <- rescale_matrix(c_matrix, max = 1)

# visualize connectivity matrix

```

```

Matrix::image(c_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)
)

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

# create single object with all solutions
s2 <- sf::st_sf(
  tibble::tibble(
    p2_1 = s2[[1]]$solution_1,
    p2_2 = s2[[2]]$solution_1,
    p2_3 = s2[[3]]$solution_1,
    p2_4 = s2[[4]]$solution_1,
    p2_5 = s2[[5]]$solution_1,
    p2_6 = s2[[6]]$solution_1,
    p2_7 = s2[[7]]$solution_1
  ),
  geometry = sf::st_geometry(s2[[1]])
)

names(s2)[1:7] <- c(
  "basic problem",
  paste0("b_matrix (", penalties, ")"),
  paste0("d_matrix (", penalties, ")"),
  paste0("c_matrix (", penalties, ")")
)

# plot solutions
plot(s2)

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

# create matrix showing which planning units are adjacent to other units

```

```
a_matrix <- adjacency_matrix(sim_zones_pu_raster)

# visualize matrix
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 <- matrix(0.1, ncol = 3, nrow = 3)
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)
)

# solve problems
s4 <- lapply(p4, solve)
s4 <- lapply(s4, category_layer)
s4 <- terra::rast(s4)
names(s4) <- c(
  "basic problem",
  paste0("zm", rep(seq_len(5), each = 2), " (", rep(penalties2, 2), ")")
)

# plot solutions
plot(s4, axes = 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
# ones or zeros
c_array <- array(0, c(rep(ncell(sim_zones_pu_raster[[1]]), 2), 3, 3))
for (z1 in seq_len(3))
  for (z2 in seq_len(3))
    c_array[, , z1, z2] <- round(
      runif(ncell(sim_zones_pu_raster[[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)
  )

# solve problems
s5 <- lapply(p5, solve)
s5 <- lapply(s5, category_layer)
s5 <- terra::rast(s5)
names(s5) <- c("basic problem", "connectivity array")

# plot solutions
plot(s5, axes = FALSE)

## End(Not run)

```

---

```
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

```

## 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	<code>problem()</code> 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 Data format section for more information.

### Details

This function uses connection data to identify solutions that form a single contiguous unit. It was inspired by the mathematical formulations detailed in Önal and Briers (2006).

### Value

An updated `problem()` object with the constraints added to it.

### Data format

The argument to data can be specified using the following formats.

**data as a NULL value** indicating that 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).

**data as a matrix/Matrix object** 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 as a data.frame object** containing columns that are named "id1", "id2", and "boundary". Here, each row denotes the connectivity between two planning units following the *Marxan* format. The "boundary" column should contain binary numeric values that indicate if the two planning units specified in the "id1" and "id2" columns 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).

### Notes

In early versions, this function was named as the `add_connected_constraints()` function.

### References

Önal H and Briers RA (2006) Optimal selection of a connected reserve network. *Operations Research*, 54: 379–388.



**See Also**

See [constraints](#) for an overview of all functions for adding constraints.

Other constraints: [add\\_feature\\_contiguity\\_constraints\(\)](#), [add\\_linear\\_constraints\(\)](#), [add\\_locked\\_in\\_constraints\(\)](#), [add\\_locked\\_out\\_constraints\(\)](#), [add\\_mandatory\\_allocation\\_constraints\(\)](#), [add\\_manual\\_bounded\\_constraints\(\)](#), [add\\_manual\\_locked\\_constraints\(\)](#), [add\\_neighbor\\_constraints\(\)](#)

**Examples**

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# 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(verbose = FALSE)

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

# solve problems
s1 <- c(solve(p1), solve(p2))
names(s1) <- c("basic solution", "connected solution")

# plot solutions
plot(s1, axes = 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_zones_pu_raster, sim_zones_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(0.2, ncol = 3, nrow = 5)) %>%
  add_binary_decisions() %>%
  add_default_solver(time_limit = 30, verbose = FALSE)

# 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 3 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 <- terra::rast(s2)
names(s2) <- c("basic solution", "p4", "p5", "p6")

# plot solutions
plot(s2, axes = FALSE)

# 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 50% 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 30% 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_zones_pu_raster[[c(1, 1)]]
pus[[2]] <- pus[[2]] * 0.3
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))[rep(1, 5)],

```

```

    target = terra::global(sim_features, "sum", na.rm = TRUE)[[1]] * 0.5,
    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(targets) %>%
  add_contiguity_constraints(z7) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problems
s7 <- category_layer(solve(p7))

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

## End(Not run)

```

---

add\_cplex\_solver      *Add a CPLEX solver*

---

## Description

Specify that the *IBM CPLEX* software should be used to solve a conservation planning problem (IBM 2017). This function can also be used to customize the behavior of the solver. It requires the **cplexAPI** package to be installed (see below for installation instructions).

## Usage

```

add_cplex_solver(
  x,
  gap = 0.1,
  time_limit = .Machine$integer.max,
  presolve = TRUE,
  threads = 1,
  verbose = TRUE
)

```

## Arguments

x                      `problem()` object.

gap	numeric gap to optimality. This gap is relative and expresses the acceptable deviance from the optimal objective. For example, a value of 0.01 will result in the solver stopping when it has found a solution within 1% of optimality. Additionally, a value of 0 will result in the solver stopping when it has found an optimal solution. The default value is 0.1 (i.e., 10% from optimality).
time_limit	numeric time limit (seconds) for generating solutions. The solver will return the current best solution when this time limit is exceeded. The default value is the largest integer value (i.e., <code>.Machine\$integer.max</code> ), effectively meaning that solver will keep running until a solution within the optimality gap is found.
presolve	logical attempt to simplify the problem before solving it? Defaults to TRUE.
threads	integer number of threads to use for the optimization algorithm. The default value is 1.
verbose	logical should information be printed while solving optimization problems? Defaults to TRUE.

### Details

*IBM CPLEX* is a commercial optimization software. It is faster than the available open source solvers (e.g., `add_lpsymphony_solver()` and `add_rsymphony_solver()`). Although formal benchmarks examining the performance of this solver for conservation planning problems have yet to be completed, preliminary analyses suggest that it performs slightly slower than the *Gurobi* solver (i.e., `add_gurobi_solver()`). We recommend using this solver if the *Gurobi* solver is not available. Licenses are available for the *IBM CPLEX* software to academics at no cost (see <<https://www.ibm.com/products/ilog-cplex-optimization-studio/cplex-optimizer>>).

### Value

An updated `problem()` object with the solver added to it.

### Installation

The `cplexAPI` package is used to interface with *IBM CPLEX* software. To install the package, the *IBM CPLEX* software must be installed (see <https://www.ibm.com/products/ilog-cplex-optimization-studio/cplex-optimizer>). Next, the `Cplex_BIN` environmental variable must be set to specify the file path for the *IBM CPLEX* software. For example, on a Linux system, this variable can be specified by adding the following text to the `~/.bashrc` file:

```
export Cplex_BIN="/opt/ibm/ILOG/Cplex_Studio128/cplex/bin/x86-64_linux/cplex"
```

Please Note that you may need to change the version number in the file path (i.e., "Cplex\_Studio128"). After specifying the `Cplex_BIN` environmental variable, the `cplexAPI` package can be installed. Since the `cplexAPI` package is not available on the the Comprehensive R Archive Network (CRAN), it must be installed from [its GitHub repository](#). To install the `cplexAPI` package, please use the following code:

```
if (!require(remotes)) install.packages("remotes")
remotes::install_github("cran/cplexAPI")
```

For further details on installing this package, please consult the [installation instructions](#).

## References

IBM (2017) IBM ILOG CPLEX Optimization Studio CPLEX User's Manual. Version 12 Release 8. IBM ILOG CPLEX Division, Incline Village, NV.

## See Also

Other solvers: [add\\_cbc\\_solver\(\)](#), [add\\_default\\_solver\(\)](#), [add\\_gurobi\\_solver\(\)](#), [add\\_highs\\_solver\(\)](#), [add\\_lysophony\\_solver](#), [add\\_rsophony\\_solver\(\)](#)

## Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()

# create problem
p <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_cplex_solver(gap = 0.1, time_limit = 5, verbose = FALSE)

# generate solution
s <- solve(p)

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

## End(Not run)
```

---

add\_cuts\_portfolio      *Add Bender's cuts portfolio*

---

## 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

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

## Arguments

`x`                      [problem\(\)](#) 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.

## Value

An updated `problem()` object with the portfolio added to it.

## Notes

In early versions (<4.0.1), this function was only compatible with *Gurobi* (i.e., `add_gurobi_solver()`). To provide functionality with exact algorithm solvers, this function now adds constraints to the problem formulation to generate multiple solutions.

## References

Rodrigues AS, Cerdeira OJ, and Gaston KJ (2000) Flexibility, efficiency, and accountability: adapting reserve selection algorithms to more complex conservation problems. *Ecography*, 23: 565–574.

## See Also

See `portfolios` for an overview of all functions for adding a portfolio.

Other portfolios: `add_default_portfolio()`, `add_extra_portfolio()`, `add_gap_portfolio()`, `add_shuffle_portfolio()`, `add_top_portfolio()`

## Examples

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# 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)
```

```
# convert portfolio into a multi-layer raster object
s1 <- terra::rast(s1)

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

# build multi-zone conservation problem with cuts portfolio
p2 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  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)

# convert each solution in the portfolio into a single category layer
s2 <- terra::rast(lapply(s2, category_layer))

# plot solutions in portfolio
plot(s2, main = "solution", axes = FALSE)

## End(Not run)
```

---

add\_default\_portfolio *Add a default portfolio*

---

### Description

Generate a portfolio containing a single solution.

### Usage

```
add_default_portfolio(x)
```

### Arguments

x [problem\(\)](#) object.

### Details

By default, this portfolio is added to [problem\(\)](#) objects if no other portfolios are manually specified.

**Value**

An updated [problem\(\)](#) object with the portfolio added to it.

**See Also**

See [portfolios](#) for an overview of all functions for adding a portfolio.

Other portfolios: [add\\_cuts\\_portfolio\(\)](#), [add\\_extra\\_portfolio\(\)](#), [add\\_gap\\_portfolio\(\)](#), [add\\_shuffle\\_portfolio\(\)](#), [add\\_top\\_portfolio\(\)](#)

---

add\_default\_solver      *Add default solver*

---

**Description**

Specify that the best solver currently available should be used to solve a conservation planning problem.

**Usage**

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

**Arguments**

x                      [problem\(\)](#) object.  
 ...                    arguments passed to the solver.

**Details**

Ranked from best to worst, the available solvers that can be used are: [add\\_gurobi\\_solver\(\)](#), [add\\_cplex\\_solver\(\)](#), [add\\_cbc\\_solver\(\)](#), [add\\_highs\\_solver\(\)](#), [add\\_lpsymphony\\_solver\(\)](#), and finally [add\\_rysymphony\\_solver\(\)](#). For information on the performance of different solvers, please see Schuster *et al.* (2020).

**Value**

An updated [problem\(\)](#) object with the solver added to it.

**References**

Schuster R, Hanson JO, Strimas-Mackey M, and Bennett JR (2020). Exact integer linear programming solvers outperform simulated annealing for solving conservation planning problems. *PeerJ*, 8: e9258.

**See Also**

See [solvers](#) for an overview of all functions for adding a solver.

Other solvers: [add\\_cbc\\_solver\(\)](#), [add\\_cplex\\_solver\(\)](#), [add\\_gurobi\\_solver\(\)](#), [add\\_highs\\_solver\(\)](#), [add\\_lsymphony\\_solver](#), [add\\_rysymphony\\_solver\(\)](#)



---

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                    `problem()` 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

An updated `problem()` object with the portfolio added to it.

### See Also

See [portfolios](#) for an overview of all functions for adding a portfolio.

Other portfolios: `add_cuts_portfolio()`, `add_default_portfolio()`, `add_gap_portfolio()`, `add_shuffle_portfolio()`, `add_top_portfolio()`

### Examples

```
## Not run:
# set seed for reproducibility
set.seed(600)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_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
s1 <- solve(p1)

# convert portfolio into a multi-layer raster object
s1 <- terra::rast(s1)

# print number of solutions found
print(terra::nlyr(s1))

# plot solutions
plot(s1, axes = FALSE)

# create multi-zone problem with a portfolio for extra solutions
p2 <-
problem(sim_zones_pu_raster, sim_zones_features) %>%
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)

# convert each solution in the portfolio into a single category layer
s2 <- terra::rast(lapply(s2, category_layer))

# print number of solutions found
print(terra::nlyr(s2))

# plot solutions in portfolio
plot(s2, axes = FALSE)

## End(Not run)

```

---

```
add_feature_contiguity_constraints
```

*Add feature contiguity constraints*

---

## Description

Add constraints to a problem 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

```
## 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	<a href="#">problem()</a> 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 <a href="#">adjacency_matrix()</a> function and so all adjacent planning units are treated as being connected for all features. See the Data format section for more information.

### Details

This function uses connection data to identify solutions that represent features in contiguous units of dispersible habitat. It was inspired by the mathematical formulations detailed in Önal and Briers (2006) and Cardeira *et al.* 2010. For an example that has used these constraints, see Hanson *et al.*

(2019). 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.**

### Value

An updated `problem()` object with the constraints added to it.

### Data format

The argument to data can be specified using the following formats.

data **as a NULL value** 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 potentially 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).

data **as a matrix/Matrix object** 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 connected with itself. Note that pairs of connected planning units are treated as being potentially dispersible for all features.

data **as a data.frame object** containing columns that are named "id1", "id2", and "boundary". Here, each row denotes the connectivity between two planning units following the *Marxan* format. The "boundary" column should contain binary numeric values that indicate if the two planning units specified in the "id1" and "id2" columns 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.

data **as a list object** 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.

### Notes

In early versions, it was named as the `add_corridor_constraints` function.

### References

- Önal H and Briers RA (2006) Optimal selection of a connected reserve network. *Operations Research*, 54: 379–388.
- Cardeira JO, Pinto LS, Cabeza M and Gaston KJ (2010) Species specific connectivity in reserve-network design using graphs. *Biological Conservation*, 2: 408–415.

Hanson JO, Fuller RA, & Rhodes JR (2019) Conventional methods for enhancing connectivity in conservation planning do not always maintain gene flow. *Journal of Applied Ecology*, 56: 913–922.

### See Also

See [constraints](#) for an overview of all functions for adding constraints.

Other constraints: [add\\_contiguity\\_constraints\(\)](#), [add\\_linear\\_constraints\(\)](#), [add\\_locked\\_in\\_constraints\(\)](#), [add\\_locked\\_out\\_constraints\(\)](#), [add\\_mandatory\\_allocation\\_constraints\(\)](#), [add\\_manual\\_bounded\\_constraints\(\)](#), [add\\_manual\\_locked\\_constraints\(\)](#), [add\\_neighbor\\_constraints\(\)](#)

### Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# create minimal problem
p1 <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.3) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# 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 5th percentile)
cm4 <- lapply(seq_len(terra::nlyr(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 0/1 values denoting values in top 5th percentile
  m <- round(m > quantile(as.vector(m), 1 - 0.05, names = FALSE))
  # remove 0s from the sparse matrix
  m <- Matrix::drop0(m)
  # return matrix
  m
})
p4 <- p1 %>% add_feature_contiguity_constraints(data = cm4)

# solve problems
s1 <- c(solve(p1), solve(p2), solve(p3), solve(p4))
names(s1) <- c(
```

```

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

  # 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_zones_pu_raster, sim_zones_features) %>%
    add_min_set_objective() %>%
    add_relative_targets(matrix(0.1, ncol = 3, nrow = 5)) %>%
    add_binary_decisions() %>%
    add_default_solver(time_limit = 30, verbose = FALSE)

  # 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_zones_features)),
    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 <- terra::rast(lapply(s2, category_layer))
  names(s2) <- c("p5", "p6", "p7", "p8")
  # plot solutions
  plot(s2, axes = FALSE)

  ## End(Not run)

```

---

add\_feature\_weights    *Add feature weights*

---

### Description

Add features weights to a conservation planning problem. Specifically, some objective functions aim to maximize (or minimize) a metric that measures how well a set of features are represented by a solution (e.g., maximize the number of features that are adequately represented, [add\\_max\\_features\\_objective\(\)](#)). In such cases, it may be desirable to prefer the representation of some features over other features (e.g., features that have higher extinction risk might be considered more important than those with lower extinction risk). To achieve this, weights can be used to specify how much more important it is for a solution to represent particular features compared with other features.

### Usage

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

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

### Arguments

x	<a href="#">problem()</a> object.
weights	numeric or matrix of weights. See the Weights format 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\(\)](#), [add\\_min\\_shortfall\\_objective\(\)](#)). They can also 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.**

### Value

An updated [problem\(\)](#) with the weights added to it.

### Weights format

The argument to weights can be specified using the following formats.

weights **as a numeric vector** containing weights for each feature. Note that this format cannot be used to specify weights for problems with multiple zones.

weights as a matrix **object** 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 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.

### See Also

See [penalties](#) for an overview of all functions for adding penalties.

Other penalties: [add\\_asym\\_connectivity\\_penalties\(\)](#), [add\\_boundary\\_penalties\(\)](#), [add\\_connectivity\\_penalties\(\)](#), [add\\_linear\\_penalties\(\)](#)

### Examples

```
## Not run:
# load package
require(ape)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_phylogeny <- get_sim_phylogeny()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# 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() %>%
  add_default_solver(verbose = FALSE)

# create weights that assign higher importance to features with less
# suitable habitat in the study area
w2 <- exp((1 / terra::global(sim_features, "sum", na.rm = TRUE)[[1]]) * 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 <- c(0, 0, 0, 100, 200)
p3 <- p1 %>% add_feature_weights(w3)

# solve problems
s1 <- c(solve(p1), solve(p2), solve(p3))
```



```

names(s1) <- c("equal weights", "rarity weights", "manual weights")

# plot solutions
plot(s1, axes = FALSE)

# plot the example phylogeny
par(mfrow = c(1, 1))
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 <-
  problem(sim_pu_raster, sim_features) %>%
  add_max_phylo_div_objective(1900, sim_phylogeny) %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s4 <- solve(p4)

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

# find out which features have their targets met
r4 <- eval_target_coverage_summary(p4, s4)
print(r4, width = Inf)

# plot the example phylogeny and color the represented features in red
plot(
  sim_phylogeny, main = "represented features",
  tip.color = replace(
    rep("black", terra::nlyr(sim_features)), which(r4$met), "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 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 <- c(0, 0, 10000, 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)

# find which features have their targets met
r5 <- eval_target_coverage_summary(p4, s5)
print(r5, width = Inf)

# 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", terra::nlyr(sim_features)), which(r5$met), "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_zones_pu_raster, sim_zones_features) %>%
  add_max_features_objective(3000) %>%
  add_relative_targets(matrix(0.1, ncol = 3, nrow = 5)) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# 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)

# convert solutions to category layers
c6 <- category_layer(s6)
c7 <- category_layer(s7)

# plot solutions

```

```

plot(c(c6, c7), main = c("equal weights", "manual weights"), axes = 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 = 3000) %>%
  add_manual_targets(
    data.frame(
      feature = c("feature_1", "feature_4"),
      type = "relative",
      target = 0.1)
  ) %>%
  add_feature_weights(matrix(c(1, 200), ncol = 1)) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s8 <- solve(p8)

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

## End(Not run)

```

---

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

```
add_gap_portfolio(x, number_solutions = 10, pool_gap = 0.1)
```

## Arguments

x	<code>problem()</code> object.
number_solutions	integer number of solutions required. Defaults to 10.
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., <code>add_gurobi_solver()</code> ) 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. Also, note that this portfolio function only works with problems that have binary decisions (i.e., specified using `add_binary_decisions()`).

## Value

An updated `problem()` object with the portfolio added to it.

## See Also

See `portfolios` for an overview of all functions for adding a portfolio.

Other portfolios: `add_cuts_portfolio()`, `add_default_portfolio()`, `add_extra_portfolio()`, `add_shuffle_portfolio()`, `add_top_portfolio()`

## Examples

```
## Not run:
# set seed for reproducibility
set.seed(600)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_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)

# convert portfolio into a multi-layer raster
s1 <- terra::rast(s1)

# print number of solutions found
print(terra::nlyr(s1))

# plot solutions
plot(s1, axes = FALSE)
```

```

# create multi-zone problem with a portfolio containing 10 solutions within
# 20% of optimality
p2 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  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)

# convert portfolio into a multi-layer raster of category layers
s2 <- terra::rast(lapply(s2, category_layer))

# print number of solutions found
print(terra::nlyr(s2))

# plot solutions in portfolio
plot(s2, axes = FALSE)

## End(Not run)

```

---

add\_gurobi\_solver      *Add a Gurobi solver*

---

## Description

Specify that the *Gurobi* software should be used to solve a conservation planning problem (Gurobi Optimization LLC 2021). This function can also be used to customize the behavior of the solver. It requires the **gurobi** package to be installed (see below for installation instructions).

## Usage

```

add_gurobi_solver(
  x,
  gap = 0.1,
  time_limit = .Machine$integer.max,
  presolve = 2,
  threads = 1,
  first_feasible = FALSE,
  numeric_focus = FALSE,
  node_file_start = Inf,
  start_solution = NULL,
  verbose = TRUE
)

```

**Arguments**

x	<code>problem()</code> object.
gap	numeric gap to optimality. This gap is relative and expresses the acceptable deviance from the optimal objective. For example, a value of 0.01 will result in the solver stopping when it has found a solution within 1% of optimality. Additionally, a value of 0 will result in the solver stopping when it has found an optimal solution. The default value is 0.1 (i.e., 10% from optimality).
time_limit	numeric time limit (seconds) for generating solutions. The solver will return the current best solution when this time limit is exceeded. The default value is the largest integer value (i.e., <code>.Machine\$integer.max</code> ), effectively meaning that solver will keep running until a solution within the optimality gap is found.
presolve	integer number indicating how intensively the solver should try to simplify the problem before solving it. Available options are: (-1) automatically determine the intensity of pre-solving, (0) disable pre-solving, (1) conservative level of pre-solving, and (2) very aggressive level of pre-solving. The default value is 2.
threads	integer number of threads to use for the optimization algorithm. The default value is 1.
first_feasible	logical should the first feasible solution be returned? If <code>first_feasible</code> 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 with problems that may suffer from numerical instability issues. Beware that it will likely substantially increase run time (sets the <i>Gurobi</i> <code>NumericFocus</code> parameter to 3). Defaults to FALSE.
node_file_start	numeric threshold amount of memory (in GB). Once the amount of memory (RAM) used to store information for solving the optimization problem exceeds this parameter value, the solver will begin storing this information on disk (using the <i>Gurobi</i> <code>NodeFileStart</code> parameter). This functionality is useful if the system has insufficient memory to solve a given problem (e.g., solving the problem with default settings yields the <code>OUT OF MEMORY</code> error message) and a system with more memory is not readily available. For example, a value of 4 indicates that the solver will start using the disk after it uses more than 4 GB of memory to store information on solving the problem. Defaults to <code>Inf</code> such that the solver will not attempt to store information on disk when solving a given problem.
start_solution	NULL or object containing the starting solution for the solver. This is can be useful because specifying a starting solution can speed up the optimization process. Defaults to NULL such that no starting solution is used. To specify a starting solution, the argument to <code>start_solution</code> should be in the same format as the planning units (i.e., a NULL, numeric, matrix, data.frame, <code>terra::rast()</code> , or <code>sf::sf()</code> object). See the Start solution format section for more information.
verbose	logical should information be printed while solving optimization problems? Defaults to TRUE.

## 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 for generating prioritizations, however, it 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. For information on the performance of different solvers, please see Schuster *et al.* (2020) for benchmarks comparing the run time and solution quality of different solvers when applied to different sized datasets.

## Value

An updated `problem()` object with the solver added to it.

## Installation

Please see the *Gurobi Installation Guide* vignette for details on installing the *Gurobi* software and the **gurobi** package. You can access this vignette [online](#) or using the following code:

```
vignette("gurobi_installation_guide", package = "prioritizr")
```

## Start solution format

Broadly speaking, the argument to `start_solution` must be in the same format as the planning unit data in the argument to `x`. Further details on the correct format are listed separately for each of the different planning unit data formats:

- x has numeric planning units** The argument to `start_solution` must be a numeric vector with each element corresponding to a different planning unit. It should have the same number of planning units as those in the argument to `x`. Additionally, any planning units missing cost (NA) values should also have missing (NA) values in the argument to `start_solution`.
- x has matrix planning units** The argument to `start_solution` must be a matrix vector with each row corresponding to a different planning unit, and each column correspond to a different management zone. It should have the same number of planning units and zones as those in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have a missing (NA) values in the argument to `start_solution`.
- x has terra::rast() planning units** The argument to `start_solution` be a `terra::rast()` object where different grid cells (pixels) correspond to different planning units and layers correspond to a different management zones. It should have the same dimensionality (rows, columns, layers), resolution, extent, and coordinate reference system as the planning units in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `start_solution`.
- x has data.frame planning units** The argument to `start_solution` must be a `data.frame` with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if a `data.frame` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example with `sf::sf()` data). Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `start_solution`.

x has `sf::sf()` **planning units** The argument to `start_solution` must be a `sf::sf()` object with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if the `sf::sf()` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example). Additionally, the argument to `start_solution` must also have the same coordinate reference system as the planning unit data. Furthermore, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `start_solution`.

## References

Gurobi Optimization LLC (2021) Gurobi Optimizer Reference Manual. <https://www.gurobi.com>.

Schuster R, Hanson JO, Strimas-Mackey M, and Bennett JR (2020). Exact integer linear programming solvers outperform simulated annealing for solving conservation planning problems. *PeerJ*, 8: e9258.

## See Also

See [solvers](#) for an overview of all functions for adding a solver.

Other solvers: [add\\_cbc\\_solver\(\)](#), [add\\_cplex\\_solver\(\)](#), [add\\_default\\_solver\(\)](#), [add\\_highs\\_solver\(\)](#), [add\\_lysophony\\_solver](#), [add\\_rsophony\\_solver\(\)](#)

## Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()

# create problem
p1 <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_gurobi_solver(gap = 0, verbose = FALSE)

# generate solution
s1 <- solve(p1)

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

# create a similar problem with boundary length penalties and
# specify the solution from the previous run as a starting solution
p2 <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_boundary_penalties(10) %>%
```



```

add_binary_decisions() %>%
add_gurobi_solver(gap = 0, start_solution = s1, verbose = FALSE)

# generate solution
s2 <- solve(p2)

# plot solution
plot(s2, main = "solution with boundary penalties", axes = FALSE)

## End(Not run)

```

---

add\_highs\_solver      *Add a HiGHS solver*

---

## Description

Specify that the *HiGHS* software should be used to solve a conservation planning problem (Huangfu and Hall 2018). This function can also be used to customize the behavior of the solver. It requires the **highs** package to be installed.

## Usage

```

add_highs_solver(
  x,
  gap = 0.1,
  time_limit = .Machine$integer.max,
  presolve = TRUE,
  threads = 1,
  verbose = TRUE
)

```

## Arguments

x	<code>problem()</code> object.
gap	numeric gap to optimality. This gap is relative and expresses the acceptable deviance from the optimal objective. For example, a value of 0.01 will result in the solver stopping when it has found a solution within 1% of optimality. Additionally, a value of 0 will result in the solver stopping when it has found an optimal solution. The default value is 0.1 (i.e., 10% from optimality).
time_limit	numeric time limit (seconds) for generating solutions. The solver will return the current best solution when this time limit is exceeded. The default value is the largest integer value (i.e., <code>.Machine\$integer.max</code> ), effectively meaning that solver will keep running until a solution within the optimality gap is found.
presolve	logical attempt to simplify the problem before solving it? Defaults to TRUE.
threads	integer number of threads to use for the optimization algorithm. The default value is 1.
verbose	logical should information be printed while solving optimization problems? Defaults to TRUE.

## Details

*HiGHS* is an open source optimization software. Although this solver can have comparable performance to the *CBC* solver (i.e., `add_cbc_solver()`) for particular problems and is generally faster than the *SYMPHONY* based solvers (i.e., `add_rysymphony_solver()`, `add_lpsymphony_solver()`), it can sometimes take much longer than the *CBC* solver for particular problems. This solver is recommended if the `add_gurobi_solver()`, `add_cplex_solver()`, `add_cbc_solver()` cannot be used.

## Value

An updated `problem()` object with the solver added to it.

## References

Huangfu Q and Hall JAJ (2018). Parallelizing the dual revised simplex method. *Mathematical Programming Computation*, 10: 119-142.

## See Also

Other solvers: `add_cbc_solver()`, `add_cplex_solver()`, `add_default_solver()`, `add_gurobi_solver()`, `add_lsymphony_solver`, `add_rysymphony_solver()`

## Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()

# create problem
p <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_highs_solver(gap = 0, verbose = FALSE)

# generate solution
s <- solve(p)

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

## End(Not run)
```

---

 add\_linear\_constraints

*Add linear constraints*


---

## Description

Add constraints to a conservation planning problem to ensure that all selected planning units meet certain criteria.

## Usage

```
## S4 method for signature 'ConservationProblem,ANY,ANY,character'
add_linear_constraints(x, threshold, sense, data)
```

```
## S4 method for signature 'ConservationProblem,ANY,ANY,numeric'
add_linear_constraints(x, threshold, sense, data)
```

```
## S4 method for signature 'ConservationProblem,ANY,ANY,matrix'
add_linear_constraints(x, threshold, sense, data)
```

```
## S4 method for signature 'ConservationProblem,ANY,ANY,Matrix'
add_linear_constraints(x, threshold, sense, data)
```

```
## S4 method for signature 'ConservationProblem,ANY,ANY,Raster'
add_linear_constraints(x, threshold, sense, data)
```

```
## S4 method for signature 'ConservationProblem,ANY,ANY,SpatRaster'
add_linear_constraints(x, threshold, sense, data)
```

```
## S4 method for signature 'ConservationProblem,ANY,ANY,dgCMatrix'
add_linear_constraints(x, threshold, sense, data)
```

## Arguments

x	<code>problem()</code> object.
threshold	numeric value. This threshold value is also known as a "right-hand-side" value per integer programming terminology.
sense	character sense for the constraint. Available options include ">=", "<=", or "=" values.
data	character, numeric, <code>terra::rast()</code> , matrix, or Matrix object containing the constraint values. These constraint values are also known as constraint coefficients per integer programming terminology. See the Data format section for more information.

## Details

This function adds general purpose constraints that can be used to ensure that solutions meet certain criteria (see Examples section below for details). For example, these constraints can be used to add multiple budgets. They can also be used to ensure that the total number of planning units allocated to a certain administrative area (e.g., country) does not exceed a certain threshold (e.g., 30% of its total area). Furthermore, they can also be used to ensure that features have a minimal level of representation (e.g., 30%) when using an objective function that aims to enhance feature representation given a budget (e.g., `add_min_shortfall_objective()`).

## Value

An updated `problem()` object with the constraints added to it.

## Mathematical formulation

The linear constraints are implemented using the following equation. Let  $I$  denote the set of planning units (indexed by  $i$ ),  $Z$  the set of management zones (indexed by  $z$ ), and  $X_{iz}$  the decision variable for allocating planning unit  $i$  to zone  $z$  (e.g., with binary values indicating if each planning unit is allocated or not). Also, let  $D_{iz}$  denote the constraint data associated with planning units  $i \in I$  for zones  $z \in Z$  (argument to `data`, if supplied as a `matrix` object),  $\theta$  denote the constraint sense (argument to `sense`, e.g., `<=`), and  $t$  denote the constraint threshold (argument to `threshold`).

$$\sum_i^I \sum_z^Z (D_{iz} \times X_{iz}) \theta t$$

## Data format

The argument to `data` can be specified using the following formats.

`data` as a character **vector** containing column name(s) that contain penalty values for planning units. This format is only compatible if the planning units in the argument to `x` are a `sf::sf()` or `data.frame` object. The column(s) must have numeric values, and must not contain any missing (NA) values. For problems that contain a single zone, the argument to `data` must contain a single column name. Otherwise, for problems that contain multiple zones, the argument to `data` must contain a column name for each zone.

`data` as a numeric **vector** containing values for planning units. These values must not contain any missing (NA) values. Note that this format is only available for planning units that contain a single zone.

`data` as a `matrix`/`Matrix` **object** containing numeric values that specify data for each planning unit. Each row corresponds to a planning unit, each column corresponds to a zone, and each cell indicates the data for penalizing a planning unit when it is allocated to a given zone.

`data` as a `terra::rast()` **object** containing values for planning units. This format is only compatible if the planning units in the argument to `x` are `sf::sf()`, or `terra::rast()` objects. If the planning unit data are a `sf::sf()` object, then the values are calculated by overlaying the planning units with the argument to `data` and calculating the sum of the values associated with each planning unit. If the planning unit data are a `terra::rast()` object, then the values are calculated by extracting the cell values (note that the planning unit data and the argument

to data must have exactly the same dimensionality, extent, and missingness). For problems involving multiple zones, the argument to data must contain a layer for each zone.

### See Also

See [constraints](#) for an overview of all functions for adding constraints.

Other constraints: [add\\_contiguity\\_constraints\(\)](#), [add\\_feature\\_contiguity\\_constraints\(\)](#), [add\\_locked\\_in\\_constraints\(\)](#), [add\\_locked\\_out\\_constraints\(\)](#), [add\\_mandatory\\_allocation\\_constraints\(\)](#), [add\\_manual\\_bounded\\_constraints\(\)](#), [add\\_manual\\_locked\\_constraints\(\)](#), [add\\_neighbor\\_constraints\(\)](#)

### Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()

# create a baseline problem with minimum shortfall objective
p0 <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_shortfall_objective(1800) %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s0 <- solve(p0)

# plot solution
plot(s0, main = "solution", axes = FALSE)

# now let's create some modified versions of this baseline problem by
# adding additional criteria using linear constraints

# first, let's create a modified version of p0 that contains
# an additional budget for a secondary cost dataset

# create a secondary cost dataset by simulating values
sim_pu_raster2 <- simulate_cost(sim_pu_raster)

# plot the primary cost dataset (sim_pu_raster) and
# the secondary cost dataset (sim_pu_raster2)
plot(
  c(sim_pu_raster, sim_pu_raster2),
  main = c("sim_pu_raster", "sim_pu_raster2"),
  axes = FALSE
)

# create a modified version of p0 with linear constraints that
# specify that the planning units in the solution must not have
# values in sim_pu_raster2 that sum to a total greater than 500
p1 <-
```

```

p0 %>%
  add_linear_constraints(
    threshold = 500, sense = "<=", data = sim_pu_raster2
  )

# solve problem
s1 <- solve(p1)

# plot solutions s1 and s2 to compare them
plot(c(s0, s1), main = c("s0", "s1"), axes = FALSE)

# second, let's create a modified version of p0 that contains
# additional constraints to ensure that each feature definitely has
# at least 8% of its overall distribution represented by the solution
# (in addition to the 20% targets which specify how much we would
# ideally want to conserve for each feature)

# to achieve this, we need to calculate the total amount of each feature
# within the planning units so we can, in turn, set the constraint thresholds
feat_abund <- feature_abundances(p0)$absolute_abundance

# create a modified version of p0 with additional constraints for each
# feature to specify that the planning units in the solution must
# secure at least 8% of the total abundance for each feature
p2 <- p0
for (i in seq_len(terra::nlyr(sim_features))) {
  p2 <-
    p2 %>%
      add_linear_constraints(
        threshold = feat_abund[i] * 0.08,
        sense = ">=",
        data = sim_features[[i]]
      )
}

# overall, p2 could be described as an optimization problem
# that maximizes feature representation as much as possible
# towards securing 20% of the total amount of each feature,
# whilst ensuring that (i) the total cost of the solution does
# not exceed 1800 (per cost values in sim_pu_raster) and (ii)
# the solution secures at least 8% of the total amount of each feature
# (if 20% is not possible due to the budget)

# solve problem
s2 <- solve(p2)

# plot solutions s0 and s2 to compare them
plot(c(s0, s2), main = c("s1", "s2"), axes = FALSE)

# third, let's create a modified version of p0 that contains
# additional constraints to ensure that the solution equitably
# distributes conservation effort across different administrative areas
# (e.g., countries) within the study region

```

```

# to begin with, we will simulate a dataset describing the spatial extent of
# four different administrative areas across the study region
sim_admin <- sim_pu_raster
sim_admin <- terra::aggregate(sim_admin, fact = 5)
sim_admin <- terra::setValues(sim_admin, seq_len(terra::ncell(sim_admin)))
sim_admin <- terra::resample(sim_admin, sim_pu_raster, method = "near")
sim_admin <- terra::mask(sim_admin, sim_pu_raster)

# plot administrative areas layer,
# we can see that the administrative areas subdivide
# the study region into four quadrants, and the sim_admin object is a
# SpatRaster with integer values denoting ids for the administrative areas
plot(sim_admin, axes = FALSE)

# next we will convert the sim_admin SpatRaster object into a SpatRaster
# object (with a layer for each administrative area) indicating which
# planning units belong to each administrative area using binary
# (presence/absence) values
sim_admin2 <- binary_stack(sim_admin)

# plot binary stack of administrative areas
plot(sim_admin2, axes = FALSE)

# we will now calculate the total amount of planning units associated
# with each administrative area, so that we can set the constraint threshold

# since we are using raster data, we won't bother explicitly
# accounting for the total area of each planning unit (because all
# planning units have the same area in raster formats) -- but if we were
# using vector data then we would need to account for the area of each unit
admin_total <- Matrix::rowSums(rij_matrix(sim_pu_raster, sim_admin2))

# create a modified version of p0 with additional constraints for each
# administrative area to specify that the planning units in the solution must
# not encompass more than 10% of the total extent of the administrative
# area
p3 <- p0
for (i in seq_len(terra::nlyr(sim_admin2))) {
  p3 <-
    p3 %>%
    add_linear_constraints(
      threshold = admin_total[i] * 0.1,
      sense = "<=",
      data = sim_admin2[[i]]
    )
}

# solve problem
s3 <- solve(p3)

# plot solutions s0 and s3 to compare them
plot(c(s0, s3), main = c("s0", "s3"), axes = FALSE)

```

```
## End(Not run)
```

---

```
add_linear_penalties Add linear penalties
```

---

## Description

Add penalties to a conservation planning problem to penalize solutions that select planning units with higher values from a specific data source (e.g., anthropogenic impact). These penalties assume a linear trade-off between the penalty values and the primary objective of the conservation planning problem (e.g., solution cost for minimum set problems; [add\\_min\\_set\\_objective\(\)](#)).

## Usage

```
## S4 method for signature 'ConservationProblem,ANY,character'
add_linear_penalties(x, penalty, data)
```

```
## S4 method for signature 'ConservationProblem,ANY,numeric'
add_linear_penalties(x, penalty, data)
```

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

```
## S4 method for signature 'ConservationProblem,ANY,Matrix'
add_linear_penalties(x, penalty, data)
```

```
## S4 method for signature 'ConservationProblem,ANY,Raster'
add_linear_penalties(x, penalty, data)
```

```
## S4 method for signature 'ConservationProblem,ANY,SpatRaster'
add_linear_penalties(x, penalty, data)
```

```
## S4 method for signature 'ConservationProblem,ANY,dgCMatrix'
add_linear_penalties(x, penalty, data)
```

## Arguments

x	<a href="#">problem()</a> object.
penalty	numeric penalty value that is used to scale the importance of not selecting planning units with high data values. Higher penalty values can be used to obtain solutions that are strongly averse to selecting places with high data values, and smaller penalty values can be used to obtain solutions that only avoid places with especially high data values. Note that negative penalty values can be used to obtain solutions that prefer places with high data values. Additionally, when adding these penalties to problems with multiple zones, the argument to penalty must have a value for each zone.



**data** character, numeric, `terra::rast()`, matrix, or Matrix object containing the values used to penalize solutions. Planning units that are associated with higher data values are penalized more strongly in the solution. See the Data format section for more information.

### Details

This function penalizes solutions that have higher values according to the sum of the penalty values associated with each planning unit, weighted by status of each planning unit in the solution.

### Value

An updated `problem()` object with the penalties added to it.

### Data format

The argument to data can be specified using the following formats.

**data as character vector** containing column name(s) that contain penalty values for planning units. This format is only compatible if the planning units in the argument to `x` are a `sf::sf()` or `data.frame` object. The column(s) must have numeric values, and must not contain any missing (NA) values. For problems that contain a single zone, the argument to data must contain a single column name. Otherwise, for problems that contain multiple zones, the argument to data must contain a column name for each zone.

**data as a numeric vector** containing values for planning units. These values must not contain any missing (NA) values. Note that this format is only available for planning units that contain a single zone.

**data as a matrix/Matrix object** containing numeric values that specify data for each planning unit. Each row corresponds to a planning unit, each column corresponds to a zone, and each cell indicates the data for penalizing a planning unit when it is allocated to a given zone.

**data as a `terra::rast()` object** containing values for planning units. This format is only compatible if the planning units in the argument to `x` are `sf::sf()`, or `terra::rast()` objects. If the planning unit data are a `sf::sf()` object, then the values are calculated by overlaying the planning units with the argument to data and calculating the sum of the values associated with each planning unit. If the planning unit data are a `terra::rast()` object, then the values are calculated by extracting the cell values (note that the planning unit data and the argument to data must have exactly the same dimensionality, extent, and missingness). For problems involving multiple zones, the argument to data must contain a layer for each zone.

### Mathematical formulation

The linear penalties are implemented using the following equations. Let  $I$  denote the set of planning units (indexed by  $i$ ),  $Z$  the set of management zones (indexed by  $z$ ), and  $X_{iz}$  the decision variable for allocating planning unit  $i$  to zone  $z$  (e.g., with binary values indicating if each planning unit is allocated or not). Also, let  $P_z$  represent the penalty scaling value for zones  $z \in Z$  (argument to penalty), and  $D_{iz}$  the penalty data for allocating planning unit  $i \in I$  to zones  $z \in Z$  (argument to data, if supplied as a matrix object).

$$\sum_i^I \sum_z^Z P_z \times D_{iz} \times X_{iz}$$

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

### See Also

See [penalties](#) for an overview of all functions for adding penalties.

Other penalties: [add\\_asym\\_connectivity\\_penalties\(\)](#), [add\\_boundary\\_penalties\(\)](#), [add\\_connectivity\\_penalties\(\)](#), [add\\_feature\\_weights\(\)](#)

### Examples

```
## Not run:
# set seed for reproducibility
set.seed(600)

# load data
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# add a column to contain the penalty data for each planning unit
# e.g., these values could indicate the level of habitat
sim_pu_polygons$penalty_data <- runif(nrow(sim_pu_polygons))

# plot the penalty data to visualise its spatial distribution
plot(sim_pu_polygons[, "penalty_data"], axes = FALSE)

# create minimal problem with minimum set objective,
# this does not use the penalty data
p1 <-
  problem(sim_pu_polygons, sim_features, cost_column = "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# print problem
print(p1)

# create an updated version of the previous problem,
# with the penalties added to it
p2 <- p1 %>% add_linear_penalties(100, data = "penalty_data")

# print problem
print(p2)

# solve the two problems
```

```

s1 <- solve(p1)
s2 <- solve(p2)

# create a new object with both solutions
s3 <- sf::st_sf(
  tibble::tibble(
    s1 = s1$solution_1,
    s2 = s2$solution_1
  ),
  geometry = sf::st_geometry(s1)
)

# plot the solutions and compare them,
# since we supplied a very high penalty value (i.e., 100), relative
# to the range of values in the penalty data and the objective function,
# the solution in s2 is very sensitive to values in the penalty data
plot(s3, axes = FALSE)

# for real conservation planning exercises,
# it would be worth exploring a range of penalty values (e.g., ranging
# from 1 to 100 increments of 5) to explore the trade-offs

# now, let's examine a conservation planning exercise involving multiple
# management zones

# create targets for each feature within each zone,
# these targets indicate that each zone needs to represent 10% of the
# spatial distribution of each feature
targ <- matrix(
  0.1, ncol = number_of_zones(sim_zones_features),
  nrow = number_of_features(sim_zones_features)
)

# create penalty data for allocating each planning unit to each zone,
# these data will be generated by simulating values
penalty_raster <- simulate_cost(
  sim_zones_pu_raster[[1]],
  n = number_of_zones(sim_zones_features)
)

# plot the penalty data, each layer corresponds to a different zone
plot(penalty_raster, main = "penalty data", axes = FALSE)

# create a multi-zone problem with the minimum set objective
# and penalties for allocating planning units to each zone,
# with a penalty scaling factor of 1 for each zone
p4 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(targ) %>%
  add_linear_penalties(c(1, 1, 1), penalty_raster) %>%
  add_binary_decisions() %>%

```

```

add_default_solver(verbose = FALSE)

# print problem
print(p4)

# solve problem
s4 <- solve(p4)

# plot solution
plot(category_layer(s4), main = "multi-zone solution", axes = FALSE)

## End(Not run)

```

---

```

add_locked_in_constraints
      Add locked in constraints

```

---

## 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.

## Usage

```

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)

## S4 method for signature 'ConservationProblem,SpatRaster'
add_locked_in_constraints(x, locked_in)
```

## Arguments

`x` `problem()` object.

`locked_in` Object that determines which planning units should be locked in. See the Data format section for more information.

## Value

An updated `problem()` object with the constraints added to it.

## Data format

The locked planning units can be specified using the following formats. Generally, the locked data should correspond to the planning units in the argument to `x`. To help make working with `terra::rast()` planning unit data easier, the locked data should correspond to cell indices in the `terra::rast()` 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.

`data` **as an integer vector** containing indices that indicate which planning units should be locked for the solution. This argument is only compatible with problems that contain a single zone.

`data` **as a 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.

`data` **as a matrix object** 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.

`data` **as a character vector** containing column name(s) that indicates if planning units should be locked for the solution. This format is only compatible if the planning units in the argument to `x` are a `sf::sf()` or `data.frame` object. The columns must have logical (i.e., TRUE or FALSE) values indicating if the planning unit is to be locked for the solution. For problems that contain a single zone, the argument to `data` must contain a single column name. Otherwise, for problems that contain multiple zones, the argument to `data` must contain a column name for each zone.

`data` **as a `sf::sf()` object** containing geometries that will be used to lock planning units for the solution. Specifically, planning units in `x` that spatially intersect with `y` will be locked (per `intersecting_units()`). Note that this option is only available for problems that contain a single management zone.

data as a `terra::rast()` object containing cells used to lock planning units for the solution. Specifically, planning units in `x` that intersect with cells that have non-zero and non-NA values are locked. For problems that contain multiple zones, the data 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 `terra::rast()` 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.

### See Also

See [constraints](#) for an overview of all functions for adding constraints.

Other constraints: [add\\_contiguity\\_constraints\(\)](#), [add\\_feature\\_contiguity\\_constraints\(\)](#), [add\\_linear\\_constraints\(\)](#), [add\\_locked\\_out\\_constraints\(\)](#), [add\\_mandatory\\_allocation\\_constraints\(\)](#), [add\\_manual\\_bounded\\_constraints\(\)](#), [add\\_manual\\_locked\\_constraints\(\)](#), [add\\_neighbor\\_constraints\(\)](#)

### Examples

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()
sim_locked_in_raster <- get_sim_locked_in_raster()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_pu_polygons <- get_sim_zones_pu_polygons()
sim_zones_features <- get_sim_zones_features()

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

# 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 column 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)

# create single object with all solutions
s6 <- sf::st_sf(
  tibble::tibble(
    s1 = s1$solution_1,
    s2 = s2$solution_1,
    s3 = s3$solution_1,
    s4 = s4$solution_1,
    s5 = s5$solution_1
  ),
  geometry = sf::st_geometry(s1)
)

# plot solutions
plot(
  s6,
  main = c(
    "none locked in", "locked in (integer input)",
    "locked in (character input)", "locked in (raster input)",
    "locked in (polygon input)"
  )
)

# create minimal multi-zone problem with spatial data
p7 <-
  problem(
    sim_zones_pu_polygons, sim_zones_features,
    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() %>%
  add_default_solver(verbose = FALSE)

# create multi-zone problem with locked in constraints using matrix data
locked_matrix <- as.matrix(sf::st_drop_geometry(
  sim_zones_pu_polygons[, c("locked_1", "locked_2", "locked_3")]
))

p8 <- p7 %>% add_locked_in_constraints(locked_matrix)

# 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(sf::st_drop_geometry(
  s8[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
))

```

```

))
s8$solution <- factor(s8$solution)

# plot solution
plot(s8[ "solution"], axes = FALSE)

# create multi-zone problem with locked in constraints using column names
p9 <- p7 %>% add_locked_in_constraints(c("locked_1", "locked_2", "locked_3"))

# solve problem
s9 <- solve(p9)

# create new column representing the zone id that each planning unit
# was allocated to in the solution
s9$solution <- category_vector(sf::st_drop_geometry(
  s9[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
))
s9$solution[s9$solution == 1 & s9$solution_1_zone_1 == 0] <- 0
s9$solution <- factor(s9$solution)

# plot solution
plot(s9[, "solution"], axes = FALSE)

# create multi-zone problem with raster planning units
p10 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_min_set_objective() %>%
  add_absolute_targets(matrix(rpois(15, 1), nrow = 5, ncol = 3)) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# create multi-layer raster with locked in units
locked_in_raster <- sim_zones_pu_raster[[1]]
locked_in_raster[!is.na(locked_in_raster)] <- 0
locked_in_raster <- locked_in_raster[[c(1, 1, 1)]]
names(locked_in_raster) <- c("zone_1", "zone_2", "zone_3")
locked_in_raster[[1]][1] <- 1
locked_in_raster[[2]][2] <- 1
locked_in_raster[[3]][3] <- 1

# plot locked in raster
plot(locked_in_raster)

# add locked in raster units to problem
p10 <- p10 %>% add_locked_in_constraints(locked_in_raster)

# solve problem
s10 <- solve(p10)

# plot solution
plot(category_layer(s10), main = "solution", axes = FALSE)

## End(Not run)

```



---

 add\_locked\_out\_constraints

*Add locked out constraints*


---

## 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\\_in\\_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

```
add_locked_out_constraints(x, locked_out)

## S4 method for signature 'ConservationProblem,numeric'
add_locked_out_constraints(x, locked_out)

## S4 method for signature 'ConservationProblem,logical'
add_locked_out_constraints(x, locked_out)

## S4 method for signature 'ConservationProblem,matrix'
add_locked_out_constraints(x, locked_out)

## S4 method for signature 'ConservationProblem,character'
add_locked_out_constraints(x, locked_out)

## S4 method for signature 'ConservationProblem,Spatial'
add_locked_out_constraints(x, locked_out)

## S4 method for signature 'ConservationProblem,sf'
add_locked_out_constraints(x, locked_out)

## S4 method for signature 'ConservationProblem,Raster'
add_locked_out_constraints(x, locked_out)

## S4 method for signature 'ConservationProblem,SpatRaster'
add_locked_out_constraints(x, locked_out)
```

## Arguments

x	<a href="#">problem()</a> object.
locked_out	Object that determines which planning units that should be locked out. See the Data format section for more information.

**Value**

An updated `problem()` object with the constraints added to it.

**Data format**

The locked planning units can be specified using the following formats. Generally, the locked data should correspond to the planning units in the argument to `x`. To help make working with `terra::rast()` planning unit data easier, the locked data should correspond to cell indices in the `terra::rast()` 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.

`data` **as an integer vector** containing indices that indicate which planning units should be locked for the solution. This argument is only compatible with problems that contain a single zone.

`data` **as a 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.

`data` **as a matrix object** 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.

`data` **as a character vector** containing column name(s) that indicates if planning units should be locked for the solution. This format is only compatible if the planning units in the argument to `x` are a `sf::sf()` or `data.frame` object. The columns must have logical (i.e., TRUE or FALSE) values indicating if the planning unit is to be locked for the solution. For problems that contain a single zone, the argument to `data` must contain a single column name. Otherwise, for problems that contain multiple zones, the argument to `data` must contain a column name for each zone.

`data` **as a `sf::sf()` object** containing geometries that will be used to lock planning units for the solution. Specifically, planning units in `x` that spatially intersect with `y` will be locked (per `intersecting_units()`). Note that this option is only available for problems that contain a single management zone.

`data` **as a `terra::rast()` object** containing cells used to lock planning units for the solution. Specifically, planning units in `x` that intersect with cells that have non-zero and non-NA values are locked. For problems that contain multiple zones, the `data` 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 `terra::rast()` 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.

**See Also**

See [constraints](#) for an overview of all functions for adding constraints.

Other constraints: `add_contiguity_constraints()`, `add_feature_contiguity_constraints()`, `add_linear_constraints()`, `add_locked_in_constraints()`, `add_mandatory_allocation_constraints()`, `add_manual_bounded_constraints()`, `add_manual_locked_constraints()`, `add_neighbor_constraints()`

**Examples**

```

## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()
sim_locked_out_raster <- get_sim_locked_out_raster()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_pu_polygons <- get_sim_zones_pu_polygons()
sim_zones_features <- get_sim_zones_features()

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

# 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 column name
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[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)

# create single object with all solutions
s6 <- sf::st_sf(
  tibble::tibble(
    s1 = s1$solution_1,
    s2 = s2$solution_1,
    s3 = s3$solution_1,
    s4 = s4$solution_1,
    s5 = s5$solution_1
  ),
  geometry = sf::st_geometry(s1)
)

```

```

# plot solutions
plot(
  s6,
  main = c(
    "none locked out", "locked out (integer input)",
    "locked out (character input)", "locked out (raster input)",
    "locked out (polygon input)"
  )
)

# reset plot
par(mfrow = c(1, 1))

# create minimal multi-zone problem with spatial data
p7 <-
  problem(
    sim_zones_pu_polygons, sim_zones_features,
    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() %>%
  add_default_solver(verbose = FALSE)

# create multi-zone problem with locked out constraints using matrix data
locked_matrix <- as.matrix(sf::st_drop_geometry(
  sim_zones_pu_polygons[, c("locked_1", "locked_2", "locked_3")]
))

p8 <- p7 %>% add_locked_out_constraints(locked_matrix)

# solve problem
s8 <- solve(p8)

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

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

# create multi-zone problem with locked out constraints using column names
p9 <-
  p7 %>%
  add_locked_out_constraints(c("locked_1", "locked_2", "locked_3"))

# solve problem
s9 <- solve(p9)

```

```

# create new column in s8 representing the zone id that each planning unit
# was allocated to in the solution
s9$solution <- category_vector(sf::st_drop_geometry(
  s9[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
))
s9$solution[s9$solution == 1 & s9$solution_1_zone_1 == 0] <- 0
s9$solution <- factor(s9$solution)

# plot solution
plot(s9[, "solution"], main = "solution", axes = FALSE)

# create multi-zone problem with raster planning units
p10 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_min_set_objective() %>%
  add_absolute_targets(matrix(rpois(15, 1), nrow = 5, ncol = 3)) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# create multi-layer raster with locked out units
locked_out_raster <- sim_zones_pu_raster[[1]]
locked_out_raster[!is.na(locked_out_raster)] <- 0
locked_out_raster <- locked_out_raster[[c(1, 1, 1)]]
names(locked_out_raster) <- c("zones_1", "zones_2", "zones_3")
locked_out_raster[[1]][1] <- 1
locked_out_raster[[2]][2] <- 1
locked_out_raster[[3]][3] <- 1

# plot locked out raster
plot(locked_out_raster)

# add locked out raster units to problem
p10 <- p10 %>% add_locked_out_constraints(locked_out_raster)

# solve problem
s10 <- solve(p10)

# plot solution
plot(category_layer(s10), main = "solution", axes = FALSE)

## End(Not run)

```

---

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).

**Usage**

```
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	<a href="#">problem()</a> 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 <a href="#">feature_abundances()</a> 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.

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  $km^2$  units). Additionally, the function can only be applied to `problem()` objects that are associated with a single zone.

### Value

An updated `problem()` object with the targets added to it.

### Notes

Early versions (< 5.0.2.4) used different equations for calculating targets.

### References

Rodrigues ASL, Akcakaya HR, Andelman SJ, Bakarr MI, Boitani L, Brooks TM, Chanson JS, Fishpool LDC, da Fonseca GAB, Gaston KJ, and others (2004) Global gap analysis: priority regions for expanding the global protected-area network. *BioScience*, 54: 1092–1100.

Butchart SHM, Clarke M, Smith RJ, Sykes RE, Scharlemann JPW, Harfoot M, Buchanan, GM, Angulo A, Balmford A, Bertzky B, and others (2015) Shortfalls and solutions for meeting national and global conservation area targets. *Conservation Letters*, 8: 329–337.

### See Also

See [targets](#) for an overview of all functions for adding targets.

Other targets: [add\\_absolute\\_targets\(\)](#), [add\\_manual\\_targets\(\)](#), [add\\_relative\\_targets\(\)](#)

### Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_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() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s <- solve(p)

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

```
## End(Not run)
```

---

```
add_lsymphony_solver  Add a SYMPHONY solver with lpsymphony
```

---

### Description

Specify that the *SYMPHONY* software – using the **lpsymphony** package – should be used to solve a conservation planning problem (Ralphs & Güzelsoy 2005). This function can also be used to customize the behavior of the solver. It requires the **lpsymphony** package to be installed (see below for installation instructions).

### Usage

```
add_lsymphony_solver(
  x,
  gap = 0.1,
  time_limit = .Machine$integer.max,
  first_feasible = FALSE,
  verbose = TRUE
)
```

### Arguments

x	<code>problem()</code> object.
gap	numeric gap to optimality. This gap is relative and expresses the acceptable deviance from the optimal objective. For example, a value of 0.01 will result in the solver stopping when it has found a solution within 1% of optimality. Additionally, a value of 0 will result in the solver stopping when it has found an optimal solution. The default value is 0.1 (i.e., 10% from optimality).
time_limit	numeric time limit (seconds) for generating solutions. The solver will return the current best solution when this time limit is exceeded. The default value is the largest integer value (i.e., <code>.Machine\$integer.max</code> ), effectively meaning that solver will keep running until a solution within the optimality gap is found.
first_feasible	logical should the first feasible solution be returned? If <code>first_feasible</code> is set to <code>TRUE</code> , 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 <code>FALSE</code> .
verbose	logical should information be printed while solving optimization problems? Defaults to <code>TRUE</code> .



## Details

**SYMPHONY** is an open-source mixed integer programming solver that is part of the Computational Infrastructure for Operations Research (COIN-OR) project. This solver is provided because it may be easier to install on some systems than the **Rsymphony** package. Additionally – although the **lpsymphony** package doesn't provide the functionality to specify the number of threads for solving a problem – the **lpsymphony** package will solve problems using parallel processing (unlike the **Rsymphony** package). As a consequence, this solver will likely generate solutions much faster than the `add_rysymphony_solver()`. Although formal benchmarks examining the performance of this solver have yet to be completed, please see Schuster *et al.* (2020) for benchmarks comparing the run time and solution quality of the **Rsymphony** solver.

## Value

An updated `problem()` object with the solver added to it.

## Installation

The **lpsymphony** package is distributed through **Bioconductor**. To install the **lpsymphony** package, please use the following code:

```
if (!require(remotes)) install.packages("remotes")
remotes::install_bioc("lpsymphony")
```

## References

Ralphs TK and Güzelsoy M (2005) The SYMPHONY callable library for mixed integer programming. In *The Next Wave in Computing, Optimization, and Decision Technologies* (pp. 61–76). Springer, Boston, MA.

Schuster R, Hanson JO, Strimas-Mackey M, and Bennett JR (2020). Exact integer linear programming solvers outperform simulated annealing for solving conservation planning problems. *PeerJ*, 8: e9258.

## See Also

Other solvers: `add_cbc_solver()`, `add_cplex_solver()`, `add_default_solver()`, `add_gurobi_solver()`, `add_highs_solver()`, `add_rysymphony_solver()`

## Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()

# create problem
p <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.05) %>%
  add_proportion_decisions() %>%
```

```
add_lpsymphony_solver(time_limit = 5, verbose = FALSE)

# generate solution
s <- solve(p)

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

## End(Not run)
```

---

add\_mandatory\_allocation\_constraints

*Add mandatory allocation constraints*

---

## Description

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

## Usage

```
add_mandatory_allocation_constraints(x)
```

## Arguments

x [problem\(\)](#) 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 planning unit to a zone. For example, when developing land-use plans, some decision makers may require that every parcel of land is allocated a specific land-use type. In other words there 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 are 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

An updated [problem\(\)](#) object with the constraints added to it.

## See Also

See [constraints](#) for an overview of all functions for adding constraints.

Other constraints: [add\\_contiguity\\_constraints\(\)](#), [add\\_feature\\_contiguity\\_constraints\(\)](#), [add\\_linear\\_constraints\(\)](#), [add\\_locked\\_in\\_constraints\(\)](#), [add\\_locked\\_out\\_constraints\(\)](#), [add\\_manual\\_bounded\\_constraints\(\)](#), [add\\_manual\\_locked\\_constraints\(\)](#), [add\\_neighbor\\_constraints\(\)](#)

**Examples**

```

## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# 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_zones_pu_raster, sim_zones_features) %>%
  add_min_set_objective() %>%
  add_absolute_targets(targets_matrix) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# 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
s1 <- solve(p1)
s2 <- solve(p2)

# convert solutions into category layers, where each pixel is assigned
# value indicating which zone it was assigned to in the zone
c1 <- category_layer(s1)
c2 <- category_layer(s2)

# plot solution category layers
plot(c(c1, c2), main = c("default", "mandatory allocation"), axes = FALSE)

## End(Not run)

```

---

```
add_manual_bounded_constraints
```

*Add manually specified bound 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** [problem\(\)](#) object.

**data** `data.frame` or `tibble::tibble()` object. See the Data format section for more information.

**Value**

An updated [problem\(\)](#) object with the constraints added to it.

**Data format**

The argument to data should be a `data.frame` with the following 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.

**See Also**

See [constraints](#) for an overview of all functions for adding constraints.

Other constraints: [add\\_contiguity\\_constraints\(\)](#), [add\\_feature\\_contiguity\\_constraints\(\)](#), [add\\_linear\\_constraints\(\)](#), [add\\_locked\\_in\\_constraints\(\)](#), [add\\_locked\\_out\\_constraints\(\)](#), [add\\_mandatory\\_allocation\\_constraints\(\)](#), [add\\_manual\\_locked\\_constraints\(\)](#), [add\\_neighbor\\_constraints\(\)](#)

**Examples**

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()
sim_zones_pu_polygons <- get_sim_zones_pu_polygons()
```

```

sim_zones_features <- get_sim_zones_features()

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

# 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)

# create object with all solutions
s4 <- sf::st_sf(
  tibble::tibble(
    s1 = s1$solution_1,
    s2 = s2$solution_1,
    s3 = s3$solution_1
  ),
  geometry = sf::st_geometry(s1)
)

# plot solutions
## s1 = none locked in
## s2 = locked in constraints
## s3 = manual bounds constraints
plot(s4)

# create minimal problem with multiple zones
p5 <-
  problem(
    sim_zones_pu_polygons, sim_zones_features,
    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() %>%
  add_default_solver(verbose = FALSE)

```

```

# 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
p6 <- p5 %>% add_manual_bounded_constraints(bounds_data2)

# solve problem
s5 <- solve(p5)
s6 <- solve(p6)

# create two new columns representing the zone id that each planning unit
# was allocated to in the two solutions
s5$solution <- category_vector(sf::st_drop_geometry(
  s5[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
))
s5$solution <- factor(s5$solution)

s5$solution_bounded <- category_vector(sf::st_drop_geometry(
  s6[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
))
s5$solution_bounded <- factor(s5$solution_bounded)

# plot solutions
plot(s5[, c("solution", "solution_bounded")], axes = FALSE)

## End(Not run)

```

---

```
add_manual_locked_constraints
```

*Add manually specified locked constraints*

---

## 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**

```
add_manual_locked_constraints(x, data)

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

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

**Arguments**

**x** [problem\(\)](#) object.

**data** `data.frame` or [tibble::tibble\(\)](#) object. See the Data format section for more information.

**Value**

An updated [problem\(\)](#) object with the constraints added to it.

**Data format**

The argument to `data` should be a `data.frame` with the following 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\(\)](#)).

**See Also**

See [constraints](#) for an overview of all functions for adding constraints.

Other constraints: [add\\_contiguity\\_constraints\(\)](#), [add\\_feature\\_contiguity\\_constraints\(\)](#), [add\\_linear\\_constraints\(\)](#), [add\\_locked\\_in\\_constraints\(\)](#), [add\\_locked\\_out\\_constraints\(\)](#), [add\\_mandatory\\_allocation\\_constraints\(\)](#), [add\\_manual\\_bounded\\_constraints\(\)](#), [add\\_neighbor\\_constraints\(\)](#)

**Examples**

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()
sim_zones_pu_polygons <- get_sim_zones_pu_polygons()
```

```

sim_zones_features <- get_sim_zones_features()

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

# 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)

# create object with all solutions
s4 <- sf::st_sf(
  tibble::tibble(
    s1 = s1$solution_1,
    s2 = s2$solution_1,
    s3 = s3$solution_1
  ),
  geometry = sf::st_geometry(s1)
)

# plot solutions
## s1 = none locked in
## s2 = locked in constraints
## s3 = manual locked constraints
plot(s4)

# create minimal problem with multiple zones
p5 <-
  problem(
    sim_zones_pu_polygons, sim_zones_features,
    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() %>%
  add_default_solver(verbose = FALSE)

```



```

# 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
p6 <- p5 %>% add_manual_locked_constraints(locked_data2)

# solve problem
s5 <- solve(p5)
s6 <- solve(p6)

# create two new columns representing the zone id that each planning unit
# was allocated to in the two solutions
s5$solution <- category_vector(sf::st_drop_geometry(
  s5[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
))
s5$solution <- factor(s5$solution)

s5$solution_locked <- category_vector(sf::st_drop_geometry(
  s6[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
))
s5$solution_locked <- factor(s5$solution_locked)

# plot solutions
plot(s5[, c("solution", "solution_locked")], axes = FALSE)

## End(Not run)

```

---

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 [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** [problem\(\)](#) object.

**targets** `data.frame` or [tibble::tibble\(\)](#) object. See the Targets format 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.

For problems associated with multiple management zones, [add\\_absolute\\_targets\(\)](#) can be used to set targets that each pertain to a single feature and a single zone. To set targets that 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**

An updated [problem\(\)](#) object with the targets added to it.

**Targets format**

The targets argument should be a `data.frame` with the following columns:

- feature** character name of features in argument to `x`.
- zone** character name of zones in the argument `x`. It can also be a list of character vectors if targets should correspond to multiple zones (see Examples section below). This column is optional for arguments to `x` that do not contain multiple zones.
- type** character describing the type of target. Acceptable values include "absolute" and "relative". These values correspond to [add\\_absolute\\_targets\(\)](#), and [add\\_relative\\_targets\(\)](#) respectively.

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

**target** numeric target threshold.

### See Also

See [targets](#) for an overview of all functions for adding targets.

Other targets: [add\\_absolute\\_targets\(\)](#), [add\\_loglinear\\_targets\(\)](#), [add\\_relative\\_targets\(\)](#)

### Examples

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# 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() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s1 <- solve(p1)

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

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

# solve problem
s2 <- solve(p2)
```

```

# plot solution
plot(s2, main = "solution", axes = 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() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s3 <- solve(p3)

# plot solution
plot(s3, main = "solution", axes = 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() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s4 <- solve(p4)

# plot solution
plot(s4, main = "solution", axes = 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_zones_pu_raster, sim_zones_features) %>%
    add_min_set_objective() %>%
    add_absolute_targets(targets_matrix) %>%
    add_binary_decisions() %>%
    add_default_solver(verbose = FALSE)

# solve problem
s5 <- solve(p5)

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

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

p6 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_min_set_objective() %>%
  add_manual_targets(targets_dataframe) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s6 <- solve(p6)

# plot solution
plot(category_layer(s6), main = "solution", axes = 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_zones_features)[[1]][[1:2]]
spp_zone2 <- spp_zone1 * 0.5
costs <- sim_zones_pu_raster[[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() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s7 <- solve(p7)

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

## End(Not run)

```

---

```
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 objective does not use targets, and feature weights should be used instead to increase the representation of certain features by a solution.

## Usage

```
add_max_cover_objective(x, budget)
```

## Arguments

x	<code>problem()</code> 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

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.

## Value

An updated `problem()` object with the objective added to it.

## Mathematical formulation

This objective is based on the maximum coverage reserve selection problem (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:

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

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  $i$ ,  $y_j$  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.

## Notes

In early versions (< 3.0.0.0), the mathematical formulation underpinning this function was very different. Specifically, as described above, the function now follows the formulations outlined in Church *et al.* (1996). The old formulation is now provided by the [add\\_max\\_utility\\_objective\(\)](#) function.

## References

- Church RL and Velle CR (1974) The maximum covering location problem. *Regional Science*, 32: 101–118.
- Church RL, Stoms DM, and Davis FW (1996) Reserve selection as a maximum covering location problem. *Biological Conservation*, 76: 105–112.

**See Also**

See [objectives](#) for an overview of all functions for adding objectives. Also, see [add\\_feature\\_weights\(\)](#) to specify weights for different features.

Other objectives: [add\\_max\\_features\\_objective\(\)](#), [add\\_max\\_phylo\\_div\\_objective\(\)](#), [add\\_max\\_phylo\\_end\\_objective\(\)](#), [add\\_max\\_utility\\_objective\(\)](#), [add\\_min\\_largest\\_shortfall\\_objective\(\)](#), [add\\_min\\_penalties\\_objective\(\)](#), [add\\_min\\_set\\_objective\(\)](#), [add\\_min\\_shortfall\\_objective\(\)](#)

**Examples**

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_features <- get_sim_features()
sim_zones_features <- get_sim_zones_features()

# threshold the feature data to generate binary biodiversity data
sim_binary_features <- sim_features
thresholds <- terra::global(
  sim_features, fun = quantile, probs = 0.5, na.rm = TRUE
)
for (i in seq_len(terra::nlyr(sim_features))) {
  sim_binary_features[[i]] <- terra::as.int(
    sim_features[[i]] > thresholds[[1]][[i]]
  )
}

# create problem with maximum cover objective
p1 <-
  problem(sim_pu_raster, sim_binary_features) %>%
  add_max_cover_objective(500) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s1 <- solve(p1)

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

# threshold the multi-zone feature data to generate binary biodiversity data
sim_binary_features_zones <- sim_zones_features
for (z in seq_len(number_of_zones(sim_zones_features))) {
  thresholds <- terra::global(
    sim_zones_features[[z]], fun = quantile, probs = 0.5, na.rm = TRUE
  )
  for (i in seq_len(number_of_features(sim_zones_features))) {
    sim_binary_features_zones[[z]][[i]] <- terra::as.int(
      sim_zones_features[[z]][[i]] > thresholds[[1]][[i]]
    )
  }
}
```



```

}

# create multi-zone problem with maximum cover objective that
# has a single budget for all zones
p2 <-
  problem(sim_zones_pu_raster, sim_binary_features_zones) %>%
  add_max_cover_objective(800) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s2 <- solve(p2)

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

# create multi-zone problem with maximum cover objective that
# has separate budgets for each zone
p3 <-
  problem(sim_zones_pu_raster, sim_binary_features_zones) %>%
  add_max_cover_objective(c(400, 400, 400)) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s3 <- solve(p3)

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

## End(Not run)

```

---

```
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, whilst ensuring that the cost of the solution does not exceed a budget.

### Usage

```
add_max_features_objective(x, budget)
```

### Arguments

x [problem\(\)](#) object.

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

### Details

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.

### Value

An updated `problem()` object with the objective added to it.

### Mathematical formulation

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:

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

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.

### References

Cabeza M and Moilanen A (2001) Design of reserve networks and the persistence of biodiversity. *Trends in Ecology & Evolution*, 16: 242–248.

### See Also

See **objectives** for an overview of all functions for adding objectives. Also, see **targets** for an overview of all functions for adding targets, and `add_feature_weights()` to specify weights for different features.

Other objectives: `add_max_cover_objective()`, `add_max_phylo_div_objective()`, `add_max_phylo_end_objective()`, `add_max_utility_objective()`, `add_min_largest_shortfall_objective()`, `add_min_penalties_objective()`, `add_min_set_objective()`, `add_min_shortfall_objective()`

**Examples**

```

## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# 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() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s1 <- solve(p1)

# plot solution
plot(s1, main = "solution", axes = 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_zones_pu_raster, sim_zones_features) %>%
  add_max_features_objective(3000) %>%
  add_relative_targets(matrix(0.1, ncol = 3, nrow = 5)) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s2 <- solve(p2)

# plot solution
plot(category_layer(s2), main = "solution", axes = 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_zones_pu_raster, sim_zones_features) %>%
  add_max_features_objective(c(3000, 3000, 3000)) %>%
  add_relative_targets(matrix(0.1, ncol = 3, nrow = 5)) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s3 <- solve(p3)

```

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

## End(Not run)
```

---

```
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 features represented in the solution subject to a budget. This objective is similar to [add\\_max\\_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

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

### Arguments

x	<a href="#">problem()</a> object.
budget	numeric value specifying the maximum expenditure of the prioritization. For problems with multiple zones, the argument to budget can be (i) a single numeric value to specify a single budget for the entire solution or (ii) a numeric vector to specify a separate budget for each management zone.
tree	<a href="#">ape::phylo()</a> object specifying a phylogenetic tree for the conservation features.

### Details

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 ([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 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.

### Value

An updated `problem()` object with the objective added to it.

### Mathematical formulation

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:

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

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  $l_b$ . 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.

### Notes

In early versions, this function was named as the `add_max_phylo_div_objective` function.

### References

Faith DP (1992) Conservation evaluation and phylogenetic diversity. *Biological Conservation*, 61: 1–10.

Rodrigues ASL and Gaston KJ (2002) Maximising phylogenetic diversity in the selection of networks of conservation areas. *Biological Conservation*, 105: 103–111.

### See Also

See [objectives](#) for an overview of all functions for adding objectives. Also, see [targets](#) for an overview of all functions for adding targets, and [add\\_feature\\_weights\(\)](#) to specify weights for different features.

Other objectives: [add\\_max\\_cover\\_objective\(\)](#), [add\\_max\\_features\\_objective\(\)](#), [add\\_max\\_phylo\\_end\\_objective\(\)](#), [add\\_max\\_utility\\_objective\(\)](#), [add\\_min\\_largest\\_shortfall\\_objective\(\)](#), [add\\_min\\_penalties\\_objective\(\)](#), [add\\_min\\_set\\_objective\(\)](#), [add\\_min\\_shortfall\\_objective\(\)](#)

**Examples**

```

## Not run:
# load ape package
require(ape)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_phylogeny <- get_sim_phylogeny()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# plot the simulated phylogeny
par(mfrow = c(1, 1))
plot(sim_phylogeny, main = "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
p1 <-
  problem(sim_pu_raster, sim_features) %>%
  add_max_phylo_div_objective(1900, sim_phylogeny) %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s1 <- solve(p1)

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

# find out which features have their targets met
r1 <- eval_target_coverage_summary(p1, s1)
print(r1, width = Inf)

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

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

# 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_zones_features),
  zone = list(zone_names(sim_zones_features))[
    rep(1, number_of_features(sim_zones_features))],
  type = rep("absolute", number_of_features(sim_zones_features)),
  target = rep(10, number_of_features(sim_zones_features))
)

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

# solve problem
s2 <- solve(p2)

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

# find out which features have their targets met
r2 <- eval_target_coverage_summary(p2, s2)
print(r2, width = Inf)

# plot the phylogeny and color the adequately represented features in red
plot(
  sim_phylogeny, main = "adequately represented features",
  tip.color = replace(
    rep("black", terra::nlyr(sim_features)), which(r2$met), "red"
  )
)

# create a multi-zone problem with a maximum phylogenetic diversity
# objective, where each zone has a separate budget.
p3 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_max_phylo_div_objective(c(2500, 500, 2000), sim_phylogeny) %>%
  add_manual_targets(targets) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s3 <- solve(p3)

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

# find out which features have their targets met
r3 <- eval_target_coverage_summary(p3, s3)
print(r3, width = Inf)

```

```
# plot the phylogeny and color the adequately represented features in red
plot(
  sim_phylogeny, main = "adequately represented features",
  tip.color = replace(
    rep("black", terra::nlyr(sim_features)), which(r3$met), "red"
  )
)

## End(Not run)
```

---

```
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\\_div\\_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	<a href="#">problem()</a> object.
budget	numeric value specifying the maximum expenditure of the prioritization. For problems with multiple zones, the argument to budget can be (i) a single numeric value to specify a single budget for the entire solution or (ii) a numeric vector to specify a separate budget for each management zone.
tree	<a href="#">ape::phylo()</a> object specifying a phylogenetic tree for the conservation features.

### Details

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.

## Value

An updated `problem()` object with the objective added to it.

## Mathematical formulation

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:

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

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 met the target  $t_j$  for feature  $j$ . Additionally,  $T$  represents a phylogenetic tree containing features  $j$  and has the branches  $b$  associated within lengths  $l_b$ . 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.

## References

- Faith DP (1992) Conservation evaluation and phylogenetic diversity. *Biological Conservation*, 61: 1–10.
- Rodrigues ASL and Gaston KJ (2002) Maximising phylogenetic diversity in the selection of networks of conservation areas. *Biological Conservation*, 105: 103–111.
- Rosauer D, Laffan SW, Crisp, MD, Donnellan SC and Cook LG (2009) Phylogenetic endemism: a new approach for identifying geographical concentrations of evolutionary history. *Molecular Ecology*, 18: 4061–4072.

**See Also**

See [objectives](#) for an overview of all functions for adding objectives. Also, see [targets](#) for an overview of all functions for adding targets, and [add\\_feature\\_weights\(\)](#) to specify weights for different features.

Other objectives: [add\\_max\\_cover\\_objective\(\)](#), [add\\_max\\_features\\_objective\(\)](#), [add\\_max\\_phylo\\_div\\_objective\(\)](#), [add\\_max\\_utility\\_objective\(\)](#), [add\\_min\\_largest\\_shortfall\\_objective\(\)](#), [add\\_min\\_penalties\\_objective\(\)](#), [add\\_min\\_set\\_objective\(\)](#), [add\\_min\\_shortfall\\_objective\(\)](#)

**Examples**

```
## Not run:
# load ape package
require(ape)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_phylogeny <- get_sim_phylogeny()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# 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() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s1 <- solve(p1)

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

# find out which features have their targets met
r1 <- eval_target_coverage_summary(p1, s1)
print(r1, width = Inf)

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

```

    "red"
  )
)

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

# 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_zones_features),
  zone = list(zone_names(sim_zones_features))[
    rep(1, number_of_features(sim_zones_features))],
  type = rep("absolute", number_of_features(sim_zones_features)),
  target = rep(10, number_of_features(sim_zones_features))
)

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

# solve problem
s2 <- solve(p2)

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

# find out which features have their targets met
r2 <- eval_target_coverage_summary(p2, s2)
print(r2, width = Inf)

# plot the phylogeny and color the adequately represented features in red
plot(
  sim_phylogeny, main = "adequately represented features",
  tip.color = replace(
    rep("black", terra::nlyr(sim_features)), which(r2$met), "red"
  )
)

# create a multi-zone problem with a maximum phylogenetic endemism
# objective, where each zone has a separate budget.
p3 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_max_phylo_end_objective(c(2500, 500, 2000), sim_phylogeny) %>%
  add_manual_targets(targets) %>%
  add_binary_decisions() %>%

```

```

add_default_solver(verbose = FALSE)

# solve problem
s3 <- solve(p3)

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

# find out which features have their targets met
r3 <- eval_target_coverage_summary(p3, s3)
print(r3, width = Inf)

# plot the phylogeny and color the adequately represented features in red
plot(
  sim_phylogeny, main = "adequately represented features",
  tip.color = replace(
    rep("black", terra::nlyr(sim_features)), which(r3$met), "red"
  )
)

## End(Not run)

```

---

add\_max\_utility\_objective

*Add maximum utility objective*

---

## Description

Set the objective of a conservation planning problem to maximize the weighted sum of the features represented by the solution as much as possible without exceeding a budget. This objective does not use targets, and feature weights should be used instead to increase the representation of particular features by a solution. Note that this objective does not aim to maximize as much of each feature individually, and so often results in solutions that are heavily biased towards just a few features.

## Usage

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

## Arguments

x	<code>problem()</code> object.
budget	numeric value specifying the maximum expenditure of the prioritization. For problems with multiple zones, the argument to budget can be (i) a single numeric value to specify a single budget for the entire solution or (ii) a numeric vector to specify a separate budget for each management zone.

## Details

The maximum utility objective seeks to maximize 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 particular features over other features (see [add\\_feature\\_weights\(\)](#)). It is essentially calculated as a weighted sum of the feature data inside the selected planning units.

## Value

An updated `problem()` object with the objective added to it.

## Mathematical formulation

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:

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

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  $i$ ,  $A_j$  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.

## Notes

In early versions (< 3.0.0.0), this function was named as the `add_max_cover_objective` function. It was renamed to avoid confusion with existing terminology.

## See Also

See [objectives](#) for an overview of all functions for adding objectives. Also, see [add\\_feature\\_weights\(\)](#) to specify weights for different features.

Other objectives: [add\\_max\\_cover\\_objective\(\)](#), [add\\_max\\_features\\_objective\(\)](#), [add\\_max\\_phylo\\_div\\_objective\(\)](#), [add\\_max\\_phylo\\_end\\_objective\(\)](#), [add\\_min\\_largest\\_shortfall\\_objective\(\)](#), [add\\_min\\_penalties\\_objective\(\)](#), [add\\_min\\_set\\_objective\(\)](#), [add\\_min\\_shortfall\\_objective\(\)](#)

## Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# create problem with maximum utility objective
```

```

p1 <-
  problem(sim_pu_raster, sim_features) %>%
  add_max_utility_objective(5000) %>%
  add_binary_decisions() %>%
  add_default_solver(gap = 0, verbose = FALSE)

# solve problem
s1 <- solve(p1)

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

# create multi-zone problem with maximum utility objective that
# has a single budget for all zones
p2 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_max_utility_objective(5000) %>%
  add_binary_decisions() %>%
  add_default_solver(gap = 0, verbose = FALSE)

# solve problem
s2 <- solve(p2)

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

# create multi-zone problem with maximum utility objective that
# has separate budgets for each zone
p3 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_max_utility_objective(c(1000, 2000, 3000)) %>%
  add_binary_decisions() %>%
  add_default_solver(gap = 0, verbose = FALSE)

# solve problem
s3 <- solve(p3)

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

## End(Not run)

```

---

```
add_min_largest_shortfall_objective
```

*Add minimum largest shortfall objective*

---

### Description

Set the objective of a conservation planning problem to minimize the largest target shortfall while ensuring that the cost of the solution does not exceed a budget. Note that if the target shortfall for

a single feature cannot be decreased beyond a certain point (e.g., because all remaining planning units occupied by that feature are too costly or are locked out), then solutions may only use a small proportion of the specified budget.

### Usage

```
add_min_largest_shortfall_objective(x, budget)
```

### Arguments

x	<a href="#">problem()</a> object.
budget	numeric value specifying the maximum expenditure of the prioritization. For problems with multiple zones, the argument to budget can be (i) a single numeric value to specify a single budget for the entire solution or (ii) a numeric vector to specify a separate budget for each management zone.

### Details

The minimum largest shortfall objective aims to find the set of planning units that minimize the largest shortfall for any of 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. This objective is different from the minimum shortfall objective ([add\\_min\\_shortfall\\_objective\(\)](#)) because this objective minimizes the largest (maximum) target shortfall, whereas the minimum shortfall objective minimizes the total (weighted sum) of the target shortfalls. Note that this objective function is not compatible with feature weights ([add\\_feature\\_weights\(\)](#)).

### Value

An updated [problem\(\)](#) object with the objective added to it.

### Mathematical formulation

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:

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

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  $i$ , and  $t_j$  is the representation target for feature  $j$ . Additionally,  $y_j$  denotes the target shortfall for the target  $t_j$  for feature  $j$ , and  $l$  denotes the largest target shortfall. Furthermore,  $B$  is the budget allocated for the solution,  $c_i$  is the cost of planning unit  $i$ . Note that  $y_j$  and  $s$  are continuous variables bounded between zero and infinity.

### See Also

See [objectives](#) for an overview of all functions for adding objectives. Also, see [targets](#) for an overview of all functions for adding targets, and [add\\_feature\\_weights\(\)](#) to specify weights for different features.

Other objectives: `add_max_cover_objective()`, `add_max_features_objective()`, `add_max_phylo_div_objective()`, `add_max_phylo_end_objective()`, `add_max_utility_objective()`, `add_min_penalties_objective()`, `add_min_set_objective()`, `add_min_shortfall_objective()`

## Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# create problem with minimum largest shortfall objective
p1 <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_largest_shortfall_objective(1800) %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s1 <- solve(p1)

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

# create multi-zone problem with minimum largest shortfall objective,
# with 10% representation targets for each feature, and set
# a budget such that the total maximum expenditure in all zones
# cannot exceed 1800
p2 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_min_largest_shortfall_objective(1800) %>%
  add_relative_targets(matrix(0.1, ncol = 3, nrow = 5)) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s2 <- solve(p2)

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

# create multi-zone problem with minimum largest shortfall objective,
# with 10% representation targets for each feature, and set
# separate budgets of 1800 for each management zone
p3 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_min_largest_shortfall_objective(c(1800, 1800, 1800)) %>%
  add_relative_targets(matrix(0.1, ncol = 3, nrow = 5)) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)
```



```
# solve problem
s3 <- solve(p3)

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

## End(Not run)
```

---

add\_min\_penalties\_objective

*Add minimum penalties objective*

---

## Description

Set the objective of a conservation planning problem to only minimize the penalties added to the problem, whilst ensuring that all [targets](#) are met and the cost of the solution does not exceed a budget. This objective is useful when using a hierarchical approach for multi-objective optimization.

## Usage

```
add_min_penalties_objective(x, budget)
```

## Arguments

x	<a href="#">problem()</a> object.
budget	numeric value specifying the maximum expenditure of the prioritization. For problems with multiple zones, the argument to budget can be (i) a single numeric value to specify a single budget for the entire solution or (ii) a numeric vector to specify a separate budget for each management zone.

## Details

The minimum penalty objective is designed to be used with problems that have penalties (see [penalties](#) for details). It can be used to generate solutions that focus entirely on minimizing the penalties, whilst ensuring that certain constraints are met. This is useful when performing multi-objective optimization using a hierarchical approach (see examples below). Although previous versions of the package recommended using the minimum set objective (i.e., [add\\_min\\_set\\_objective\(\)](#)) with zero costs and linear constraints for this purpose, the minimum penalty objective provides a dedicated objective for performing hierarchical multi-objective optimization.

## Value

An updated [problem\(\)](#) object with the objective added to it.

### Mathematical formulation

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:

$$\text{Minimize } 0 \text{ subject to } \sum_{i=1}^I x_i r_{ij} \geq T_j \forall j \in J \quad \sum_{i=1}^I x_i c_i \leq B$$

Here,  $x_i$  is the [decisions](#) variable (e.g., specifying whether planning unit  $i$  has been selected (1) or not (0)),  $c_i$  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  $j$ . Since the objective is to minimize zero, this function does not actually provide any criteria to compare competing solutions. As such, when used in conjunction with a penalty function (see [penalties](#)), only the penalty (e.g., [add\\_boundary\\_penalties\(\)](#)) will be used to compare competing solutions during optimization.

### See Also

See [objectives](#) for an overview of all functions for adding objectives. Also see [targets](#) for an overview of all functions for adding targets. Additionally, see [penalties](#) for an overview of all functions for adding penalties.

Other objectives: [add\\_max\\_cover\\_objective\(\)](#), [add\\_max\\_features\\_objective\(\)](#), [add\\_max\\_phylo\\_div\\_objective\(\)](#), [add\\_max\\_phylo\\_end\\_objective\(\)](#), [add\\_max\\_utility\\_objective\(\)](#), [add\\_min\\_largest\\_shortfall\\_objective\(\)](#), [add\\_min\\_set\\_objective\(\)](#), [add\\_min\\_shortfall\\_objective\(\)](#)

### Examples

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# create initial problem with minimum set objective
p1 <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve initial problem
s1 <- solve(p1)

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

# calculate total cost of initial solution
```

```

c1 <- eval_cost_summary(p1, s1)

# since the solution is spatially fragmented, we will now use
# a hierarchical multi-objective optimization approach to reduce
# spatial fragmentation

# calculate budget for new prioritization based on cost of initial solution,
# this budget will specify that we are willing to accept a 10%
# increase in the total cost of the solution to minimize fragmentation
b <- c1$cost[[1]] * 1.1

# create problem with minimum penalty objective using the budget and
# boundary penalties to reduce spatial fragmentation
#
# note that although we use a penalty value of 0.01 as a placeholder,
# any penalty value would give the same result since the optimization
# process is focused entirely on the boundary penalties
p2 <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_penalties_objective(budget = b) %>%
  add_boundary_penalties(penalty = 0.001) %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem with minimum penalty objective
s2 <- solve(p2)

# plot solution with minimum penalty objective
plot(s2, main = "solution", axes = FALSE)

## End(Not run)

```

---

add\_min\_set\_objective *Add minimum 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 [problem\(\)](#) object.

## Details

The minimum set objective – in the the context of systematic reserve design – 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 difference between this objective and the *Marxan* software is that the targets for the features will always be met (and as such it does not use Species Penalty Factors).

## Value

An updated `problem()` object with the objective added to it.

## Mathematical formulation

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:

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

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.

## References

Rodrigues AS, Cerdeira OJ, and Gaston KJ (2000) Flexibility, efficiency, and accountability: adapting reserve selection algorithms to more complex conservation problems. *Ecography*, 23: 565–574.

## See Also

See [objectives](#) for an overview of all functions for adding objectives. Also see [targets](#) for an overview of all functions for adding targets.

Other objectives: [add\\_max\\_cover\\_objective\(\)](#), [add\\_max\\_features\\_objective\(\)](#), [add\\_max\\_phylo\\_div\\_objective\(\)](#), [add\\_max\\_phylo\\_end\\_objective\(\)](#), [add\\_max\\_utility\\_objective\(\)](#), [add\\_min\\_largest\\_shortfall\\_objective\(\)](#), [add\\_min\\_penalties\\_objective\(\)](#), [add\\_min\\_shortfall\\_objective\(\)](#)

## Examples

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
```

```

sim_zones_features <- get_sim_zones_features()

# create minimal problem with minimum set objective
p1 <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s1 <- solve(p1)

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

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

p2 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_min_set_objective() %>%
  add_absolute_targets(targets_matrix) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s2 <- solve(p2)

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

## End(Not run)

```

---

```

add_min_shortfall_objective
  Add minimum shortfall objective

```

---

### Description

Set the objective of a conservation planning problem to minimize the overall 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	<a href="#">problem()</a> object.
budget	numeric value specifying the maximum expenditure of the prioritization. For problems with multiple zones, the argument to budget can be (i) a single numeric value to specify a single budget for the entire solution or (ii) a numeric vector to specify a separate budget for each management zone.

**Details**

The minimum shortfall objective aims to find the set of planning units that minimize the overall (weighted sum) 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\(\)](#)).

**Value**

An updated [problem\(\)](#) object with the objective added to it.

**Mathematical formulation**

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:

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

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  $j$ .

**References**

Arponen A, Heikkinen RK, Thomas CD, and Moilanen A (2005) The value of biodiversity in reserve selection: representation, species weighting, and benefit functions. *Conservation Biology*, 19: 2009–2014.

**See Also**

See [objectives](#) for an overview of all functions for adding objectives. Also, see [targets](#) for an overview of all functions for adding targets, and [add\\_feature\\_weights\(\)](#) to specify weights for different features.

Other objectives: [add\\_max\\_cover\\_objective\(\)](#), [add\\_max\\_features\\_objective\(\)](#), [add\\_max\\_phylo\\_div\\_objective\(\)](#), [add\\_max\\_phylo\\_end\\_objective\(\)](#), [add\\_max\\_utility\\_objective\(\)](#), [add\\_min\\_largest\\_shortfall\\_objective\(\)](#), [add\\_min\\_penalties\\_objective\(\)](#), [add\\_min\\_set\\_objective\(\)](#)

**Examples**

```

## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# 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() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s1 <- solve(p1)

# plot solution
plot(s1, main = "solution", axes = 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_zones_pu_raster, sim_zones_features) %>%
  add_min_shortfall_objective(3000) %>%
  add_relative_targets(matrix(0.1, ncol = 3, nrow = 5)) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s2 <- solve(p2)

# plot solution
plot(category_layer(s2), main = "solution", axes = 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_zones_pu_raster, sim_zones_features) %>%
  add_min_shortfall_objective(c(3000, 3000, 3000)) %>%
  add_relative_targets(matrix(0.1, ncol = 3, nrow = 5)) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s3 <- solve(p3)

```

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

## End(Not run)
```

---

```
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

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

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

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

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

### Arguments

x	<code>problem()</code> 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.
clamp	logical should the minimum number of neighbors for selected planning units in the solution be clamped to feasibility? For example, if a planning unit has two neighbors, k = 3, and clamp = FALSE, then the planning unit could not ever be selected in the solution. However, if clamp = TRUE, then the planning unit could potentially be selected in the solution if both of its two neighbors were also selected. Defaults to TRUE.
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 Data format section for more information.

### Details

This function uses neighborhood data to 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).

### Value

An updated `problem()` object with the constraints added to it.

### Data format

The argument to data can be specified using the following formats:

**data as a NULL value** 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).

**data as a matrix/Matrix object** 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 as a data.frame object** containing columns that are named "id1", "id2", and "boundary". Here, each row denotes the connectivity between two planning units following the *Marxan* format. The "boundary" column should contain binary numeric values that indicate if the two planning units specified in the "id1" and "id2" columns 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 "zone1" and "zone2" columns can optionally be provided to manually specify if the neighborhood data pertain to specific zones. The "zone1" and "zone2" columns should contain the character names of the zones. If the columns "zone1" and "zone2" are present, then the argument to `zones` must be NULL.

**data as an array object** 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.

## References

Beyer HL, Dujardin Y, Watts ME, and Possingham HP (2016) Solving conservation planning problems with integer linear programming. *Ecological Modelling*, 228: 14–22.

Billionnet A (2013) Mathematical optimization ideas for biodiversity conservation. *European Journal of Operational Research*, 231: 514–534.

## See Also

Other constraints: [add\\_contiguity\\_constraints\(\)](#), [add\\_feature\\_contiguity\\_constraints\(\)](#), [add\\_linear\\_constraints\(\)](#), [add\\_locked\\_in\\_constraints\(\)](#), [add\\_locked\\_out\\_constraints\(\)](#), [add\\_mandatory\\_allocation\\_constraints\(\)](#), [add\\_manual\\_bounded\\_constraints\(\)](#), [add\\_manual\\_locked\\_constraints\(\)](#)

## Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

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

# 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 neighbor
# 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 <- terra::rast(list(solve(p1), solve(p2), solve(p3), solve(p4)))
names(s1) <- c("basic solution", "1 neighbor", "2 neighbors", "3 neighbors")

# plot solutions
plot(s1, axes = FALSE)

# create minimal problem with multiple zones
p5 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(0.1, ncol = 3, nrow = 5)) %>%
  add_default_solver(verbose = FALSE)

# 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), zones = 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), zones = 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), zones = z8)

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

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

## End(Not run)
```

---

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 [problem\(\)](#) 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). Only a single decision should be added to a [problem\(\)](#) object. Note that if multiple decisions are added to an object, then the last one to be added will be used.

## Value

An updated [problem\(\)](#) object with the decisions added to it.

## See Also

See [decisions](#) for an overview of all functions for adding decisions.

Other decisions: [add\\_binary\\_decisions\(\)](#), [add\\_semicontinuous\\_decisions\(\)](#)

## Examples

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# create minimal problem with proportion decisions
p1 <-
  problem(sim_pu_raster, sim_features) %>%
```

```

    add_min_set_objective() %>%
    add_relative_targets(0.1) %>%
    add_proportion_decisions() %>%
    add_default_solver(verbose = FALSE)

# solve problem
s1 <- solve(p1)

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

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

# 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)

## End(Not run)

```

---

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 values) using the [feature\\_abundances\(\)](#) function.

## Usage

```

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** `problem()` object.

**targets** Object that specifies the targets for each feature. See the Targets format 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.

For problems associated with multiple management zones, `add_absolute_targets()` can be used to set targets that each pertain to a single feature and a single zone. To set targets that 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

An updated `problem()` object with the targets added to it.

### Targets format

The targets for a problem can be specified using the following formats.

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

**targets as a matrix object** 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.

**targets as a character vector** containing the column name(s) in the feature data associated with the argument to `x` that contain targets. This format can only be used when the feature data associated with `x` is a `sf::st_sf()` or `data.frame`. For problems that contain a single zone, the argument to `targets` must contain a single column name. Otherwise, for problems that contain multiple zones, the argument to `targets` must contain a column name for each zone.

**See Also**

See [targets](#) for an overview of all functions for adding targets.

Other targets: [add\\_absolute\\_targets\(\)](#), [add\\_loglinear\\_targets\(\)](#), [add\\_manual\\_targets\(\)](#)

**Examples**

```
## Not run:
# set seed for reproducibility
set.seed(500)
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

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

# 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
s3 <- c(solve(p1), solve(p2))
names(s3) <- c("10% targets", "varying targets")

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

# create a problem with multiple management zones
p4 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_min_set_objective() %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# 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_zones_features), zone_names(sim_zones_features)
  )
)
print(p4_targets)

p5 <- p4 %>% add_relative_targets(p4_targets)
```

```

# solve problem
s5 <- solve(p5)

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

# create a problem with targets that require a varying amount of each
# feature to be represented in each zone
p6_targets <- matrix(
  runif(15, 0.01, 0.2), nrow = 5, ncol = 3, dimnames = list(
    feature_names(sim_zones_features), zone_names(sim_zones_features)
  )
)
print(p6_targets)

p6 <- p4 %>% add_relative_targets(p6_targets)

# solve problem
s6 <- solve(p6)

# plot solution (pixel values correspond to zone identifiers)
plot(category_layer(s6), main = "varying targets")

## End(Not run)

```

---

add\_rsymphony\_solver *Add a SYMPHONY solver with Rsymphony*

---

### Description

Specify that the *SYMPHONY* software – using the **Rsymphony** package – should be used to solve a conservation planning problem (Ralphs & Güzelsoy 2005). This function can also be used to customize the behavior of the solver. It requires the **Rsymphony** package to be installed.

### Usage

```

add_rsymphony_solver(
  x,
  gap = 0.1,
  time_limit = .Machine$integer.max,
  first_feasible = FALSE,
  verbose = TRUE
)

```

### Arguments

x [problem\(\)](#) object.



gap	numeric gap to optimality. This gap is relative and expresses the acceptable deviance from the optimal objective. For example, a value of 0.01 will result in the solver stopping when it has found a solution within 1% of optimality. Additionally, a value of 0 will result in the solver stopping when it has found an optimal solution. The default value is 0.1 (i.e., 10% from optimality).
time_limit	numeric time limit (seconds) for generating solutions. The solver will return the current best solution when this time limit is exceeded. The default value is the largest integer value (i.e., <code>.Machine\$integer.max</code> ), effectively meaning that solver will keep running until a solution within the optimality gap is found.
first_feasible	logical should the first feasible solution be returned? If <code>first_feasible</code> is set to <code>TRUE</code> , 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 <code>FALSE</code> .
verbose	logical should information be printed while solving optimization problems? Defaults to <code>TRUE</code> .

## Details

***SYMPHONY*** is an open-source mixed integer programming solver that is part of the Computational Infrastructure for Operations Research (COIN-OR) project. The ***Rsymphony*** package provides an interface to COIN-OR and – unlike dependencies for other solvers – is available on *CRAN*. For information on the performance of different solvers, please see Schuster *et al.* (2020) for benchmarks comparing the run time and solution quality of different solvers when applied to different sized datasets.

## Value

An updated `problem()` object with the solver added to it.

## References

Ralphs TK and Güzelsoy M (2005) The SYMPHONY callable library for mixed integer programming. In *The Next Wave in Computing, Optimization, and Decision Technologies* (pp. 61–76). Springer, Boston, MA.

Schuster R, Hanson JO, Strimas-Mackey M, and Bennett JR (2020). Exact integer linear programming solvers outperform simulated annealing for solving conservation planning problems. *PeerJ*, 8: e9258.

## See Also

See `solvers` for an overview of all functions for adding a solver.

Other solvers: `add_cbc_solver()`, `add_cplex_solver()`, `add_default_solver()`, `add_gurobi_solver()`, `add_highs_solver()`, `add_ksymphony_solver()`

## Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()

# create problem
p <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_rsymphony_solver(time_limit = 10, verbose = FALSE)

# generate solution
s <- solve(p)

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

## End(Not run)
```

---

add\_semicontinuous\_decisions

*Add semi-continuous decisions*

---

## 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. 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 prioritized. 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	<a href="#">problem()</a> 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). Only a single decision should be added to a `problem()` object. Note that if multiple decisions are added to an object, then the last one to be added will be used.

## Value

An updated `problem()` object with the decisions added to it.

## See Also

See [decisions](#) for an overview of all functions for adding decisions.

Other decisions: [add\\_binary\\_decisions\(\)](#), [add\\_proportion\\_decisions\(\)](#)

## Examples

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# 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) %>%
  add_default_solver(verbose = FALSE)

# solve problem
s1 <- solve(p1)

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

# build multi-zone conservation problem with semi-continuous decisions
p2 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5, ncol = 3)) %>%
  add_semicontinuous_decisions(0.5) %>%
  add_default_solver(verbose = FALSE)

# 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)

## End(Not run)
```

---

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. Although this function can be useful for generating multiple different solutions for a given problem, it is recommended to use [add\\_pool\\_portfolio](#) if the *Gurobi* software is available.

## Usage

```
add_shuffle_portfolio(
  x,
  number_solutions = 10,
  threads = 1,
  remove_duplicates = TRUE
)
```

## Arguments

`x` [problem\(\)](#) 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

An updated [problem\(\)](#) object with the portfolio added to it.

**See Also**

See [portfolios](#) for an overview of all functions for adding a portfolio.

Other portfolios: [add\\_cuts\\_portfolio\(\)](#), [add\\_default\\_portfolio\(\)](#), [add\\_extra\\_portfolio\(\)](#), [add\\_gap\\_portfolio\(\)](#), [add\\_top\\_portfolio\(\)](#)

**Examples**

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# 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)

# convert portfolio into a multi-layer raster
s1 <- terra::rast(s1)

# print number of solutions found
print(terra::nlyr(s1))

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

# build multi-zone conservation problem with shuffle portfolio
p2 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  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)

# convert each solution in the portfolio into a single category layer
s2 <- terra::rast(lapply(s2, category_layer))
```

```
# print number of solutions found
print(terra::nlyr(s2))

# plot solutions in portfolio
plot(s2, axes = FALSE)

## End(Not run)
```

---

add\_top\_portfolio      *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

```
add_top_portfolio(x, number_solutions = 10)
```

## Arguments

`x`                    [problem\(\)](#) object.  
`number_solutions`    integer number of solutions required. Defaults to 10.

## 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. 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

An updated [problem\(\)](#) object with the portfolio added to it.

## See Also

See [portfolios](#) for an overview of all functions for adding a portfolio.

Other portfolios: [add\\_cuts\\_portfolio\(\)](#), [add\\_default\\_portfolio\(\)](#), [add\\_extra\\_portfolio\(\)](#), [add\\_gap\\_portfolio\(\)](#), [add\\_shuffle\\_portfolio\(\)](#)

**Examples**

```
## Not run:
# set seed for reproducibility
set.seed(600)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

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

# convert portfolio into a multi-layer raster
s1 <- terra::rast(s1)

# print number of solutions found
print(terra::nlyr(s1))

# plot solutions
plot(s1, axes = FALSE)

# create multi-zone problem with a portfolio for the top 5 solutions
p2 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  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)

# convert each solution in the portfolio into a single category layer
s2 <- terra::rast(lapply(s2, category_layer))

# print number of solutions found
print(terra::nlyr(s2))

# plot solutions in portfolio
plot(s2, axes = FALSE)

## End(Not run)
```

---

adjacency\_matrix      *Adjacency matrix*


---

### Description

Create a matrix showing which planning units are spatially adjacent to each other.

### Usage

```
adjacency_matrix(x, ...)

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

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

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

## 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	<code>terra::rast()</code> or <code>sf::sf()</code> object representing planning units.
...	not used.
directions	integer If x is a <code>terra::rast()</code> 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" to for cells with one-cell diagonal moves.

### Details

Spatial processing is completed using `sf::st_intersects()` for `sf::sf()` objects, and `terra::adjacent()` for `terra::rast()` objects. Note that spatially overlapping planning units are considered adjacent.



**Value**

A `Matrix::dsMatrix` 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 `terra::rast()` object, then cells with NA values are set to zero too.

**Notes**

In earlier versions (< 5.0.0), this function was named as the `connected_matrix` function. It has been renamed to be consistent with other spatial association matrix functions.

**Examples**

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_pu_polygons <- get_sim_pu_polygons()

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

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

# create adjacency matrix using polygon data
## subset 9 polygons
ply <- sim_pu_polygons[c(1:3, 11:13, 20:22), ]

## make adjacency matrix
am_ply <- adjacency_matrix(ply)

# plot data and the adjacency matrices

## plot raster and adjacency matrix
plot(r, main = "raster", axes = FALSE)
Matrix::image(am_raster, main = "adjacency matrix")

## plot polygons and adjacency matrix
plot(ply[, 1], main = "polygons")
Matrix::image(am_ply, main = "adjacency matrix")

## End(Not run)
```

**Description**

Convert a single-layer `terra::rast()` object that contains integer values into a multi-layer `terra::rast()` object with pixel values denote the presence/absence of a given integer value. This methodology is also known as "one-hot encoding".

**Usage**

```
binary_stack(x, keep_all = TRUE)

## S3 method for class 'Raster'
binary_stack(x, keep_all = TRUE)

## S3 method for class 'SpatRaster'
binary_stack(x, keep_all = TRUE)
```

**Arguments**

<code>x</code>	<code>terra::rast()</code> object with a single layer that contains integer values.
<code>keep_all</code>	logical value indicating if all integers should be kept in the output. If TRUE, the output will contain a layer for each sequential integer between 1 and the maximum value in <code>x</code> . If FALSE, the output will only contain layers for integer values present in <code>x</code> . Defaults to TRUE.

**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 rasters as input arguments. It is essentially a wrapper for `terra::segregate()`. Note that this function assumes `x` contains integer values.

**Value**

A `terra::rast()` object.

**See Also**

`category_layer()`, `terra::segregate()`.

**Examples**

```
# create raster with categorical values
x <- terra::rast(matrix(c(1, 2, 4, 0, NA, 1), nrow = 3))

# plot the raster
## Not run:
plot(x, main = "x")

## End(Not run)
```

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

# plot result
## Not run:
plot(y)

## End(Not run)
```

---

boundary_matrix	<i>Boundary matrix</i>
-----------------	------------------------

---

### Description

Generate a matrix describing the amount of shared boundary length between different planning units, and the total amount of boundary length for each planning unit.

### Usage

```
boundary_matrix(x, ...)

## S3 method for class 'Raster'
boundary_matrix(x, ...)

## S3 method for class 'SpatRaster'
boundary_matrix(x, ...)

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

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

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

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

## Default S3 method:
boundary_matrix(x, ...)
```

### Arguments

x	<code>terra::rast()</code> or <code>sf::sf()</code> object representing planning units.
...	not used.

## Details

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 (i.e., **WGS84**) should be reprojected to another coordinate system before using this function. Note that for `terra::rast()` objects boundaries are missing for cells that have missing (NA) values in all cells.

## Value

A `Matrix::dsCMatrix` symmetric sparse matrix object. Each row and column represents a planning unit. Cell values indicate the shared boundary length between different pairs of planning units. Values along the matrix diagonal indicate the total perimeter associated with each planning unit.

## Notes

In earlier versions, this function had an extra `str_tree` parameter that could be used to leverage STR query trees to speed up processing for planning units in vector format. Although this functionality improved performance, it was not enabled by default because the underlying function (i.e., `rgeos:gUnarySTRtreeQuery()`) was documented as experimental. The `boundary_matrix()` function has since been updated so that it will use STR query trees to speed up processing for planning units in vector format (using `terra::sharedPaths()`).

Also, note that in previous versions, cell values along the matrix diagonal indicated the perimeter associated with planning units that did not contain any neighbors. This has now changed such that values along the diagonal now correspond to the total perimeter associated with each planning unit.

## See Also

Boundary matrix data might need rescaling to improve optimization performance, see `rescale_matrix()` to perform these calculations.

## Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_pu_polygons <- get_sim_pu_polygons()

# subset data to reduce processing time
r <- terra::crop(sim_pu_raster, c(0, 0.3, 0, 0.3))
ply <- sim_pu_polygons[c(1:3, 11:13, 20:22), ]

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

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

# plot raster and boundary matrix
plot(r, main = "raster", axes = FALSE)
Matrix::image(bm_raster, main = "boundary matrix")
```

```
# plot polygons and boundary matrices
plot(ply[, 1], main = "polygons", axes = FALSE)
Matrix::image(bm_ply, main = "boundary matrix")

## End(Not run)
```

---

branch\_matrix

*Branch matrix*

---

## Description

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

```
branch_matrix(x)

## Default S3 method:
branch_matrix(x)

## S3 method for class 'phylo'
branch_matrix(x)
```

## Arguments

x [ape::phylo\(\)](#) tree object.

## Value

A [Matrix::dgCMatrix](#) 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

```
# load data
sim_phylogeny <- get_sim_phylogeny()

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

# plot data
## Not run:
plot(sim_phylogeny, main = "phylogeny")
```

```
Matrix::image(m, main = "branch matrix")
## End(Not run)
```

---

category_layer	<i>Category layer</i>
----------------	-----------------------

---

### Description

Convert a `terra::rast()` object where each layer corresponds to a different identifier and values indicate the presence/absence of that category into a `terra::rast()` object containing categorical identifiers.

### Usage

```
category_layer(x)

## S3 method for class 'Raster'
category_layer(x)

## Default S3 method:
category_layer(x)
```

### Arguments

`x` `terra::rast()` object containing 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. It is essentially a wrapper for `terra::which.lyr()`.

### Value

A `terra::rast()` object.

### See Also

`binary_stack()`.

**Examples**

```

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

# plot data
plot(x)

# convert to category layer
y <- category_layer(x)

# plot result
## Not run:
plot(y)

## End(Not run)

```

---

category\_vector

*Category vector*


---

**Description**

Convert an object containing binary (integer) 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, or `sf::sf()` object.

**Details**

This function is conceptually similar to `base::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**

An integer vector.

**See Also**

`base::max.col()`.

**Examples**

```
# create matrix with logical columns
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)
```

---

compile

*Compile a problem*

---

**Description**

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

**Usage**

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

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

**Arguments**

`x` `problem()` 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 `compressed_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**

A `optimization_problem()` object.

**Examples**

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()

# 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)

## End(Not run)
```

**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 'sf,SpatRaster'
connectivity_matrix(x, y, ...)

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

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

**Arguments**

x	<a href="#">terra::rast()</a> or <a href="#">sf::sf()</a> object representing planning units.
y	<a href="#">terra::rast()</a> 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 <a href="#">sf::sf()</a> object. Also, note that if the argument to x is a <a href="#">terra::rast()</a> object then argument to y must have the same spatial properties as it (i.e., coordinate system, extent, resolution).
...	additional arguments passed to <a href="#">fast_extract()</a> for extracting and calculating the conductance values for each planning unit. These arguments are only used if argument to x is a <a href="#">sf::sf()</a> object and argument to y is a <a href="#">terra::rast()</a> object.

**Details**

Shared boundary calculations are performed using [boundary\\_matrix\(\)](#).

**Value**

A `Matrix::dsMatrix` symmetric sparse matrix object. 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 `terra::rast()` object, then cells with missing (NA) values are set to zero too.

**See Also**

Connectivity matrix data might need rescaling to improve optimization performance, see `rescale_matrix()` to perform these calculations.

**Examples**

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()

# create connectivity matrix using raster planning unit data using
# the raster cost values to represent conductance
## extract 9 planning units
r <- terra::crop(sim_pu_raster, terra::ext(c(0, 0.3, 0, 0.3)))

## extract conductance data for the 9 planning units
cd <- terra::crop(sim_features, r)

## make connectivity matrix using the habitat suitability data for the
## second feature to represent the planning unit conductance data
cm_raster <- connectivity_matrix(r, cd[[2]])

## plot data and matrix
plot(r, main = "planning units (raster)", axes = FALSE)
plot(cd[[2]], main = "conductivity", axes = FALSE)
Matrix::image(cm_raster, main = "connectivity matrix")

# create connectivity matrix using polygon planning unit data using
# the habitat suitability data for the second feature to represent
# planning unit conductances
## subset data to 9 polygons
ply <- sim_pu_polygons[c(1:3, 11:13, 20:22), ]

## make connectivity matrix
cm_ply <- connectivity_matrix(ply, sim_features[[2]])

## plot data and matrix
plot(sf::st_geometry(ply), main = "planning units (polygons)")
plot(terra::crop(sim_features[[2]], ply), main = "connectivity")
Matrix::image(cm_ply, main = "connectivity matrix")

# create connectivity matrix using habitat suitability data for each feature,
# this could be useful if prioritizations should spatially clump
```

```

# together adjacent planning units that have suitable habitat
# for the same species (e.g., to maintain functional connectivity)

## let's use the raster data for this example, and we can generate the
## connectivity matrix that we would use in the prioritization by
## (1) generating a connectivity matrix for each feature separately, and
## and then (2) summing the values together
cm_sum <- lapply(as.list(cd), connectivity_matrix, x = r) # make matrices
cm_sum <- Reduce("+", cm_sum) # sum matrices together

## plot data and matrix
plot(r, main = "planning units (raster)", axes = FALSE)
Matrix::image(cm_sum, main = "connectivity matrix")

## we could take this example one step further, and use weights to indicate
## relative importance of maintaining functional connectivity
## for each feature (i.e., use the weighted sum instead of the sum)

## let's pretend that the first feature is 20 times more important
## than all the other species
weights <- c(20, 1, 1, 1, 1)

## calculate connectivity matrix using weighted sum
cm_wsum <- lapply(as.list(cd), connectivity_matrix, x = r) # make matrices
cm_wsum <- Map("*", cm_wsum, weights) # multiply by weights
cm_wsum <- Reduce("+", cm_wsum) # sum matrices together

## plot data and matrix
plot(r, main = "planning units (raster)", axes = FALSE)
Matrix::image(cm_wsum, main = "connectivity matrix")

## since the statistical distribution of the connectivity values
## for each feature (e.g., the mean and standard deviation of the
## connectivity values) are different, it might make sense -- depending
## on the goal of the conservation planning exercise and the underlying
## data -- to first normalize the conductance values before applying the
## weights and summing the data for feature together

### calculate functional connectivity matrix using the weighted sum of
### connectivity values that have been normalized by linearly re-scaling
### values
cm_lwsum <- lapply(as.list(cd), connectivity_matrix, x = r) # make matrices
cm_lwsum <- lapply(cm_lwsum, rescale_matrix, max = 1) # rescale matrices
cm_lwsum <- Map("*", cm_lwsum, weights) # multiply by weights
cm_lwsum <- Reduce("+", cm_lwsum) # sum matrices together

## plot data and matrix
plot(r, main = "planning units (raster)", axes = FALSE)
Matrix::image(cm_lwsum, main = "connectivity matrix")

## another approach for normalizing the data could be using z-scores
## note that after normalizing the data we would need to add a constant
## value so that none of the connectivity values are negative

```

```

### define helper functions
zscore <- function(x) {x@x <- (x@x - mean(x@x)) / sd(x@x); x}
min_non_zero_value <- function(x) min(x@x)
add_non_zero_value <- function(x, y) {x@x <- x@x + y; x}

### calculate functional connectivity matrix using the weighted sum of
### connectivity values that have been normalized using z-scores,
### and transformed to account for negative values
cm_zwsum <- lapply(as.list(cd), connectivity_matrix, x = r) # make matrices
cm_zwsum <- lapply(cm_zwsum, zscore) # normalize using z-scores
min_value <- min(sapply(cm_zwsum, min_non_zero_value)) # find min value
min_value <- abs(min_value) + 0.01 # prepare constant for adding to matrices
cm_zwsum <- lapply(cm_zwsum, add_non_zero_value, min_value) # add constant
cm_zwsum <- Map("*", cm_zwsum, weights) # multiply by weights
cm_zwsum <- Reduce("+", cm_zwsum) # sum matrices together

## plot data and matrix
plot(r, main = "planning units (raster)", axes = FALSE)
Matrix::image(cm_zwsum, main = "connectivity matrix")

## End(Not run)

```

---

ConservationModifier-class

*Conservation problem modifier class*

---

## Description

This super-class is used to construct [Objective Penalty](#), [Target](#), [Constraint](#), [Portfolio](#), [Solver](#), and [Decision](#) objects. **Only experts should use the fields and methods for this class directly.**

## Public fields

name character value.

data list containing data.

internal list containing internal computed values.

compressed\_formulation logical value indicating if the object is compatible with a compressed formulation.

## Methods

### Public methods:

- [ConservationModifier#print\(\)](#)
- [ConservationModifier\\$show\(\)](#)
- [ConservationModifier\\$repr\(\)](#)

- `ConservationModifier$calculate()`
- `ConservationModifier$get_data()`
- `ConservationModifier$set_data()`
- `ConservationModifier$get_internal()`
- `ConservationModifier$set_internal()`
- `ConservationModifier$clone()`

**Method** `print()`: Print information about the object.

*Usage:*

`ConservationModifier$print()`

*Returns:* None.

**Method** `show()`: Print information about the object.

*Usage:*

`ConservationModifier$show()`

*Returns:* None.

**Method** `repr()`: Generate a character representation of the object.

*Usage:*

`ConservationModifier$repr(compact = TRUE)`

*Arguments:*

`compact` logical value indicating if the output value should be compact? Defaults to FALSE.

*Returns:* A character value.

**Method** `calculate()`: Perform computations that need to be completed before applying the object.

*Usage:*

`ConservationModifier$calculate(x, y)`

*Arguments:*

`x` `optimization_problem()` object.

`y` `problem()` object.

*Returns:* Invisible TRUE.

**Method** `get_data()`: Get values stored in the data field.

*Usage:*

`ConservationModifier$get_data(x)`

*Arguments:*

`x` character name of data.

*Returns:* An object. If the data field does not contain an object associated with the argument to `x`, then a `new_waiver()` object is returned.

**Method** `set_data()`: Set values stored in the data field. Note that this method will overwrite existing data.

*Usage:*

```
ConservationModifier$set_data(x, value)
```

*Arguments:*

x character name of data.

value Object to store.

*Returns:* Invisible TRUE.

**Method** `get_internal()`: Get values stored in the internal field.

*Usage:*

```
ConservationModifier$get_internal(x)
```

*Arguments:*

x character name of data.

*Returns:* An object. If the internal field does not contain an object associated with the argument to x, then a [new\\_waiver\(\)](#) object is returned.

**Method** `set_internal()`: Set values stored in the internal field. Note that this method will overwrite existing data.

*Usage:*

```
ConservationModifier$set_internal(x, value)
```

*Arguments:*

x character name of data.

value Object to store.

*Returns:* An object. If the internal field does not contain an object associated with the argument to x, then a [new\\_waiver\(\)](#) object is returned.

**Method** `clone()`: The objects of this class are cloneable with this method.

*Usage:*

```
ConservationModifier$clone(deep = FALSE)
```

*Arguments:*

deep Whether to make a deep clone.

**See Also**

Other classes: [ConservationProblem-class](#), [Constraint-class](#), [Decision-class](#), [Objective-class](#), [OptimizationProblem-class](#), [Penalty-class](#), [Portfolio-class](#), [Solver-class](#), [Target-class](#)

---

ConservationProblem-class

*Conservation problem class*

---

## Description

This class is used to represent conservation planning problems. It stores the data (e.g., planning units, and features) and mathematical formulation (e.g., the objective, constraints, and other design criteria) needed to generate prioritizations. Most users should use `problem()` to generate new conservation problem objects, and the functions distributed with the package to interact with them (e.g., `number_of_features()`, `number_of_planning_units()`). **Only experts should use the fields and methods for this class directly.**

## Public fields

`data` list containing data (e.g., planning units, costs).

`defaults` list indicating if other fields contain defaults.

`objective` `Objective` object specifying the objective function for the problem formulation.

`decisions` `Decision` object specifying the decision types for the problem formulation.

`targets` `Target` object specifying the representation targets for the problem formulation.

`constraints` list containing `Constraint` objects that specify constraints for the problem formulation.

`penalties` list containing `Penalty` objects that specify penalties for the problem formulation.

`portfolio` `Portfolio` object specifying the approach for generating multiple solutions.

`solver` `Solver` object specifying the solver for generating solutions.

## Methods

### Public methods:

- `ConservationProblem$new()`
- `ConservationProblem$summary()`
- `ConservationProblem$print()`
- `ConservationProblem$show()`
- `ConservationProblem$repr()`
- `ConservationProblem$get_data()`
- `ConservationProblem$set_data()`
- `ConservationProblem$number_of_planning_units()`
- `ConservationProblem$planning_unit_indices()`
- `ConservationProblem$planning_unit_indices_with_finite_costs()`
- `ConservationProblem$set_planning_unit_indices_with_finite_costs()`
- `ConservationProblem$number_of_total_units()`
- `ConservationProblem$planning_unit_costs()`



- `ConservationProblem$set_planning_unit_costs()`
- `ConservationProblem$number_of_features()`
- `ConservationProblem$feature_names()`
- `ConservationProblem$feature_abundances_in_planning_units()`
- `ConservationProblem$set_feature_abundances_in_planning_units()`
- `ConservationProblem$feature_positive_abundances_in_planning_units()`
- `ConservationProblem$set_feature_positive_abundances_in_planning_units()`
- `ConservationProblem$feature_abundances_in_total_units()`
- `ConservationProblem$feature_targets()`
- `ConservationProblem$has_negative_feature_data()`
- `ConservationProblem$number_of_zones()`
- `ConservationProblem$zone_names()`
- `ConservationProblem$add_portfolio()`
- `ConservationProblem$add_solver()`
- `ConservationProblem$add_targets()`
- `ConservationProblem$add_objective()`
- `ConservationProblem$add_decisions()`
- `ConservationProblem$add_constraint()`
- `ConservationProblem$add_penalty()`
- `ConservationProblem$clone()`

**Method** `new()`: Create a new conservation problem object.

*Usage:*

```
ConservationProblem$new(data = list())
```

*Arguments:*

`data` list containing data

*Returns:* A new `ConservationProblem` object.

**Method** `summary()`: Print extended information about the object.

*Usage:*

```
ConservationProblem$summary()
```

*Returns:* Invisible TRUE.

**Method** `print()`: Print concise information about the object.

*Usage:*

```
ConservationProblem$print()
```

*Returns:* Invisible TRUE.

**Method** `show()`: Display concise information about the object.

*Usage:*

```
ConservationProblem$show()
```

*Returns:* Invisible TRUE.

**Method** repr(): Generate a character representation of the object.

*Usage:*

```
ConservationProblem$repr()
```

*Returns:* A character value.

**Method** get\_data(): Get values stored in the data field.

*Usage:*

```
ConservationProblem$get_data(x)
```

*Arguments:*

x character name of data.

*Returns:* An object. If the data field does not contain an object associated with the argument to x, then a [new\\_waiver\(\)](#) object is returned.

**Method** set\_data(): Set values stored in the data field. Note that this method will overwrite existing data.

*Usage:*

```
ConservationProblem$set_data(x, value)
```

*Arguments:*

x character name of data.

value Object to store.

*Returns:* Invisible TRUE.

**Method** number\_of\_planning\_units(): Obtain the number of planning units. The planning units correspond to elements in the cost data (e.g., indices, rows, geometries, pixels) that have finite values in at least one zone. In other words, planning unit are elements in the cost data that do not have missing (NA) values in every zone.

*Usage:*

```
ConservationProblem$number_of_planning_units()
```

*Returns:* An integer value.

**Method** planning\_unit\_indices(): Obtain the planning unit indices.

*Usage:*

```
ConservationProblem$planning_unit_indices()
```

*Returns:* An integer vector.

**Method** planning\_unit\_indices\_with\_finite\_costs(): Obtain the planning unit indices that are associated with finite cost values.

*Usage:*

```
ConservationProblem$planning_unit_indices_with_finite_costs()
```

*Returns:* A list of integer vectors. Each list element corresponds to a different zone.

**Method** set\_planning\_unit\_indices\_with\_finite\_costs(): Perform calculations to cache the planning unit indices that are associated with finite cost values.

*Usage:*

```
ConservationProblem$set_planning_unit_indices_with_finite_costs()
```

*Returns:* Invisible TRUE.

**Method** `number_of_total_units()`: Obtain the number of total units. The total units include all elements in the cost data (e.g., indices, rows, geometries, pixels), including those with missing (NA) values.

*Usage:*

```
ConservationProblem$number_of_total_units()
```

*Returns:* An integer value.

**Method** `planning_unit_costs()`: Obtain the planning unit costs.

*Usage:*

```
ConservationProblem$planning_unit_costs()
```

*Returns:* A numeric matrix.

**Method** `set_planning_unit_costs()`: Perform calculations to cache the planning unit costs.

*Usage:*

```
ConservationProblem$set_planning_unit_costs()
```

*Returns:* Invisible TRUE.

**Method** `number_of_features()`: Obtain the number of features.

*Usage:*

```
ConservationProblem$number_of_features()
```

*Returns:* An integer value.

**Method** `feature_names()`: Obtain the names of the features.

*Usage:*

```
ConservationProblem$feature_names()
```

*Returns:* A character vector.

**Method** `feature_abundances_in_planning_units()`: Obtain the abundance of the features in the planning units.

*Usage:*

```
ConservationProblem$feature_abundances_in_planning_units()
```

*Returns:* A numeric matrix. Each column corresponds to a different zone and each row corresponds to a different feature.

**Method** `set_feature_abundances_in_planning_units()`: Perform calculations to cache the abundance of the features in the planning units.

*Usage:*

```
ConservationProblem$set_feature_abundances_in_planning_units()
```

*Returns:* Invisible TRUE.

**Method** `feature_positive_abundances_in_planning_units()`: Obtain the positive abundance of the features in the planning units. Note that this method, unlike `feature_abundances_in_planning_units`,

*Usage:*

```
ConservationProblem$feature_positive_abundances_in_planning_units()
```

*Returns:* A numeric matrix. Each column corresponds to a different zone and each row corresponds to a different feature.

**Method** `set_feature_positive_abundances_in_planning_units()`: Perform calculations to cache the positive abundance of the features in the planning units.

*Usage:*

```
ConservationProblem$set_feature_positive_abundances_in_planning_units()
```

*Returns:* Invisible TRUE.

**Method** `feature_abundances_in_total_units()`: Obtain the abundance of the features in the total units.

*Usage:*

```
ConservationProblem$feature_abundances_in_total_units()
```

*Returns:* A numeric matrix. Each column corresponds to a different zone and each row corresponds to a different feature.

**Method** `feature_targets()`: Obtain the representation targets for the features.

*Usage:*

```
ConservationProblem$feature_targets()
```

*Returns:* A `tibble::tibble()` data frame.

**Method** `has_negative_feature_data()`: See if the feature data contain any negative values.

*Usage:*

```
ConservationProblem$has_negative_feature_data()
```

*Returns:* A logical value.

**Method** `number_of_zones()`: Obtain the number of zones.

*Usage:*

```
ConservationProblem$number_of_zones()
```

*Returns:* An integer value.

**Method** `zone_names()`: Obtain the zone names.

*Usage:*

```
ConservationProblem$zone_names()
```

*Returns:* A character vector.

**Method** `add_portfolio()`: Create a new object with a portfolio added to the problem formulation.

*Usage:*

```
ConservationProblem$add_portfolio(x)
```

*Arguments:*

x [Portfolio](#) object.

*Returns:* An updated ConservationProblem object.

**Method** `add_solver()`: Create a new object with a solver added to the problem formulation.

*Usage:*

`ConservationProblem$add_solver(x)`

*Arguments:*

x [Solver](#) object.

*Returns:* An updated ConservationProblem object.

**Method** `add_targets()`: Create a new object with targets added to the problem formulation.

*Usage:*

`ConservationProblem$add_targets(x)`

*Arguments:*

x [Target](#) object.

*Returns:* An updated ConservationProblem object.

**Method** `add_objective()`: Create a new object with an objective added to the problem formulation.

*Usage:*

`ConservationProblem$add_objective(x)`

*Arguments:*

x [Objective](#) object.

*Returns:* An updated ConservationProblem object.

**Method** `add_decisions()`: Create a new object with decisions added to the problem formulation.

*Usage:*

`ConservationProblem$add_decisions(x)`

*Arguments:*

x [Decision](#) object.

*Returns:* An updated ConservationProblem object.

**Method** `add_constraint()`: Create a new object with a constraint added to the problem formulation.

*Usage:*

`ConservationProblem$add_constraint(x)`

*Arguments:*

x [Constraint](#) object.

*Returns:* An updated ConservationProblem object.

**Method** `add_penalty()`: Create a new object with a penalty added to the problem formulation.

*Usage:*

`ConservationProblem$add_penalty(x)`

*Arguments:*

x [Penalty](#) object.

*Returns:* An updated `ConservationProblem` object.

**Method** `clone()`: The objects of this class are cloneable with this method.

*Usage:*

`ConservationProblem$clone(deep = FALSE)`

*Arguments:*

deep Whether to make a deep clone.

### See Also

Other classes: [ConservationModifier-class](#), [Constraint-class](#), [Decision-class](#), [Objective-class](#), [OptimizationProblem-class](#), [Penalty-class](#), [Portfolio-class](#), [Solver-class](#), [Target-class](#)

---

Constraint-class	<i>Constraint class</i>
------------------	-------------------------

---

### Description

This class is used to represent the constraints used in optimization. **Only experts should use the fields and methods for this class directly.**

### Super class

`prioritizr::ConservationModifier` -> `Constraint`

### Methods

#### Public methods:

- [Constraint\\$apply\(\)](#)
- [Constraint\\$clone\(\)](#)

**Method** `apply()`: Update an optimization problem formulation.

*Usage:*

`Constraint$apply(x)`

*Arguments:*

x `optimization_problem()` object.

*Returns:* Invisible TRUE.

**Method** `clone()`: The objects of this class are cloneable with this method.

*Usage:*

`Constraint$clone(deep = FALSE)`

*Arguments:*

deep Whether to make a deep clone.

**See Also**

Other classes: [ConservationModifier-class](#), [ConservationProblem-class](#), [Decision-class](#), [Objective-class](#), [OptimizationProblem-class](#), [Penalty-class](#), [Portfolio-class](#), [Solver-class](#), [Target-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 a 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\\_linear\\_constraints\(\)](#) Add constraints to ensure that all selected planning units meet certain criteria. For example, they can be used to add multiple budgets, or limit the number of planning units selected in different administrative areas within a study region (e.g., different countries).

[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**

Other overviews: [decisions](#), [importance](#), [objectives](#), [penalties](#), [portfolios](#), [solvers](#), [summaries](#), [targets](#)

**Examples**

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_locked_in_raster <- get_sim_locked_in_raster()
sim_locked_out_raster <- get_sim_locked_in_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() %>%
  add_default_solver(verbose = FALSE)

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

# create problem with locked in 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 <- terra::rast(lapply(list(p1, p2, p3, p4, p5, p6), solve))
names(s) <- c(
  "minimal problem", "locked in", "locked out",
  "neighbor", "contiguity", "feature contiguity"
)

# plot solutions
plot(s, axes = FALSE, nr = 2)

## End(Not run)
```



**Description**

This class is used to represent the decision variables used in optimization. **Only experts should use the fields and methods for this class directly.**

**Super class**

`prioritizr::ConservationModifier` -> Decision

**Methods****Public methods:**

- `Decision$apply()`
- `Decision$clone()`

**Method** `apply()`: Update an optimization problem formulation.

*Usage:*

`Decision$apply(x)`

*Arguments:*

x `optimization_problem()` object.

*Returns:* Invisible TRUE.

**Method** `clone()`: The objects of this class are cloneable with this method.

*Usage:*

`Decision$clone(deep = FALSE)`

*Arguments:*

deep Whether to make a deep clone.

**See Also**

Other classes: [ConservationModifier-class](#), [ConservationProblem-class](#), [Constraint-class](#), [Objective-class](#), [OptimizationProblem-class](#), [Penalty-class](#), [Portfolio-class](#), [Solver-class](#), [Target-class](#)

---

decisions

*Add decision types*

---

**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()`. Note that if multiple decisions are added to a problem, then the last one 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.

## See Also

Other overviews: [constraints](#), [importance](#), [objectives](#), [penalties](#), [portfolios](#), [solvers](#), [summaries](#), [targets](#)

## Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()

# create basic problem and using the default decision types (binary)
p1 <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_default_solver(verbose = FALSE)

# create problem with manually specified binary decisions
p2 <- p1 %>% add_binary_decisions()

# create problem with proportion decisions
p3 <- p1 %>% add_proportion_decisions()

# create problem with semicontinuous decisions
p4 <- p1 %>% add_semicontinuous_decisions(upper_limit = 0.5)
```

```

# solve problem
s <- c(solve(p1), solve(p2), solve(p3), solve(p4))
names(s) <- c(
  "default (binary)", "binary", "proportion", "semicontinuous (upper = 0.5)"
)
# plot solutions
plot(s)

## End(Not run)

```

---

```
eval_asym_connectivity_summary
```

*Evaluate asymmetric connectivity of solution*

---

## Description

Calculate the connectivity held within a solution to a conservation planning problem. This summary statistic evaluates the connectivity of a solution using pair-wise connectivity values between combinations of planning units. It is specifically designed for asymmetric connectivity data.

## Usage

```

## S4 method for signature 'ConservationProblem,ANY,ANY,matrix'
eval_asym_connectivity_summary(x, solution, zones, data)

## S4 method for signature 'ConservationProblem,ANY,ANY,Matrix'
eval_asym_connectivity_summary(x, solution, zones, data)

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

## S4 method for signature 'ConservationProblem,ANY,ANY,dgCMatrix'
eval_asym_connectivity_summary(x, solution, zones, data)

## S4 method for signature 'ConservationProblem,ANY,ANY,array'
eval_asym_connectivity_summary(x, solution, zones, data)

```

## Arguments

x	<code>problem()</code> object.
solution	numeric, matrix, data.frame, <code>terra::rast()</code> , or <code>sf::sf()</code> object. The argument should be in the same format as the planning unit cost data in the argument to x. See the Solution format section for more information.
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 working with multiple zones and the argument to `data` is a `matrix` or `Matrix` object. If the argument to `data` is an array or `data.frame` with data for multiple zones (e.g., using the "zone1" and "zone2" column names), 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 Data format section for more information.

### Details

This summary statistic is comparable to the Connectivity metric reported by the *Marxan software* (Ball *et al.* 2009). It is calculated using the same equations used to penalize solutions with asymmetric connectivity data (i.e., `add_asym_connectivity_penalties()`). Specifically, it is calculated as the sum of the connectivity values (in the argument to `data`) that correspond pairs of planning units, wherein one planning unit is selected by the solution and the other planning unit is not selected by solution.

### Value

A `tibble::tibble()` object describing the connectivity of the solution. It contains the following columns:

**summary** character description of the summary statistic. The statistic associated with the "overall" value in this column is calculated using the entire solution (including all management zones if there are multiple zones). If multiple management zones are present, then summary statistics are also provided for each zone separately (indicated using zone names).

**asym\_connectivity** numeric connectivity value. Greater values correspond to solutions associated with greater connectivity. Thus conservation planning exercises typically prefer solutions with greater values.

### Solution format

Broadly speaking, the argument to `solution` must be in the same format as the planning unit data in the argument to `x`. Further details on the correct format are listed separately for each of the different planning unit data formats:

**x has numeric planning units** The argument to `solution` must be a numeric vector with each element corresponding to a different planning unit. It should have the same number of planning units as those in the argument to `x`. Additionally, any planning units missing cost (NA) values should also have missing (NA) values in the argument to `solution`.

- x **has matrix planning units** The argument to `solution` must be a `matrix` vector with each row corresponding to a different planning unit, and each column correspond to a different management zone. It should have the same number of planning units and zones as those in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have a missing (NA) values in the argument to `solution`.
- x **has `terra::rast()` planning units** The argument to `solution` be a `terra::rast()` object where different grid cells (pixels) correspond to different planning units and layers correspond to a different management zones. It should have the same dimensionality (rows, columns, layers), resolution, extent, and coordinate reference system as the planning units in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- x **has `data.frame` planning units** The argument to `solution` must be a `data.frame` with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if a `data.frame` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example with `sf::sf()` data). Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- x **has `sf::sf()` planning units** The argument to `solution` must be a `sf::sf()` object with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if the `sf::sf()` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example). Additionally, the argument to `solution` must also have the same coordinate reference system as the planning unit data. Furthermore, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.

## Data format

The argument to `data` can be specified using several different formats.

- `data` **as a `matrix/Matrix` object** 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` **as a `data.frame` object** containing columns that are named "id1", "id2", and "boundary". Here, each row denotes the connectivity between a pair of planning units (per values in the "id1" and "id2" columns) following the *Marxan* format. If the argument to `x` contains multiple zones, then the "zone1" and "zone2" columns can optionally be provided to manually specify the connectivity values between planning units when they are allocated to specific zones. If the "zone1" and "zone2" columns are present, then the argument to `zones` must be `NULL`.
- `data` **as an array object** 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.

## References

Ball IR, Possingham HP, and Watts M (2009) *Marxan and relatives: Software for spatial conservation prioritisation* in Spatial conservation prioritisation: Quantitative methods and computational tools. Eds Moilanen A, Wilson KA, and Possingham HP. Oxford University Press, Oxford, UK.

## See Also

See [summaries](#) for an overview of all functions for summarizing solutions. Also, see [add\\_asym\\_connectivity\\_penalties\(\)](#) to penalize solutions with low asymmetric connectivity.

Other summaries: [eval\\_boundary\\_summary\(\)](#), [eval\\_connectivity\\_summary\(\)](#), [eval\\_cost\\_summary\(\)](#), [eval\\_feature\\_representation\\_summary\(\)](#), [eval\\_n\\_summary\(\)](#), [eval\\_target\\_coverage\\_summary\(\)](#)

## Examples

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()
sim_zones_pu_polygons <- get_sim_zones_pu_polygons()
sim_zones_features <- get_sim_zones_features()

# build minimal conservation problem with polygon data
p1 <-
  problem(sim_pu_polygons, sim_features, cost_column = "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve the problem
s1 <- solve(p1)

# print solution
print(s1)

# plot solution
plot(s1[, "solution_1"])

# simulate connectivity matrix
# here, we will generate connectivity values randomly
# between all pairs of planning units
```

```
acm1 <- matrix(
  runif(nrow(sim_pu_polygons) ^ 2),
  nrow = nrow(sim_pu_polygons)
)

# calculate connectivity associated with the solution
r1 <- eval_asym_connectivity_summary(p1, s1[, "solution_1"], data = acm1)
print(r1)

# build multi-zone conservation problem with polygon data
p2 <-
  problem(
    sim_zones_pu_polygons, sim_zones_features,
    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() %>%
  add_default_solver(verbose = FALSE)

# solve the problem
s2 <- solve(p2)

# print solution
print(s2)

# create new column representing the zone id that each planning unit
# was allocated to in the solution
s2$solution <- category_vector(
  s2[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
)
s2$solution <- factor(s2$solution)

# plot solution
plot(s2[, "solution"])

# simulate asymmetric connectivity matrix
acm2 <- matrix(
  runif(nrow(sim_zones_pu_polygons) ^ 2),
  nrow = nrow(sim_zones_pu_polygons)
)

# calculate connectivity associated with the solution
r2 <- eval_asym_connectivity_summary(
  p2,
  s2[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")],
  data = acm2
)
print(r2)

## End(Not run)
```

---

eval\_boundary\_summary *Evaluate boundary length of solution*

---

### Description

Calculate the exposed boundary length (i.e., perimeter) associated with a solution to a conservation planning problem. This summary statistic is useful for evaluating the spatial fragmentation of planning units selected within a solution.

### Usage

```
eval_boundary_summary(
  x,
  solution,
  edge_factor = rep(0.5, number_of_zones(x)),
  zones = diag(number_of_zones(x)),
  data = NULL
)
```

### Arguments

x	<code>problem()</code> object.
solution	numeric, matrix, data.frame, <code>terra::rast()</code> , or <code>sf::sf()</code> object. The argument should be in the same format as the planning unit cost data in the argument to x. See the Solution format section for more information.
edge_factor	numeric proportion to scale planning unit edges (borders) that do not have any neighboring planning units. For example, an edge factor of 0.5 is commonly used to avoid overly penalizing planning units along a coastline. 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 combination 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 range 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. If the cells along the matrix diagonal contain markedly smaller values than those found elsewhere in the matrix, then solutions are preferred that surround planning units with those allocated to different zones (i.e., greater spatial fragmentation).
data	NULL, data.frame, matrix, or Matrix object containing the boundary data. These data describe the total amount of boundary (perimeter) length for each planning unit, and the amount of boundary (perimeter) length shared between different planning units (i.e., planning units that are adjacent to each other). See the Data format section for more information.



## Details

This summary statistic is equivalent to the `Connectivity_Edge` metric reported by the *Marxan software* (Ball *et al.* 2009). It is calculated using the same equations used to penalize solutions according to their total exposed boundary (i.e., `add_boundary_penalties()`). See the Examples section for examples on how differences zone arguments can be used to calculate boundaries for different combinations of zones.

## Value

A `tibble::tibble()` object containing the boundary length of the solution. It contains the following columns:

**summary** character description of the summary statistic. The statistic associated with the "overall" value in this column is calculated using the entire solution (including all management zones if there are multiple zones). If multiple management zones are present, then summary statistics are also provided for each zone separately (indicated using zone names).

**boundary** numeric exposed boundary length value. Greater values correspond to solutions with greater boundary length and, in turn, greater spatial fragmentation. Thus conservation planning exercises typically prefer solutions with smaller values.

## Data format

The argument to `data` can be specified using the following formats. Note that boundary data must always describe symmetric relationships between planning units.

`data` **as a NULL value** indicating that the data should be automatically calculated using the `boundary_matrix()` function. This argument is the default. Note that the boundary data must be supplied using one of the other formats below if the planning unit data in the argument to `x` do not explicitly contain spatial information (e.g., planning unit data are a `data.frame` or `numeric` class).

`data` **as a matrix/Matrix object** 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 denote the total boundary length associated with each planning unit.

`data` **as a data.frame object** with the columns "id1", "id2", and "boundary". The "id1" and "id2" columns contain identifiers (indices) for a pair of planning units, and the "boundary" column contains the amount of shared boundary length between these two planning units. Additionally, if the values in the "id1" and "id2" columns contain the same values, then the value denotes the amount of exposed boundary length (not total boundary). This format follows the standard *Marxan* format for boundary data (i.e., per the "bound.dat" file).

## Solution format

Broadly speaking, the argument to `solution` must be in the same format as the planning unit data in the argument to `x`. Further details on the correct format are listed separately for each of the different planning unit data formats:

`x` **has numeric planning units** The argument to `solution` must be a numeric vector with each element corresponding to a different planning unit. It should have the same number of planning

units as those in the argument to `x`. Additionally, any planning units missing cost (NA) values should also have missing (NA) values in the argument to `solution`.

- x has matrix `planning units`** The argument to `solution` must be a `matrix` vector with each row corresponding to a different planning unit, and each column correspond to a different management zone. It should have the same number of planning units and zones as those in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have a missing (NA) values in the argument to `solution`.
- x has `terra::rast()` `planning units`** The argument to `solution` be a `terra::rast()` object where different grid cells (pixels) correspond to different planning units and layers correspond to a different management zones. It should have the same dimensionality (rows, columns, layers), resolution, extent, and coordinate reference system as the planning units in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- x has `data.frame` `planning units`** The argument to `solution` must be a `data.frame` with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if a `data.frame` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example with `sf::sf()` data). Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- x has `sf::sf()` `planning units`** The argument to `solution` must be a `sf::sf()` object with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if the `sf::sf()` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example). Additionally, the argument to `solution` must also have the same coordinate reference system as the planning unit data. Furthermore, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.

## References

Ball IR, Possingham HP, and Watts M (2009) *Marxan and relatives: Software for spatial conservation prioritisation* in Spatial conservation prioritisation: Quantitative methods and computational tools. Eds Moilanen A, Wilson KA, and Possingham HP. Oxford University Press, Oxford, UK.

## See Also

See [summaries](#) for an overview of all functions for summarizing solutions. Also, see [add\\_boundary\\_penalties\(\)](#) to penalize solutions with high boundary length.

Other summaries: [eval\\_asym\\_connectivity\\_summary\(\)](#), [eval\\_connectivity\\_summary\(\)](#), [eval\\_cost\\_summary\(\)](#), [eval\\_feature\\_representation\\_summary\(\)](#), [eval\\_n\\_summary\(\)](#), [eval\\_target\\_coverage\\_summary\(\)](#)

## Examples

```
## Not run:
# set seed for reproducibility
set.seed(500)
```

```
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()
sim_zones_pu_polygons <- get_sim_zones_pu_polygons()
sim_zones_features <- get_sim_zones_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(verbose = FALSE)

# solve the problem
s1 <- solve(p1)

# print solution
print(s1)

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

# calculate boundary associated with the solution
r1 <- eval_boundary_summary(p1, s1)
print(r1)

# build minimal conservation problem with polygon data
p2 <-
  problem(sim_pu_polygons, sim_features, cost_column = "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve the problem
s2 <- solve(p2)

# print solution
print(s2)

# plot solution
plot(s2[, "solution_1"])

# calculate boundary associated with the solution
r2 <- eval_boundary_summary(p2, s2[, "solution_1"])
print(r2)

# build multi-zone conservation problem with polygon data
p3 <-
  problem(
    sim_zones_pu_polygons, sim_zones_features,
```

```

    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() %>%
  add_default_solver(verbose = FALSE)

# solve the problem
s3 <- solve(p3)

# print solution
print(s3)

# create new column representing the zone id that each planning unit
# was allocated to in the solution
s3$solution <- category_vector(
  s3[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
)
s3$solution <- factor(s3$solution)

# plot solution
plot(s3[, "solution"])

# calculate boundary associated with the solution
# here we will use the default argument for zones which treats each
# zone as completely separate, meaning that the "overall"
# boundary is just the sum of the boundaries for each zone
r3 <- eval_boundary_summary(
  p3, s3[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
)
print(r3)

# let's calculate the overall exposed boundary across the entire
# solution, assuming that the shared boundaries between planning
# units allocated to different zones "count" just as much
# as those for planning units allocated to the same zone

# in other words, let's calculate the overall exposed boundary
# across the entire solution by "combining" all selected planning units
# together (regardless of which zone they are allocated to in the solution)
r3_combined <- eval_boundary_summary(
  p3, zones = matrix(1, ncol = 3, nrow = 3),
  s3[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
)
print(r3_combined)

# we can see that the "overall" boundary is now less than the
# sum of the individual zone boundaries, because it does not
# consider the shared boundary between two planning units allocated to
# different zones as "exposed" when performing the calculations

## End(Not run)

```

---

 eval\_connectivity\_summary

*Evaluate connectivity of solution*


---

## Description

Calculate the connectivity held within a solution to a conservation planning problem. This summary statistic evaluates the connectivity of a solution using pair-wise connectivity values between combinations of planning units. It is specifically designed for symmetric connectivity data.

## Usage

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

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

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

```
## S4 method for signature 'ConservationProblem,ANY,ANY,dgCMatrix'
eval_connectivity_summary(x, solution, zones, data)
```

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

## Arguments

x	<code>problem()</code> object.
solution	numeric, matrix, data.frame, <code>terra::rast()</code> , or <code>sf::sf()</code> object. The argument should be in the same format as the planning unit cost data in the argument to x. See the Solution format section for more information.
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 working with multiple zones and the argument to data is a matrix or Matrix object. If the argument to data is an array or data.frame with data for multiple zones (e.g., using the "zone1" and "zone2" column names), 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 Data format section for more information.

### Details

This summary statistic is comparable to the Connectivity\_In metric reported by the *Marxan software* (Ball *et al.* 2009). It is calculated using the same equations used to penalize solutions with connectivity data (i.e., `add_connectivity_penalties()`). Specifically, it is calculated as the sum of the pair-wise connectivity values in the argument to `data`, weighted by the value of the planning units in the solution.

### Value

A `tibble::tibble()` object describing the connectivity of the solution. It contains the following columns:

**summary** character description of the summary statistic. The statistic associated with the "overall" value in this column is calculated using the entire solution (including all management zones if there are multiple zones). If multiple management zones are present, then summary statistics are also provided for each zone separately (indicated using zone names).

**connectivity** numeric connectivity value. Greater values correspond to solutions associated with greater connectivity. Thus conservation planning exercises typically prefer solutions with greater values.

### Solution format

Broadly speaking, the argument to `solution` must be in the same format as the planning unit data in the argument to `x`. Further details on the correct format are listed separately for each of the different planning unit data formats:

- x has numeric planning units** The argument to `solution` must be a numeric vector with each element corresponding to a different planning unit. It should have the same number of planning units as those in the argument to `x`. Additionally, any planning units missing cost (NA) values should also have missing (NA) values in the argument to `solution`.
- x has matrix planning units** The argument to `solution` must be a matrix vector with each row corresponding to a different planning unit, and each column correspond to a different management zone. It should have the same number of planning units and zones as those in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have a missing (NA) values in the argument to `solution`.
- x has terra::rast() planning units** The argument to `solution` be a `terra::rast()` object where different grid cells (pixels) correspond to different planning units and layers correspond to a different management zones. It should have the same dimensionality (rows, columns, layers), resolution, extent, and coordinate reference system as the planning units in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.

- x has **data.frame** **planning units** The argument to `solution` must be a `data.frame` with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if a `data.frame` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example with `sf::sf()` data). Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- x has **sf::sf()** **planning units** The argument to `solution` must be a `sf::sf()` object with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if the `sf::sf()` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example). Additionally, the argument to `solution` must also have the same coordinate reference system as the planning unit data. Furthermore, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.

### Data format

The argument to `data` can be specified using several different formats.

**data as a matrix/Matrix object** 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 as a data.frame object** containing columns that are named "id1", "id2", and "boundary". Here, each row denotes the connectivity between a pair of planning units (per values in the "id1" and "id2" columns) following the *Marxan* format. If the argument to `x` contains multiple zones, then the "zone1" and "zone2" columns can optionally be provided to manually specify the connectivity values between planning units when they are allocated to specific zones. If the "zone1" and "zone2" columns are present, then the argument to `zones` must be NULL.

**data as an array object** 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.

### References

Ball IR, Possingham HP, and Watts M (2009) *Marxan and relatives: Software for spatial conservation prioritisation* in *Spatial conservation prioritisation: Quantitative methods and computational tools*. Eds Moilanen A, Wilson KA, and Possingham HP. Oxford University Press, Oxford, UK.

**See Also**

See [summaries](#) for an overview of all functions for summarizing solutions. Also, see [add\\_connectivity\\_penalties\(\)](#) to penalize solutions with low connectivity.

Other summaries: [eval\\_asym\\_connectivity\\_summary\(\)](#), [eval\\_boundary\\_summary\(\)](#), [eval\\_cost\\_summary\(\)](#), [eval\\_feature\\_representation\\_summary\(\)](#), [eval\\_n\\_summary\(\)](#), [eval\\_target\\_coverage\\_summary\(\)](#)

**Examples**

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_polygons <- get_sim_zones_pu_polygons()
sim_zones_features <- get_sim_zones_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(verbose = FALSE)

# solve the problem
s1 <- solve(p1)

# print solution
print(s1)

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

# simulate a connectivity matrix to describe the relative strength
# of connectivity between different planning units
# for brevity, we will use cost data here so that pairs
# of adjacent planning units with higher cost values will have a
# higher connectivity value
# (but see ?connectivity_matrix for more information)
cm1 <- connectivity_matrix(sim_pu_raster, sim_pu_raster)

# calculate connectivity associated with the solution
r1 <- eval_connectivity_summary(p1, s1, data = cm1)
print(r1)

# build multi-zone conservation problem with polygon data
p2 <-
  problem(
    sim_zones_pu_polygons, sim_zones_features,
```



```

    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() %>%
  add_default_solver(verbose = FALSE)

# solve the problem
s2 <- solve(p2)

# print solution
print(s2)

# create new column representing the zone id that each planning unit
# was allocated to in the solution
s2$solution <- category_vector(
  s2[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
)
s2$solution <- factor(s2$solution)

# plot solution
plot(s2[, "solution"])

# simulate connectivity matrix
# here, we will add a new column to sim_zones_pu_polygons with
# randomly simulated values and create a connectivity matrix
# based on the average simulated values of adjacent planning units
sim_zones_pu_polygons$con <- runif(nrow(sim_zones_pu_polygons))
cm2 <- connectivity_matrix(sim_zones_pu_polygons, "con")

# calculate connectivity associated with the solution
r2 <- eval_connectivity_summary(
  p2, s2[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")],
  data = cm2
)
print(r2)

## End(Not run)

```

---

eval\_cost\_summary      *Evaluate cost of solution*

---

### Description

Calculate the total cost of a solution to a conservation planning problem. For example, if the planning unit cost data describe land acquisition costs (USD), then the total cost would be net cost (USD) needed to acquire all planning units selected within the solution.

**Usage**

```
eval_cost_summary(x, solution)
```

**Arguments**

`x` `problem()` object.

`solution` numeric, matrix, data.frame, `terra::rast()`, or `sf::sf()` object. The argument should be in the same format as the planning unit cost data in the argument to `x`. See the Solution format section for more information.

**Details**

This metric is equivalent to the Cost metric reported by the *Marxan software* (Ball *et al.* 2009). Specifically, the cost of a solution is defined as the sum of the cost values, supplied when creating a `problem()` object (e.g., using the `cost_column` argument), weighted by the status of each planning unit in the solution.

**Value**

A `tibble::tibble()` object containing the solution cost. It contains the following columns:

- summary** character description of the summary statistic. The statistic associated with the "overall" value in this column is calculated using the entire solution (including all management zones if there are multiple zones). If multiple management zones are present, then summary statistics are also provided for each zone separately (indicated using zone names).
- cost** numeric cost value. Greater values correspond to solutions that are more costly to implement. Thus conservation planning exercises typically prefer solutions with smaller values, because they are cheaper to implement (assuming all other relevant factors, such as feature representation, are equal).

**Solution format**

Broadly speaking, the argument to `solution` must be in the same format as the planning unit data in the argument to `x`. Further details on the correct format are listed separately for each of the different planning unit data formats:

- x has numeric `planning units`** The argument to `solution` must be a numeric vector with each element corresponding to a different planning unit. It should have the same number of planning units as those in the argument to `x`. Additionally, any planning units missing cost (NA) values should also have missing (NA) values in the argument to `solution`.
- x has matrix `planning units`** The argument to `solution` must be a matrix vector with each row corresponding to a different planning unit, and each column correspond to a different management zone. It should have the same number of planning units and zones as those in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have a missing (NA) values in the argument to `solution`.
- x has `terra::rast()` `planning units`** The argument to `solution` be a `terra::rast()` object where different grid cells (pixels) correspond to different planning units and layers correspond to a different management zones. It should have the same dimensionality (rows, columns, layers),

resolution, extent, and coordinate reference system as the planning units in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.

- x **has** `data.frame` **planning units** The argument to `solution` must be a `data.frame` with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if a `data.frame` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example with `sf::sf()` data). Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- x **has** `sf::sf()` **planning units** The argument to `solution` must be a `sf::sf()` object with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if the `sf::sf()` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example). Additionally, the argument to `solution` must also have the same coordinate reference system as the planning unit data. Furthermore, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.

## References

Ball IR, Possingham HP, and Watts M (2009) *Marxan and relatives: Software for spatial conservation prioritisation* in Spatial conservation prioritisation: Quantitative methods and computational tools. Eds Moilanen A, Wilson KA, and Possingham HP. Oxford University Press, Oxford, UK.

## See Also

See [summaries](#) for an overview of all functions for summarizing solutions.

Other summaries: [eval\\_asym\\_connectivity\\_summary\(\)](#), [eval\\_boundary\\_summary\(\)](#), [eval\\_connectivity\\_summary\(\)](#), [eval\\_feature\\_representation\\_summary\(\)](#), [eval\\_n\\_summary\(\)](#), [eval\\_target\\_coverage\\_summary\(\)](#)

## Examples

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()
sim_zones_pu_polygons <- get_sim_zones_pu_polygons()
sim_zones_features <- get_sim_zones_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(verbose = FALSE)

# solve the problem
s1 <- solve(p1)

# print solution
print(s1)

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

# calculate cost of the solution
r1 <- eval_cost_summary(p1, s1)
print(r1)

# build minimal conservation problem with polygon data
p2 <-
  problem(sim_pu_polygons, sim_features, cost_column = "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve the problem
s2 <- solve(p2)

# plot solution
plot(s2[, "solution_1"])

# print solution
print(s2)

# calculate cost of the solution
r2 <- eval_cost_summary(p2, s2[, "solution_1"])
print(r2)

# manually calculate cost of the solution
r2_manual <- sum(s2$solution_1 * sim_pu_polygons$cost, na.rm = TRUE)
print(r2_manual)

# build multi-zone conservation problem with polygon data
p3 <-
  problem(
    sim_zones_pu_polygons, sim_zones_features,
    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() %>%
  add_default_solver(verbose = FALSE)

# solve the problem
s3 <- solve(p3)
```

```

# print solution
print(s3)

# create new column representing the zone id that each planning unit
# was allocated to in the solution
s3$solution <- category_vector(
  s3[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
)
s3$solution <- factor(s3$solution)

# plot solution
plot(s3[, "solution"])

# calculate cost of the solution
r3 <- eval_cost_summary(
  p3, s3[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
)
print(r3)

## End(Not run)

```

---

```
eval_feature_representation_summary
```

*Evaluate feature representation by solution*

---

## Description

Calculate how well features are represented by a solution to a conservation planning problem. These summary statistics are reported for each and every feature, and each and every zone, within a conservation planning problem.

## Usage

```
eval_feature_representation_summary(x, solution)
```

## Arguments

x	<code>problem()</code> object.
solution	numeric, matrix, data.frame, <code>terra::rast()</code> , or <code>sf::sf()</code> object. The argument should be in the same format as the planning unit cost data in the argument to x. See the Solution format section for more information.

## Value

A `tibble::tibble()` object describing feature representation. Here, each row describes a specific summary statistic (e.g., different management zone) for a specific feature. It contains the following columns:

**summary** character description of the summary statistic. The statistic associated with the "overall" value in this column is calculated using the entire solution (including all management zones if there are multiple zones). If multiple management zones are present, then summary statistics are also provided for each zone separately (indicated using zone names).

**feature** character name of the feature.

**total\_amount** numeric total amount of each feature available in the entire conservation planning problem (not just planning units selected within the solution). It is calculated as the sum of the feature data, supplied when creating a `problem()` object (e.g., presence/absence values).

**absolute\_held** numeric total amount of each feature secured within the solution. It is calculated as the sum of the feature data, supplied when creating a `problem()` object (e.g., presence/absence values), weighted by the status of each planning unit in the solution (e.g., selected or not for prioritization).

**relative\_held** numeric proportion of each feature secured within the solution. It is calculated by dividing values in the "absolute\_held" column by those in the "total\_amount" column.

### Solution format

Broadly speaking, the argument to `solution` must be in the same format as the planning unit data in the argument to `x`. Further details on the correct format are listed separately for each of the different planning unit data formats:

- x **has numeric planning units** The argument to `solution` must be a numeric vector with each element corresponding to a different planning unit. It should have the same number of planning units as those in the argument to `x`. Additionally, any planning units missing cost (NA) values should also have missing (NA) values in the argument to `solution`.
- x **has matrix planning units** The argument to `solution` must be a matrix vector with each row corresponding to a different planning unit, and each column correspond to a different management zone. It should have the same number of planning units and zones as those in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have a missing (NA) values in the argument to `solution`.
- x **has `terra::rast()` planning units** The argument to `solution` be a `terra::rast()` object where different grid cells (pixels) correspond to different planning units and layers correspond to a different management zones. It should have the same dimensionality (rows, columns, layers), resolution, extent, and coordinate reference system as the planning units in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- x **has `data.frame` planning units** The argument to `solution` must be a `data.frame` with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if a `data.frame` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example with `sf::sf()` data). Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- x **has `sf::sf()` planning units** The argument to `solution` must be a `sf::sf()` object with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if the `sf::sf()` object

containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example). Additionally, the argument to solution must also have the same coordinate reference system as the planning unit data. Furthermore, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to solution.

### See Also

See [summaries](#) for an overview of all functions for summarizing solutions.

Other summaries: [eval\\_asym\\_connectivity\\_summary\(\)](#), [eval\\_boundary\\_summary\(\)](#), [eval\\_connectivity\\_summary\(\)](#), [eval\\_cost\\_summary\(\)](#), [eval\\_n\\_summary\(\)](#), [eval\\_target\\_coverage\\_summary\(\)](#)

### Examples

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_pu_polygons <- get_sim_zones_pu_polygons()
sim_zones_features <- get_sim_zones_features()

# create a simple conservation planning dataset 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
p1 <-
  problem(pu, c("spp1", "spp2"), cost_column = "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# create a solution
# specifically, a data.frame with a single column that contains
# binary values indicating if each planning units was selected or not
s1 <- data.frame(s = c(1, NA, rep(c(1, 0), 4)))
print(s1)

# calculate feature representation
r1 <- eval_feature_representation_summary(p1, s1)
print(r1)
```

```

# let's verify that feature representation calculations are correct
# by manually performing the calculations and compare the results with r1
## calculate total amount for each feature
print(
  setNames(
    c(sum(pu$spp1, na.rm = TRUE), sum(pu$spp2, na.rm = TRUE)),
    c("spp1", "spp2")
  )
)

## calculate absolute amount held for each feature
print(
  setNames(
    c(sum(pu$spp1 * s1$s, na.rm = TRUE), sum(pu$spp2 * s1$s, na.rm = TRUE)),
    c("spp1", "spp2")
  )
)

## calculate relative amount held for each feature
print(
  setNames(
    c(
      sum(pu$spp1 * s1$s, na.rm = TRUE) / sum(pu$spp1, na.rm = TRUE),
      sum(pu$spp2 * s1$s, na.rm = TRUE) / sum(pu$spp2, na.rm = TRUE)
    ),
    c("spp1", "spp2")
  )
)

# solve problem using an exact algorithm solver
s1_2 <- solve(p1)
print(s1_2)

# calculate feature representation in this solution
r1_2 <- eval_feature_representation_summary(
  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() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s2 <- solve(p2)

# print solution
print(s2)

```



```
# calculate feature representation in the solution
r2 <- eval_feature_representation_summary(p2, s2)
print(r2)

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

# build minimal conservation problem with polygon data
p3 <-
  problem(sim_pu_polygons, sim_features, cost_column = "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s3 <- solve(p3)

# print first six rows of the attribute table
print(head(s3))

# calculate feature representation in the solution
r3 <- eval_feature_representation_summary(p3, s3[, "solution_1"])
print(r3)

# plot solution
plot(s3[, "solution_1"], main = "solution", axes = FALSE)

# build multi-zone conservation problem with raster data
p4 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5, ncol = 3)) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s4 <- solve(p4)

# print solution
print(s4)

# calculate feature representation in the solution
r4 <- eval_feature_representation_summary(p4, s4)
print(r4)

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

# build multi-zone conservation problem with polygon data
p5 <-
  problem(
```

```

    sim_zones_pu_polygons, sim_zones_features,
    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() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s5 <- solve(p5)

# print first six rows of the attribute table
print(head(s5))

# calculate feature representation in the solution
r5 <- eval_feature_representation_summary(
  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"])

## End(Not run)

```

---

```
eval_ferrier_importance
```

*Evaluate solution importance using Ferrier scores*

---

## Description

Calculate importance scores for planning units selected in a solution following Ferrier *et al.* (2000).

## Usage

```
eval_ferrier_importance(x, solution)
```

```
## S4 method for signature 'ConservationProblem,numeric'
eval_ferrier_importance(x, solution)
```

```
## S4 method for signature 'ConservationProblem,matrix'
eval_ferrier_importance(x, solution)
```

```
## S4 method for signature 'ConservationProblem,data.frame'
eval_ferrier_importance(x, solution)

## S4 method for signature 'ConservationProblem,Spatial'
eval_ferrier_importance(x, solution)

## S4 method for signature 'ConservationProblem,sf'
eval_ferrier_importance(x, solution)

## S4 method for signature 'ConservationProblem,Raster'
eval_ferrier_importance(x, solution)

## S4 method for signature 'ConservationProblem,SpatRaster'
eval_ferrier_importance(x, solution)
```

### Arguments

`x` [problem\(\)](#) object.

`solution` numeric, matrix, data.frame, [terra::rast\(\)](#), or [sf::sf\(\)](#) object. The argument should be in the same format as the planning unit cost data in the argument to `x`. See the Solution format section for more information.

### Details

Importance scores are reported separately for each feature within each planning unit. Additionally, a total importance score is also calculated as the sum of the scores for each feature. Note that this function only works for problems that use targets and a single zone. It will throw an error for problems that do not meet these criteria.

### Value

A matrix, [tibble::tibble\(\)](#), [terra::rast\(\)](#), or [sf::st\\_sf\(\)](#) object containing the scores for each planning unit selected in the solution. Specifically, the returned object is in the same format (except if the planning units are a numeric vector) as the planning unit data in the argument to `x`.

### Notes

In previous versions, the documentation for this function had a warning indicating that the mathematical formulation for this function required verification. The mathematical formulation for this function has since been corrected and verified, so now this function is recommended for general use.

### Solution format

Broadly speaking, the argument to `solution` must be in the same format as the planning unit data in the argument to `x`. Further details on the correct format are listed separately for each of the different planning unit data formats:

- x **has numeric planning units** The argument to `solution` must be a numeric vector with each element corresponding to a different planning unit. It should have the same number of planning units as those in the argument to `x`. Additionally, any planning units missing cost (NA) values should also have missing (NA) values in the argument to `solution`.
- x **has matrix planning units** The argument to `solution` must be a matrix vector with each row corresponding to a different planning unit, and each column correspond to a different management zone. It should have the same number of planning units and zones as those in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have a missing (NA) values in the argument to `solution`.
- x **has `terra::rast()` planning units** The argument to `solution` be a `terra::rast()` object where different grid cells (pixels) correspond to different planning units and layers correspond to a different management zones. It should have the same dimensionality (rows, columns, layers), resolution, extent, and coordinate reference system as the planning units in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- x **has `data.frame` planning units** The argument to `solution` must be a `data.frame` with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if a `data.frame` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example with `sf::sf()` data). Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- x **has `sf::sf()` planning units** The argument to `solution` must be a `sf::sf()` object with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if the `sf::sf()` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example). Additionally, the argument to `solution` must also have the same coordinate reference system as the planning unit data. Furthermore, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `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

See [importance](#) for an overview of all functions for evaluating the importance of planning units selected in a solution.

Other importances: [eval\\_rank\\_importance\(\)](#), [eval\\_rare\\_richness\\_importance\(\)](#), [eval\\_replacement\\_importance\(\)](#)

## Examples

```
## Not run:
# seed seed for reproducibility
set.seed(600)
```

```
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_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)

# calculate importance scores using Ferrier et al. 2000 method
fs1 <- eval_ferrier_importance(p1, s1)

# print importance scores,
# each planning unit has an importance score for each feature
# (as indicated by the column names) and each planning unit also
# has an overall total importance score (in the "total" column)
print(fs1)

# plot total importance scores
plot(fs1, main = names(fs1), axes = FALSE)

# create minimal problem with polygon planning units
p2 <-
  problem(sim_pu_polygons, sim_features, cost_column = "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.05) %>%
  add_binary_decisions() %>%
  add_default_solver(gap = 0, verbose = FALSE)

# solve problem
s2 <- solve(p2)

# print solution
print(s2)

# plot solution
plot(s2[, "solution_1"], main = "solution")

# calculate importance scores
```

```
fs2 <- eval_ferrier_importance(p2, s2[, "solution_1"])

# plot importance scores
plot(fs2)

## End(Not run)
```

---

eval\_n\_summary

*Evaluate number of planning units selected by solution*


---

## Description

Calculate the number of planning units selected within a solution to a conservation planning problem.

## Usage

```
eval_n_summary(x, solution)
```

## Arguments

x	<a href="#">problem()</a> object.
solution	numeric, matrix, data.frame, <a href="#">terra::rast()</a> , or <a href="#">sf::sf()</a> object. The argument should be in the same format as the planning unit cost data in the argument to x. See the Solution format section for more information.

## Details

This summary statistic is calculated as the sum of the values in the solution. As a consequence, this metric can produce a non-integer value (e.g., 4.3) for solutions containing proportion values (e.g., generated by solving a [problem\(\)](#) built using the [add\\_proportion\\_decisions\(\)](#) function).

## Value

A [tibble::tibble\(\)](#) object containing the number of planning units selected within a solution. It contains the following columns:

**summary** character description of the summary statistic. The statistic associated with the "overall" value in this column is calculated using the entire solution (including all management zones if there are multiple zones). If multiple management zones are present, then summary statistics are also provided for each zone separately (indicated using zone names).

**n** numeric number of selected planning units.

### Solution format

Broadly speaking, the argument to `solution` must be in the same format as the planning unit data in the argument to `x`. Further details on the correct format are listed separately for each of the different planning unit data formats:

- × **has numeric `planning units`** The argument to `solution` must be a numeric vector with each element corresponding to a different planning unit. It should have the same number of planning units as those in the argument to `x`. Additionally, any planning units missing cost (NA) values should also have missing (NA) values in the argument to `solution`.
- × **has matrix `planning units`** The argument to `solution` must be a matrix vector with each row corresponding to a different planning unit, and each column correspond to a different management zone. It should have the same number of planning units and zones as those in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have a missing (NA) values in the argument to `solution`.
- × **has `terra::rast()` `planning units`** The argument to `solution` be a `terra::rast()` object where different grid cells (pixels) correspond to different planning units and layers correspond to a different management zones. It should have the same dimensionality (rows, columns, layers), resolution, extent, and coordinate reference system as the planning units in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- × **has `data.frame` `planning units`** The argument to `solution` must be a `data.frame` with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if a `data.frame` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example with `sf::sf()` data). Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- × **has `sf::sf()` `planning units`** The argument to `solution` must be a `sf::sf()` object with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if the `sf::sf()` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example). Additionally, the argument to `solution` must also have the same coordinate reference system as the planning unit data. Furthermore, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.

### See Also

See [summaries](#) for an overview of all functions for summarizing solutions.

Other summaries: [eval\\_asym\\_connectivity\\_summary\(\)](#), [eval\\_boundary\\_summary\(\)](#), [eval\\_connectivity\\_summary\(\)](#), [eval\\_cost\\_summary\(\)](#), [eval\\_feature\\_representation\\_summary\(\)](#), [eval\\_target\\_coverage\\_summary\(\)](#)

### Examples

```
## Not run:  
# set seed for reproducibility  
set.seed(500)
```

```
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()
sim_zones_pu_polygons <- get_sim_zones_pu_polygons()
sim_zones_features <- get_sim_zones_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(verbose = FALSE)

# solve the problem
s1 <- solve(p1)

# print solution
print(s1)

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

# calculate number of selected planning units within solution
r1 <- eval_n_summary(p1, s1)
print(r1)

# build minimal conservation problem with polygon data
p2 <-
  problem(sim_pu_polygons, sim_features, cost_column = "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve the problem
s2 <- solve(p2)

# plot solution
plot(s2[, "solution_1"])

# print solution
print(s2)

# calculate number of selected planning units within solution
r2 <- eval_n_summary(p2, s2[, "solution_1"])
print(r2)

# manually calculate number of selected planning units
r2_manual <- sum(s2$solution_1, na.rm = TRUE)
print(r2_manual)
```



```

# build multi-zone conservation problem with polygon data
p3 <-
  problem(
    sim_zones_pu_polygons, sim_zones_features,
    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() %>%
  add_default_solver(verbose = FALSE)

# solve the problem
s3 <- solve(p3)

# print solution
print(s3)

# create new column representing the zone id that each planning unit
# was allocated to in the solution
s3$solution <- category_vector(
  s3[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
)
s3$solution <- factor(s3$solution)

# plot solution
plot(s3[, "solution"])

# calculate number of selected planning units within solution
r3 <- eval_n_summary(
  p3, s3[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
)
print(r3)

## End(Not run)

```

---

eval\_rank\_importance *Evaluate solution importance using incremental ranks*

---

### Description

Calculate importance scores for planning units selected in a solution by calculating ranks via an incremental optimization process (based on Jung *et al.* 2021).

### Usage

```

eval_rank_importance(x, solution, ...)

## S4 method for signature 'ConservationProblem,numeric'
eval_rank_importance(x,

```

```

solution, ..., rescale, run_checks, force, by_zone, objective, extra_args,
n, budgets)

## S4 method for signature 'ConservationProblem,matrix'
eval_rank_importance(x,
solution, ..., rescale, run_checks, force, by_zone, objective, extra_args,
n, budgets)

## S4 method for signature 'ConservationProblem,data.frame'
eval_rank_importance(x,
solution, ..., rescale, run_checks, force, by_zone, objective, extra_args,
n, budgets)

## S4 method for signature 'ConservationProblem,Spatial'
eval_rank_importance(x,
solution, ..., rescale, run_checks, force, by_zone, objective, extra_args,
n, budgets)

## S4 method for signature 'ConservationProblem,sf'
eval_rank_importance(x, solution,
..., rescale, run_checks, force, by_zone, objective, extra_args, n, budgets)

## S4 method for signature 'ConservationProblem,Raster'
eval_rank_importance(x,
solution, ..., rescale, run_checks, force, by_zone, objective, extra_args,
n, budgets)

## S4 method for signature 'ConservationProblem,SpatRaster'
eval_rank_importance(x,
solution, ..., rescale, run_checks, force, by_zone, objective, extra_args,
n, budgets)

```

## Arguments

x	<a href="#">problem()</a> object.
solution	numeric, matrix, data.frame, <a href="#">terra::rast()</a> , or <a href="#">sf::sf()</a> object. The argument should be in the same format as the planning unit cost data in the argument to x. See the Solution format 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 <a href="#">presolve_check()</a> 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.

by_zone	logical indicating value. If TRUE, then the optimization process will increment budgets for each zone separately. If FALSE, then the optimization process will increment a single budget that is applied to all zones. Note that this parameter is only considered if n is specified, and does not affect processing if budgets is specified. Defaults to TRUE.
objective	character value with the name of the objective function that should be used for the incremental optimization process. This function must be budget limited (e.g., cannot be <code>add_min_set_objective()</code> ). For example, "add_min_shortfall_objective" can be used to specify the minimum shortfall objective (per <code>add_min_shortfall_objective()</code> ). Defaults to NULL such that the same objective is used as specified in x. If using this default and x has the minimum set objective, then the minimum shortfall objective is used.
extra_args	list value with additional arguments for the objective function (excluding the budgets parameter). For example, this parameter can be used to supply phylogenetic data for the phylogenetic diversity objective function (i.e., when using <code>objective = "add_max_phylo_div_objective"</code> ). Defaults to NULL such that no additional arguments are supplied.
n	integer number of ranks to evaluate. Note that either n or budgets (not both) must be specified. If n is specified, then by_zone is considered during processing for problems with multiple zones.
budgets	numeric vector with the budget thresholds for generating solutions at different steps in an iterative procedure. Note that either n or budgets (not both) must be specified.

## Details

Importance scores are calculated using an incremental optimization process. Note that if a problem has complex constraints (i.e., constraints that do not involve locking in or locking out planning units), then the budgets parameter must be specified. This optimization process involves the following steps.

1. A set of budgets are defined. then the budgets are defined using the budgets. Otherwise, if an argument to the n parameter is supplied, then the budgets are defined as a set of n values with equal increments between them that sum to the total cost of solution. For example, if considering a problem with a single zone, a solution with a total cost of 400, and n = 4: then the budgets will be 100, 200, 300, and 400. If considering a multiple zone problem and by\_zone = FALSE, then the budgets will be based calculated based on the total cost of the solution across all zones. Otherwise if by\_zone = TRUE, then the budgets are calculated and set based on the total cost of planning units allocated to each zone (separately) in the solution. Note that after running this function, you can see what budgets were used to calculate the ranks by accessing attributes from the result (see below for examples).
2. The problem (per x) is checked for potential issues. This step is performed to avoid issues during subsequent optimization steps. Note that this step can be skipped using `run_checks = FALSE`. Also, if issues are detected and you wish to proceed anyway, then `useforce = TRUE` ignore any detected issues.
3. The problem is modified for subsequent optimization. In particular, any planning units not selected in solution are locked out. This is important to ensure that all subsequent optimization procedures produce solutions that only contain planning units selected in the solution.

4. The problem is further modified for subsequent optimization. Specifically, its objective is overwritten using the objective defined for the rank calculations (per objective) with the smallest budget defined in the first step. Additionally, if an argument to the `extra_args` parameter is specified, this argument is also used when overwriting the objective.
5. The modified problem is solved to generate a solution. Depending on the budget and objective specified when modifying the problem, the newly generated solution will contain a subset of the planning units selected in the original solution. are assigned a rank. In particular, all selected planning units in the newly generated solution are assigned the same rank. This rank is based on the number of increments that have been previously completed. If no previous increments have been completed, then the rank is equal to the total number of budget increments. Otherwise, if previous increments have been completed, then the rank is equal to the total number of budget increments minus the number of completed increments. Note that if previous increments have been completed, then only planning units in the newly generated solution that have not been previously selected are assigned this rank. For example, if no previous increments have been completed and there are 5 budget increments (e.g.  $n = 5$ ), then the planning units selected in the newly generated solution are assigned a rank of 5. Alternatively, if 3 previous increments have been completed, then the planning units would be assigned a rank of 2.
6. The problem is further modified for subsequent optimization. Specifically, the planning units selected in the newly generated solution are locked in. This is to ensure that all subsequent solutions will select these planning units and, in turn, build on this solution. Additionally, the newly generated solution is used to specify the starting solution for the subsequent optimization procedure to reduce processing time (note this is only done when using the *CBC* and *Gurobi* solvers).
7. Steps 4–7 are repeated for each of the remaining budget increments. As the increasingly greater budgets are used at higher increments, the modified problem will generate new solutions that become increasingly similar to the original solution. Planning units that are selected at lower budget increments are assigned greater ranks and considered more important, and those selected at higher budget increments are assigned lower ranks and considered less important. This is because if a planning unit is highly cost-effective for meeting the objective (per objective), then it is more likely to be selected earlier in the incremental optimization process.
8. The incremental optimization process has completed. If `rescale = TRUE`, then the ranks are linearly rescaled to range between 0.01 and 1. Otherwise, the ranks remain unchanged.
9. The rank values are output in the same format as the planning units in the problem (per `x`) (see the Solution Format section for details).

## Value

A numeric, matrix, data.frame, `terra::rast()`, or `sf::sf()` object containing the importance scores for each planning unit in the solution. Specifically, the returned object is in the same format as the planning unit data in the argument to `x`. The object also has the following attributes that provide information on the incremental optimization process.

`budgets` numeric or matrix containing the budgets used for each increment in the incremental optimization process. If the problem (per `x`) has a single zone, then the budgets are a numeric vector, wherein values correspond to the budgets for each increment. Otherwise, if the problem (per `x`) has multiple zones, then the budgets are a matrix and their format depends on the

- by\_zone parameter. If by\_zone = FALSE, then the budgets are matrix with a column for each zone and a row for each budget increment. Alternatively, if by\_zone = TRUE, then the matrix has a single column and a row for each budget increment.
- objective numeric mathematical objective values for each solution generated during the incremental optimization process.
- runtime numeric total amount of time elapsed during the optimization (reported in seconds) of each solution generated throughout the incremental optimization process.
- status character status of the optimization process for each solution generated during the incremental optimization process. See `solve()` for further details.
- gap numeric optimality of each solution generated during the incremental optimization process. See `solve()` for further details.

### Solution format

Broadly speaking, the argument to `solution` must be in the same format as the planning unit data in the argument to `x`. Further details on the correct format are listed separately for each of the different planning unit data formats:

- x has numeric planning units** The argument to `solution` must be a numeric vector with each element corresponding to a different planning unit. It should have the same number of planning units as those in the argument to `x`. Additionally, any planning units missing cost (NA) values should also have missing (NA) values in the argument to `solution`.
- x has matrix planning units** The argument to `solution` must be a matrix vector with each row corresponding to a different planning unit, and each column correspond to a different management zone. It should have the same number of planning units and zones as those in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have a missing (NA) values in the argument to `solution`.
- x has terra::rast() planning units** The argument to `solution` be a `terra::rast()` object where different grid cells (pixels) correspond to different planning units and layers correspond to a different management zones. It should have the same dimensionality (rows, columns, layers), resolution, extent, and coordinate reference system as the planning units in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- x has data.frame planning units** The argument to `solution` must be a `data.frame` with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if a `data.frame` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example with `sf::sf()` data). Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- x has sf::sf() planning units** The argument to `solution` must be a `sf::sf()` object with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if the `sf::sf()` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example). Additionally, the argument to `solution` must also have the same coordinate reference system as the planning unit data. Furthermore, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.

## References

Jung M, Arnell A, de Lamo X, García-Rangel S, Lewis M, Mark J, Merow C, Miles L, Ondo I, Pironon S, Ravilious C, Rivers M, Schepaschenko D, Tallowin O, van Soesbergen A, Govaerts R, Boyle BL, Enquist BJ, Feng X, Gallagher R, Maitner B, Meiri S, Mulligan M, Ofer G, Roll U, Hanson JO, Jetz W, Di Marco M, McGowan J, Rinnan DS, Sachs JD, Lesiv M, Adams VM, Andrew SC, Burger JR, Hannah L, Marquet PA, McCarthy JK, Morueta-Holme N, Newman EA, Park DS, Roehrdanz PR, Svenning J-C, Violle C, Wieringa JJ, Wynne G, Fritz S, Strassburg BBN, Obersteiner M, Kapos V, Burgess N, Schmidt-Traub G, Visconti P (2021) Areas of global importance for conserving terrestrial biodiversity, carbon and water. *Nature Ecology and Evolution*, 5: 1499–1509.

## See Also

Other importances: [eval\\_ferrier\\_importance\(\)](#), [eval\\_rare\\_richness\\_importance\(\)](#), [eval\\_replacement\\_importance\(\)](#)

## Examples

```
## Not run:
# seed seed for reproducibility
set.seed(600)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_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)

# calculate importance scores using ranks based on 10 budgets
# N.B. since the objective for calculating ranks is not explicitly
# defined and the problem has a minimum set objective, the
# ranks are calculated using the minimum shortfall objective by default
rs1 <- eval_rank_importance(p1, s1, n = 10)

# print importance scores
```

```
print(rs1)

# plot importance scores
plot(rs1, main = "rank importance (10, min shortfall obj", axes = FALSE)

# display optimization information from the attributes
## status
print(attr(rs1, "status"))
## optimality gap
print(attr(rs1, "gap"))
## run time
print(attr(rs1, "runtime"))
## objective value
print(attr(rs1, "objective"))

# plot relationship between objective values and rank
plot(
  y = attr(rs1, "objective"),
  x = seq_along(attr(rs1, "objective")),
  ylab = "objective value", xlab = "rank",
  main = "relationship between objective values and rank"
)

# calculate importance scores using the maximum utility objective and
# based on 10 different budgets
rs2 <- eval_rank_importance(
  p1, s1, n = 10, objective = "add_max_utility_objective"
)

# print importance scores
print(rs2)

# plot importance scores
plot(rs2, main = "rank importance (10, max utility obj)", axes = FALSE)

# calculate importance scores using ranks based on 5 manually specified
# budgets

# calculate 5 ranks using equal intervals
# N.B. we use length.out = 6 because we want 5 budgets > 0
budgets <- seq(0, eval_cost_summary(p1, s1)$cost[[1]], length.out = 6)[-1]

# calculate importance using manually specified budgets
# N.B. since the objective for calculating ranks is not explicitly
# defined and the problem has a minimum set objective, the
# ranks are calculated using the minimum shortfall objective by default
rs3 <- eval_rank_importance(p1, s1, budgets = budgets)

# print importance scores
print(rs3)

# plot importance scores
plot(rs3, main = "rank importance (manual)", axes = FALSE)
```

```

# build multi-zone conservation problem with raster data
p4 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  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
s4 <- solve(p4)
names(s4) <- paste0("zone ", seq_len(terra::nlyr(sim_zones_pu_raster)))

# print solution
print(s4)

# plot solution
# each panel corresponds to a different zone, and data show the
# status of each planning unit in a given zone
plot(s4, axes = FALSE)

# calculate importance scores
rs4 <- eval_rank_importance(p4, s4, n = 5)
names(rs4) <- paste0("zone ", seq_len(terra::nlyr(sim_zones_pu_raster)))

# plot importance
# each panel corresponds to a different zone, and data show the
# importance of each planning unit in a given zone
plot(rs4, axes = FALSE)

## End(Not run)

```

---

```
eval_rare_richness_importance
```

*Evaluate solution importance using rarity weighted richness scores*

---

### Description

Calculate importance scores for planning units selected in a solution using rarity weighted richness scores (based on Williams *et al.* 1996).

### Usage

```
eval_rare_richness_importance(x, solution, ...)
```

```
## S4 method for signature 'ConservationProblem,numeric'
eval_rare_richness_importance(x, solution, rescale, ...)
```



```

## S4 method for signature 'ConservationProblem,matrix'
eval_rare_richness_importance(x, solution, rescale, ...)

## S4 method for signature 'ConservationProblem,data.frame'
eval_rare_richness_importance(x, solution, rescale, ...)

## S4 method for signature 'ConservationProblem,Spatial'
eval_rare_richness_importance(x, solution, rescale, ...)

## S4 method for signature 'ConservationProblem,sf'
eval_rare_richness_importance(x, solution, rescale, ...)

## S4 method for signature 'ConservationProblem,Raster'
eval_rare_richness_importance(x, solution, rescale, ...)

## S4 method for signature 'ConservationProblem,SpatRaster'
eval_rare_richness_importance(x, solution, rescale, ...)

```

## Arguments

x	<code>problem()</code> object.
solution	numeric, matrix, data.frame, <code>terra::rast()</code> , or <code>sf::sf()</code> object. The argument should be in the same format as the planning unit cost data in the argument to x. See the Solution format 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.

## 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  $k$ :

$$RWR_k = \sum_j \frac{\frac{r_{jk}}{m_j}}{\sum_i r_{ij}}$$

This method is only recommended for large-scaled conservation planning exercises (i.e., more than 100,000 planning units) where importance scores cannot be calculated using other methods 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.

## Value

A numeric, matrix, data.frame, `terra::rast()`, or `sf::sf()` object containing the importance scores for each planning unit in the solution. Specifically, the returned object is in the same format as the planning unit data in the argument to `x`.

## Solution format

Broadly speaking, the argument to `solution` must be in the same format as the planning unit data in the argument to `x`. Further details on the correct format are listed separately for each of the different planning unit data formats:

- x has numeric planning units** The argument to `solution` must be a numeric vector with each element corresponding to a different planning unit. It should have the same number of planning units as those in the argument to `x`. Additionally, any planning units missing cost (NA) values should also have missing (NA) values in the argument to `solution`.
- x has matrix planning units** The argument to `solution` must be a matrix vector with each row corresponding to a different planning unit, and each column correspond to a different management zone. It should have the same number of planning units and zones as those in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have a missing (NA) values in the argument to `solution`.
- x has terra::rast() planning units** The argument to `solution` be a `terra::rast()` object where different grid cells (pixels) correspond to different planning units and layers correspond to a different management zones. It should have the same dimensionality (rows, columns, layers), resolution, extent, and coordinate reference system as the planning units in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- x has data.frame planning units** The argument to `solution` must be a data.frame with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if a data.frame object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example with `sf::sf()` data). Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- x has sf::sf() planning units** The argument to `solution` must be a `sf::sf()` object with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if the `sf::sf()` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example). Additionally, the argument to `solution` must also have the same coordinate reference system as the planning unit data. Furthermore, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.

## References

Williams P, Gibbons D, Margules C, Rebelo A, Humphries C, and Pressey RL (1996) A comparison of richness hotspots, rarity hotspots and complementary areas for conserving diversity using British birds. *Conservation Biology*, 10: 155–174.

**See Also**

See [importance](#) for an overview of all functions for evaluating the importance of planning units selected in a solution.

Other importances: [eval\\_ferrier\\_importance\(\)](#), [eval\\_rank\\_importance\(\)](#), [eval\\_replacement\\_importance\(\)](#)

**Examples**

```
## Not run:
# seed seed for reproducibility
set.seed(600)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()

# create minimal problem with raster planning units
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)

# calculate importance scores
rwr1 <- eval_rare_richness_importance(p1, s1)

# print importance scores
print(rwr1)

# plot importance scores
plot(rwr1, main = "rarity weighted richness", axes = FALSE)

# create minimal problem with polygon planning units
p2 <-
  problem(sim_pu_polygons, sim_features, cost_column = "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.05) %>%
  add_binary_decisions() %>%
  add_default_solver(gap = 0, verbose = FALSE)

# solve problem
s2 <- solve(p2)
```

```

# print solution
print(s2)

# plot solution
plot(s2[, "solution_1"], main = "solution")

# calculate importance scores
rwr2 <- eval_rare_richness_importance(p2, s2[, "solution_1"])

# plot importance scores
plot(rwr2, main = "rarity weighted richness")

## End(Not run)

```

---

```
eval_replacement_importance
```

*Evaluate solution importance using replacement cost scores*

---

### Description

Calculate importance scores for planning units selected in a solution based on the replacement cost method (Cabeza and Moilanen 2006).

### Usage

```

eval_replacement_importance(x, solution, ...)

## S4 method for signature 'ConservationProblem,numeric'
eval_replacement_importance(x, solution, rescale, run_checks, force, threads, ...)

## S4 method for signature 'ConservationProblem,matrix'
eval_replacement_importance(x, solution, rescale, run_checks, force, threads, ...)

## S4 method for signature 'ConservationProblem,data.frame'
eval_replacement_importance(x, solution, rescale, run_checks, force, threads, ...)

## S4 method for signature 'ConservationProblem,Spatial'
eval_replacement_importance(x, solution, rescale, run_checks, force, threads, ...)

## S4 method for signature 'ConservationProblem,sf'
eval_replacement_importance(x, solution, rescale, run_checks, force, threads, ...)

## S4 method for signature 'ConservationProblem,Raster'
eval_replacement_importance(x, solution, rescale, run_checks, force, threads, ...)

## S4 method for signature 'ConservationProblem,SpatRaster'
eval_replacement_importance(x, solution, rescale, run_checks, force, threads, ...)

```

## Arguments

x	<code>problem()</code> object.
solution	numeric, matrix, data.frame, <code>terra::rast()</code> , or <code>sf::sf()</code> object. The argument should be in the same format as the planning unit cost data in the argument to x. See the Solution format 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 <code>presolve_check()</code> 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.
threads	integer number of threads to use for the optimization algorithm. Defaults to 1 such that only a single thread is used.

## Details

This function implements a modified version of the replacement cost method (Cabeza and Moilanen 2006). Specifically, 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 important (and 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 (`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 be 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).

These calculations can take a long time to complete for large or complex conservation planning problems. As such, we recommend using this method for small or moderate-sized conservation planning problems (e.g., < 30,000 planning units). To reduce run time, we recommend calculating these scores without additional penalties (e.g., `add_boundary_penalties()`) or spatial constraints (e.g., `add_contiguity_constraints()`). To further reduce run time, we recommend using proportion-type decisions when calculating the scores (see below for an example).

## Value

A numeric, matrix, data.frame, `terra::rast()`, or `sf::sf()` object containing the importance scores for each planning unit in the solution. Specifically, the returned object is in the same format as the planning unit data in the argument to x.

### Solution format

Broadly speaking, the argument to `solution` must be in the same format as the planning unit data in the argument to `x`. Further details on the correct format are listed separately for each of the different planning unit data formats:

- x has numeric `planning units`** The argument to `solution` must be a numeric vector with each element corresponding to a different planning unit. It should have the same number of planning units as those in the argument to `x`. Additionally, any planning units missing cost (NA) values should also have missing (NA) values in the argument to `solution`.
- x has matrix `planning units`** The argument to `solution` must be a matrix vector with each row corresponding to a different planning unit, and each column correspond to a different management zone. It should have the same number of planning units and zones as those in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have a missing (NA) values in the argument to `solution`.
- x has `terra::rast()` `planning units`** The argument to `solution` be a `terra::rast()` object where different grid cells (pixels) correspond to different planning units and layers correspond to a different management zones. It should have the same dimensionality (rows, columns, layers), resolution, extent, and coordinate reference system as the planning units in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- x has `data.frame` `planning units`** The argument to `solution` must be a `data.frame` with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if a `data.frame` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example with `sf::sf()` data). Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- x has `sf::sf()` `planning units`** The argument to `solution` must be a `sf::sf()` object with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if the `sf::sf()` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example). Additionally, the argument to `solution` must also have the same coordinate reference system as the planning unit data. Furthermore, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.

### References

Cabeza M and Moilanen A (2006) Replacement cost: A practical measure of site value for cost-effective reserve planning. *Biological Conservation*, 132: 336–342.

### See Also

See [importance](#) for an overview of all functions for evaluating the importance of planning units selected in a solution.

Other importances: [eval\\_ferrier\\_importance\(\)](#), [eval\\_rank\\_importance\(\)](#), [eval\\_rare\\_richness\\_importance\(\)](#)

**Examples**

```

## Not run:
# seed seed for reproducibility
set.seed(600)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_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)

# calculate importance scores
rc1 <- eval_replacement_importance(p1, s1)

# print importance scores
print(rc1)

# plot importance scores
plot(rc1, main = "replacement cost", axes = 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 importance scores using proportion type decisions
rc2 <- eval_replacement_importance(p2, s1)

```

```

# print importance scores based on proportion type decisions
print(rc2)

# plot importance scores based on proportion type decisions
# we can see that the importance 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)

# create minimal problem with polygon planning units
p3 <-
  problem(sim_pu_polygons, sim_features, cost_column = "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.05) %>%
  add_binary_decisions() %>%
  add_default_solver(gap = 0, verbose = FALSE)

# solve problem
s3 <- solve(p3)

# print solution
print(s3)

# plot solution
plot(s3[, "solution_1"], main = "solution")

# calculate importance scores
rc3 <- eval_rare_richness_importance(p3, s3[, "solution_1"])

# plot importance scores
plot(rc3, main = "replacement cost")

# build multi-zone conservation problem with raster data
p4 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  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
s4 <- solve(p4)
names(s4) <- paste0("zone ", seq_len(terra::nlyr(s4)))

# print solution
print(s4)

# plot solution
# each panel corresponds to a different zone, and data show the
# status of each planning unit in a given zone
plot(s4, axes = FALSE)

```



```

# calculate importance scores
rc4 <- eval_replacement_importance(p4, s4)
names(rc4) <- paste0("zone ", seq_len(terra::nlyr(s4)))

# plot importance
# each panel corresponds to a different zone, and data show the
# importance of each planning unit in a given zone
plot(rc4, axes = FALSE)

## End(Not run)

```

---

```
eval_target_coverage_summary
```

*Evaluate target coverage by solution*

---

## Description

Calculate how well feature representation [targets](#) are met by a solution to a conservation planning problem. It is useful for understanding if features are adequately represented by a solution. Note that this function can only be used with problems that contain [targets](#).

## Usage

```

eval_target_coverage_summary(
  x,
  solution,
  include_zone = number_of_zones(x) > 1,
  include_sense = number_of_zones(x) > 1
)

```

## Arguments

<code>x</code>	<a href="#">problem()</a> object.
<code>solution</code>	numeric, matrix, data.frame, <a href="#">terra::rast()</a> , or <a href="#">sf::sf()</a> object. The argument should be in the same format as the planning unit cost data in the argument to <code>x</code> . See the Solution format section for more information.
<code>include_zone</code>	logical include the zone column in the output? Defaults to TRUE for problems that contain multiple zones.
<code>include_sense</code>	logical include the sense column in the output? Defaults to TRUE for problems that contain multiple zones.

## Value

A [tibble::tibble\(\)](#) object. Here, each row describes information for a different target. It contains the following columns:

**feature** character name of the feature associated with each target.

- zone** list of character zone names associated with each target. This column is in a list-column format because a single target can correspond to multiple zones (see `add_manual_targets()` for details and examples). For an example of converting the list-column format to a standard character column format, please see the Examples section. This column is only included if the argument to `include_zones` is TRUE.
- sense** character sense associated with each target. Sense values specify the nature of the target. Typically (e.g., when using the `add_absolute_targets()` or `add_relative_targets()` functions), targets are specified using sense values indicating that the total amount of a feature held within a solution (ideally) be greater than or equal to a threshold amount (i.e., a sense value of " $\geq$ "). Additionally, targets (i.e., using the `add_manual_targets()` function) can also be specified using sense values indicating that the total amount of a feature held within a solution must be equal to a threshold amount (i.e., a sense value of "=") or smaller than or equal to a threshold amount (i.e., a sense value of " $\leq$ "). This column is only included if the argument to `include_sense` is TRUE.
- total\_amount** numeric total amount of the feature available across the entire conservation planning problem for meeting each target (not just planning units selected within the solution). For problems involving a single zone, this column is calculated as the sum of all of the values for a given feature (similar to values in the `total_amount` column produced by the `eval_feature_representation_summary()` function). For problems involving multiple zones, this column is calculated as the sum of the values for the feature associated with target (per the "feature" column), across the zones associated with the target (per the "zone" column).
- absolute\_target** numeric total threshold amount associated with each target.
- absolute\_held** numeric total amount held within the solution for the feature and (if relevant) zones associated with each target (per the "feature" and "zone" columns, respectively). This column is calculated as the sum of the feature data, supplied when creating a `problem()` object (e.g., presence/absence values), weighted by the status of each planning unit in the solution (e.g., selected or not for prioritization).
- absolute\_shortfall** numeric total amount by which the solution fails to meet each target. This column is calculated as the difference between the total amount held within the solution for the feature and (if relevant) zones associated with the target (i.e., "absolute\_held" column) and the target total threshold amount (i.e., "absolute\_target" column), with values set to zero depending on the sense specified for the target (e.g., if the target sense is  $\geq$  then the difference is set to zero if the value in the "absolute\_held" is smaller than that in the "absolute\_target" column).
- relative\_target** numeric proportion threshold amount associated with each target. This column is calculated by dividing the total threshold amount associated with each target (i.e., "absolute\_target" column) by the total amount associated with each target (i.e., "total\_amount" column).
- relative\_held** numeric proportion held within the solution for the feature and (if relevant) zones associated with each target (per the "feature" and "zone" columns, respectively). This column is calculated by dividing the total amount held for each target (i.e., "absolute\_held" column) by the total amount for with each target (i.e., "total\_amount" column).
- relative\_shortfall** numeric proportion by which the solution fails to meet each target. This column is calculated by dividing the total shortfall for each target (i.e., "absolute\_shortfall" column) by the total amount for each target (i.e., "total\_amount" column).
- met** logical indicating if each target is met by the solution. This column is calculated by checking if the total shortfall associated with each target (i.e., "absolute\_shortfall" column) is equal to zero.

### Solution format

Broadly speaking, the argument to `solution` must be in the same format as the planning unit data in the argument to `x`. Further details on the correct format are listed separately for each of the different planning unit data formats:

- × **has numeric `planning units`** The argument to `solution` must be a numeric vector with each element corresponding to a different planning unit. It should have the same number of planning units as those in the argument to `x`. Additionally, any planning units missing cost (NA) values should also have missing (NA) values in the argument to `solution`.
- × **has matrix `planning units`** The argument to `solution` must be a matrix vector with each row corresponding to a different planning unit, and each column correspond to a different management zone. It should have the same number of planning units and zones as those in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have a missing (NA) values in the argument to `solution`.
- × **has `terra::rast()` `planning units`** The argument to `solution` be a `terra::rast()` object where different grid cells (pixels) correspond to different planning units and layers correspond to a different management zones. It should have the same dimensionality (rows, columns, layers), resolution, extent, and coordinate reference system as the planning units in the argument to `x`. Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- × **has `data.frame` `planning units`** The argument to `solution` must be a `data.frame` with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if a `data.frame` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example with `sf::sf()` data). Additionally, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.
- × **has `sf::sf()` `planning units`** The argument to `solution` must be a `sf::sf()` object with each column corresponding to a different zone, each row corresponding to a different planning unit, and cell values corresponding to the solution value. This means that if the `sf::sf()` object containing the solution also contains additional columns, then these columns will need to be subsetted prior to using this function (see below for example). Additionally, the argument to `solution` must also have the same coordinate reference system as the planning unit data. Furthermore, any planning units missing cost (NA) values for a particular zone should also have missing (NA) values in the argument to `solution`.

### See Also

See [summaries](#) for an overview of all functions for summarizing solutions.

Other summaries: [eval\\_asym\\_connectivity\\_summary\(\)](#), [eval\\_boundary\\_summary\(\)](#), [eval\\_connectivity\\_summary\(\)](#), [eval\\_cost\\_summary\(\)](#), [eval\\_feature\\_representation\\_summary\(\)](#), [eval\\_n\\_summary\(\)](#)

### Examples

```
## Not run:  
# set seed for reproducibility  
set.seed(500)
```

```
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()
sim_zones_pu_polygons <- get_sim_zones_pu_polygons()
sim_zones_features <- get_sim_zones_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(verbose = FALSE)

# solve the problem
s1 <- solve(p1)

# print solution
print(s1)

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

# calculate target coverage by the solution
r1 <- eval_target_coverage_summary(p1, s1)
print(r1, width = Inf) # note: `width = Inf` tells R to print all columns

# build minimal conservation problem with polygon data
p2 <-
  problem(sim_pu_polygons, sim_features, cost_column = "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve the problem
s2 <- solve(p2)

# print first six rows of the attribute table
print(head(s2))

# plot solution
plot(s2[, "solution_1"])

# calculate target coverage by the solution
r2 <- eval_target_coverage_summary(p2, s2[, "solution_1"])
print(r2, width = Inf)

# build multi-zone conservation problem with polygon data
p3 <-
  problem(
```

```

    sim_zones_pu_polygons, sim_zones_features,
    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() %>%
  add_default_solver(verbose = FALSE)

# solve the problem
s3 <- solve(p3)

# print solution
print(s3)

# create new column representing the zone id that each planning unit
# was allocated to in the solution
s3$solution <- category_vector(
  s3[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
)
s3$solution <- factor(s3$solution)

# plot solution
plot(s3[, "solution"])

# calculate target coverage by the solution
r3 <- eval_target_coverage_summary(
  p3, s3[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
)
print(r3, width = Inf)

# create a new column with character values containing the zone names,
# by extracting these data out of the zone column
# (which is in list-column format)
r3$zone2 <- vapply(r3$zone, FUN.VALUE = character(1), paste, sep = " & ")

# print r3 again to show the new column
print(r3, width = Inf)

## End(Not run)

```

---

fast\_extract

*Fast extract*


---

## Description

Extract data from a `terra::rast()` object.

## Usage

```
fast_extract(x, y, ...)
```

```
## S4 method for signature 'Raster,Spatial'
fast_extract(x, y, fun = "mean", ...)

## S4 method for signature 'Raster,sfc'
fast_extract(x, y, fun = "mean", ...)

## S4 method for signature 'SpatRaster,sfc'
fast_extract(x, y, fun = "mean", ...)

## S4 method for signature 'Raster,sf'
fast_extract(x, y, fun = "mean", ...)

## S4 method for signature 'SpatRaster,sf'
fast_extract(x, y, fun = "mean", ...)
```

### Arguments

x	<a href="#">terra::rast()</a> object.
y	<a href="#">sf::sf()</a> object.
...	not used.
fun	character name of statistic to summarize data. Defaults to "mean". Available options include "sum" or "mean". Defaults to "mean".

### Details

The performance of this function for large [terra::rast\(\)](#) objects can be improved by increasing the GDAL cache size. The default cache size is 25 MB. For example, the following code can be used to set the cache size to 4 GB.

```
terra::gdalCache(size = 4000)
```

This function is simply a wrapper that uses [exactextractr::exact\\_extract\(\)](#) for polygon geometries, and [terra::extract\(\)](#) for other geometry types.

### Value

A 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.

### See Also

[terra::extract\(\)](#), [exactextractr::exact\\_extract\(\)](#).

## Examples

```
# load data
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()

# extract data
result <- fast_extract(sim_features, sim_pu_polygons)

# show result
print(head(result))
```

---

feature_abundances	<i>Feature abundances</i>
--------------------	---------------------------

---

## 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	<code>problem()</code> 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 `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**

A `tibble::tibble()` object 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\(\)](#), [eval\\_feature\\_representation\\_summary\(\)](#).

**Examples**

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()

# create a simple conservation planning dataset 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))
  )

  all.equal(
    a2$absolute_abundance,
    c(
      sum(pu$spp1[!is.na(pu$cost)]),
      sum(pu$spp2[!is.na(pu$cost)], na.rm = TRUE)
    )
  )

  all.equal(
    a2$relative_abundance,
    c(
      sum(pu$spp1[!is.na(pu$cost)] / sum(pu$spp1, na.rm = TRUE),
      sum(pu$spp2[!is.na(pu$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 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() %>%
  add_default_solver(verbose = FALSE)

  # 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 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() %>%
  add_default_solver(verbose = FALSE)

# 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)

## End(Not run)

```

---

feature\_names

*Feature names*


---

## Description

Extract the names of the features in an object.

## Usage

```

feature_names(x, ...)

## S3 method for class 'ConservationProblem'
feature_names(x, ...)

## S3 method for class 'ZonesRaster'
feature_names(x, ...)

## S3 method for class 'ZonesSpatRaster'
feature_names(x, ...)

## S3 method for class 'ZonesCharacter'
feature_names(x, ...)

```

## Arguments

x                    [problem\(\)](#) or [Zones\(\)](#) object.  
...                    not used.

## Value

A character vector of feature names.

**Examples**

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_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))

## End(Not run)
```

---

importance

*Evaluate solution importance*


---

**Description**

Importance scores (also known as irreplaceability scores) can be used to assess the relative importance of planning units selected in a solution to a conservation planning problem.

**Details**

The following methods are available for calculating importance scores for a solution to a conservation planning `problem()`:

`eval_replacement_importance()` Calculate importance scores using replacement costs (based on Cabeza and Moilanen 2006). These scores 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).

`eval_rank_importance()` Calculate importance scores using ranks (based on Jung *et al.* 2021). These scores measure importance using an incremental optimization approach. They can (i) account for the cost of different planning units, (ii) account for multiple management zones, and (iii) apply to solutions generated with any objective function.

`eval_ferrier_importance()` Calculate importance scores following Ferrier *et al.* (2000). These scores measure importance based on how critical planning units are for meeting targets. They can only be applied to conservation problems that use targets and a single zone (e.g., the classic *Marxan*-type problem). Furthermore – unlike the replacement cost scores – these 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.

`eval_rare_richness_importance()` Calculate importance scores using the rarity weighted richness metric (based on Williams *et al.* 1996). These score are simply a measure of biodiversity. 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.

Broadly speaking, we recommend using replacement cost scores where possible. This is because they can be applied to any type of conservation planning problem – regardless of the objective function or number of zones considered in the problem – and measure planning unit importance based on degradation of the prioritization. Although the replacement cost scores can be calculated for small and moderate sized problems (e.g., less than 30,000 planning units), they may not be feasible for particularly large problems (e.g., more than 100,000 planning units). In such cases, we recommend calculating importance scores using the rank method. This is because it can be calculated relatively quickly for large-sized problems and can explicitly account for costs and representation targets (depending on the objective function used). If using the the rank method with a solution generated using the minimum set objective (i.e., `add_min_set_objective()`), we recommend using the minimum shortfall objective. The Ferrier method can also be useful to highly identify irreplaceable planning units. We only recommend using the rarity weighted richness metric when neither of the other two methods can be used.

## References

- Cabeza M and Moilanen A (2006) Replacement cost: A practical measure of site value for cost-effective reserve planning. *Biological Conservation*, 132: 336–342.
- 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.
- Jung M, Arnell A, de Lamo X, García-Rangel S, Lewis M, Mark J, Merow C, Miles L, Ondo I, Pironon S, Ravilious C, Rivers M, Schepaschenko D, Tallowin O, van Soesbergen A, Govaerts R, Boyle BL, Enquist BJ, Feng X, Gallagher R, Maitner B, Meiri S, Mulligan M, Ofer G, Roll U, Hanson JO, Jetz W, Di Marco M, McGowan J, Rinnan DS, Sachs JD, Lesiv M, Adams VM, Andrew SC, Burger JR, Hannah L, Marquet PA, McCarthy JK, Morueta-Holme N, Newman EA, Park DS, Roehrdanz PR, Svenning J-C, Violle C, Wieringa JJ, Wynne G, Fritz S, Strassburg BBN, Obersteiner M, Kapos V, Burgess N, Schmidt-Traub G, Visconti P (2021) Areas of global importance for conserving terrestrial biodiversity, carbon and water. *Nature Ecology and Evolution*, 5: 1499–1509.
- Williams P, Gibbons D, Margules C, Rebelo A, Humphries C, and Pressey RL (1996) A comparison of richness hotspots, rarity hotspots and complementary areas for conserving diversity using British birds. *Conservation Biology*, 10: 155–174.

## See Also

Other overviews: [constraints](#), [decisions](#), [objectives](#), [penalties](#), [portfolios](#), [solvers](#), [summaries](#), [targets](#)

## Examples

```
## Not run:
# load data
```

```
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_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)

# calculate importance scores using replacement cost scores
ir1 <- eval_replacement_importance(p1, s1)

# calculate importance scores using Ferrier et al 2000 method,
# and extract the total importance scores
ir2 <- eval_ferrier_importance(p1, s1)[["total"]]

# calculate importance scores using rarity weighted richness scores
ir3 <- eval_rare_richness_importance(p1, s1)

# create multi-band raster with different importance scores
ir <- c(ir1, ir2, ir3)
names(ir) <- c(
  "replacement cost", "Ferrier score", "rarity weighted richness"
)

# plot importance scores
plot(ir, axes = FALSE)

## End(Not run)
```

---

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,ANY'
```

```
intersecting_units(x, y)

## S4 method for signature 'ANY,Raster'
intersecting_units(x, y)

## S4 method for signature 'Spatial,ANY'
intersecting_units(x, y)

## S4 method for signature 'ANY,Spatial'
intersecting_units(x, y)

## S4 method for signature 'SpatRaster,SpatRaster'
intersecting_units(x, y)

## S4 method for signature 'sf,sf'
intersecting_units(x, y)

## S4 method for signature 'SpatRaster,sf'
intersecting_units(x, y)

## S4 method for signature 'sf,SpatRaster'
intersecting_units(x, y)
```

### Arguments

x [sf::st\\_sf\(\)](#) or [terra::rast\(\)](#) object.  
y [sf::st\\_sf\(\)](#) or [terra::rast\(\)](#) object.

### Details

The performance of this function for large [terra::rast\(\)](#) objects can be improved by increasing the GDAL cache size. The default cache size is 25 MB. For example, the following code can be used to set the cache size to 4 GB.

```
terra::gdalCache(size = 4000)
```

### Value

An integer vector of indices of the units in x that intersect with y.

### See Also

See [fast\\_extract\(\)](#) for extracting data from spatial datasets.

### Examples

```
## Not run:
# create data
r <- terra::rast(matrix(1:9, byrow = TRUE, ncol = 3))
r_with_holes <- r
```

```

r_with_holes[c(1, 5, 9)] <- NA
ply <- sf::st_as_sf(terra::as.polygons(r))
ply_with_holes <- sf::st_as_sf(terra::as.polygons(r_with_holes))

# intersect raster with raster
par(mfrow = c(1, 2))
plot(r, main = "x = SpatRaster", axes = FALSE)
plot(r_with_holes, main = "y = SpatRaster", axes = FALSE)
print(intersecting_units(r, r_with_holes))

# intersect raster with sf
par(mfrow = c(1, 2))
plot(r, main = "x = SpatRaster", axes = FALSE)
plot(ply_with_holes, main = "y = sf", key.pos = NULL, reset = FALSE)
print(intersecting_units(r, ply_with_holes))

# intersect sf with raster
par(mfrow = c(1, 2))
plot(ply, main = "x = sf", key.pos = NULL, reset = FALSE)
plot(r_with_holes, main = "y = SpatRaster")
print(intersecting_units(ply, r_with_holes))

# intersect sf with sf
par(mfrow = c(1, 2))
plot(ply, main = "x = sf", key.pos = NULL, reset = FALSE)
plot(ply_with_holes, main = "y = sf", key.pos = NULL, reset = FALSE)
print(intersecting_units(ply, ply_with_holes))

## End(Not run)

```

---

knit\_print

*Print an object for knitr package.*


---

### Description

This function is used to ensure that `problem()` and `new_optimization_problem()` objects are displayed correctly in **rmarkdown** reports.

### Usage

```
knit_print.ConservationProblem(x, ...)
```

```
knit_print.OptimizationProblem(x, ...)
```

### Arguments

x	Object.
...	Not used.

**Details**

This function should not be called directly. It is intended to be used by the **knitr** package when displaying objects.

**Value**

A character vector for knitting.

---

loglinear\_interpolation  
*Log-linear interpolation*

---

**Description**

Log-linearly interpolate values between two thresholds.

**Usage**

```
loglinear_interpolation(  
  x,  
  coordinate_one_x,  
  coordinate_one_y,  
  coordinate_two_x,  
  coordinate_two_y  
)
```

**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**

A numeric vector.



**Examples**

```

## Not run:
# 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)

# this function can also be used to calculate representation targets
# following Rodrigues et al. (2014). For example, let's say that
# we had a set of species we were interested in calculating representation
# targets for and we had information on their range sizes (in km^2).
spp_range_size_km2 <- seq(0.01, 15000000, by = 100)

# we can now use this function to calculate representation targets
# (expressed as a percentage of the species' range sizes) using
# the thresholds and cap sizes reported by Rodrigues et al. 2014
spp_target_percentage_rodrigues <- loglinear_interpolation(
  x = spp_range_size_km2,
  coordinate_one_x = 1000,
  coordinate_one_y = 1,
  coordinate_two_x = 250000,
  coordinate_two_y = 0.1
) * 100

# it is also common to apply a cap to the representation targets,
# so let's apply the cap these targets following Butchart et al. (2015)
spp_target_percentage_butchart <- ifelse(
  spp_range_size_km2 >= 10000000,
  (1000000 / spp_range_size_km2) * 100,
  spp_target_percentage_rodrigues
)

# plot species range sizes and representation targets
plot(
  spp_target_percentage_butchart ~ spp_range_size_km2,
  xlab = "Range size km^2" , ylab = "Representation target (%)", type = "l"
)

# plot species range sizes and representation targets on a log10 scale
plot(
  spp_target_percentage_butchart ~ log10(spp_range_size_km2),
  xlab = "Range size km^2" , ylab = "Representation target (%)",
  type = "l", xaxt = "n"
)

```

```
axis(
  1, pretty(log10(spp_range_size_km2)),
  10^pretty(log10(spp_range_size_km2))
)

## End(Not run)
```

---

```
marxan_boundary_data_to_matrix
```

*Convert Marxan boundary data to matrix format*

---

### Description

Convert a `data.frame` object containing *Marxan* boundary data to matrix format. This function is designed specifically for boundary data (not connectivity data). It ensures that the output matrix correctly specifies symmetric spatial relationships between planning units.

### Usage

```
marxan_boundary_data_to_matrix(x, data)
```

### Arguments

`x` [problem\(\)](#) 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".

### Value

A `Matrix::dgCMatrix` sparse matrix object.

### Notes

In earlier versions, the function could convert boundary data that pertain to multiple zones. This is no longer possible, following updates to streamline the package.

### Examples

```
# create example planning unit layer
pu_data <-
  matrix(1:3, nrow = 1) %>%
  terra::rast() %>%
  setNames("id") %>%
  terra::as.polygons() %>%
  sf::st_as_sf()

# plot planning units
plot(pu_data)
```

```

# manually create Marxan boundary data for these planning units following
# the Marxan boundary data format specification
bldf <- data.frame(
  id1 = c(1, 2, 3, 1, 2),
  id2 = c(1, 2, 3, 2, 3),
  boundary = c(3, 2, 3, 1, 1)
)

# print data
print(bldf)

# convert to boundary matrix format for use in prioritizr
m1 <- marxan_boundary_data_to_matrix(NULL, bldf)

# print converted matrix
## we can see that the values in bldf and m1 are different,
## this is because Marxan and prioritizr use different formats
## for storing boundary information
print(m1)

# automatically create boundary data for use in prioritizr,
# by using the boundary_matrix() function
m2 <- boundary_matrix(pu_data)

# print matrix
## we can see that the values in m1 and m2 are exactly the same,
## this is because marxan_boundary_data_to_matrix() automatically
## converts Marxan data to the same format as boundary_matrix()
print(m2)

```

---

```
marxan_connectivity_data_to_matrix
```

*Convert Marxan connectivity data to matrix format*

---

## Description

Convert a `data.frame` object containing *Marxan* connectivity data to matrix format. This function is designed specifically for connectivity data (not boundary data). It ensures that the output matrix correctly specifies symmetric or asymmetric connectivity relationships between planning units.

## Usage

```
marxan_connectivity_data_to_matrix(x, data, symmetric = TRUE)
```

## Arguments

`x` [problem\(\)](#) 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".
symmetric	logical does the connectivity data describe symmetric relationships between planning units? If the data contain asymmetric connectivity data, this parameter should be set to FALSE. Defaults to TRUE.

### Value

A `Matrix::dgCMatrix` sparse matrix object.

### Examples

```
## Not run:
# set seed for reproducibility
set.seed(500)

# create marxan connectivity data with four planning units and one zone,
# and symmetric connectivity values
bldf1 <- expand.grid(id1 = seq_len(4), id2 = seq_len(4))
bldf1$boundary <- 1
bldf1$boundary[bldf1$id1 == bldf1$id2] <- 0.5

# print data
print(bldf1)

# convert to matrix
m1 <- marxan_connectivity_data_to_matrix(NULL, bldf1)

# print matrix
print(m1)

# visualize matrix
Matrix::image(m1)

# create marxan connectivity data with four planning units and one zone,
# and asymmetric connectivity values
bldf2 <- expand.grid(id1 = seq_len(4), id2 = seq_len(4))
bldf2$boundary <- runif(nrow(bldf2))
bldf2$boundary[bldf2$id1 == bldf2$id2] <- 0.5

# print data
print(bldf2)

# convert to matrix
m2 <- marxan_connectivity_data_to_matrix(NULL, bldf2, symmetric = FALSE)

# print matrix
print(m2)

# visualize matrix
Matrix::image(m2)

# create marxan connectivity with three planning units and two zones,
```

```

# and asymmetric connectivity values
bldf3 <- expand.grid(
  id1 = seq_len(3), id2 = seq_len(3),
  zone1 = c("z1", "z2"),
  zone2 = c("z1", "z2")
)
bldf3$boundary <- runif(nrow(bldf3))
bldf3$boundary[bldf3$id1 == bldf3$id2] <- 0

# print data
print(bldf3)

# convert to array
m3 <- marxan_connectivity_data_to_matrix(NULL, bldf3, symmetric = FALSE)

# print array
print(m3)

## End(Not run)

```

---

marxan\_problem

Marxan *conservation problem*


---

## Description

Create a conservation planning `problem()` following the mathematical formulations used in *Marxan* (detailed in Beyer *et al.* 2016). Note that these problems are solved using exact algorithms and not simulated annealing (i.e., the *Marxan* software).

## 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, symmetric = TRUE, ...)

## 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:

	<p><b>id</b> integer unique identifier for each planning unit. These identifiers are used in the argument to puvspr.</p> <p><b>cost</b> numeric cost of each planning unit.</p> <p><b>status</b> 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 <i>Marxan</i> allows planning units to be selected in the initial solution (using values of 1), these values have no effect here. This column is optional.</p>
...	not used.
spec	<p>data.frame containing information on the features. The argument to spec must follow the conventions used by <i>Marxan</i> 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"—<b>but not both columns with both of these names</b>—to specify the target for each feature.</p> <p><b>id</b> integer unique identifier for each feature These identifiers are used in the argument to puvspr.</p> <p><b>name</b> character name for each feature.</p> <p><b>prop</b> numeric relative target for each feature (optional).'</p> <p><b>amount</b> numeric absolute target for each feature (optional).</p>
puvspr	<p>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 <i>Marxan</i> input data file (conventionally called "puvspr.dat"). It must contain the following columns:</p> <p><b>pu</b> integer planning unit identifier.</p> <p><b>species</b> integer feature identifier.</p> <p><b>amount</b> numeric amount of the feature in the planning unit.</p>
bound	<p>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 <i>Marxan</i> input data file (conventionally called "bound.dat"). It must contain the following columns:</p> <p><b>id1</b> integer planning unit identifier.</p> <p><b>id2</b> integer planning unit identifier.</p> <p><b>boundary</b> numeric length of shared boundary between the planning units identified in the previous two columns.</p>
blm	numeric boundary length modifier. This argument only has an effect when argument to x is a data.frame. The default argument is zero.
symmetric	logical does the boundary data (i.e., argument to bound) describe symmetric relationships between planning units? If the boundary data contain asymmetric connectivity data, this parameter should be set to FALSE. Defaults to TRUE.

## Details

This function is provided as a convenient wrapper for solving *Marxan* problems using the **prioritizr** package. Please note that it requires installation of the **data.table** package to import *Marxan* data files.

## Value

A `problem()` object.

## Notes

In previous versions, this function could not accommodate asymmetric connectivity data. It has now been updated to handle asymmetric connectivity data.

## References

Ball IR, Possingham HP, and Watts M (2009) *Marxan and relatives: Software for spatial conservation prioritisation* in *Spatial conservation prioritisation: Quantitative methods and computational tools*. Eds Moilanen A, Wilson KA, and Possingham HP. Oxford University Press, Oxford, UK.

Beyer HL, Dujardin Y, Watts ME, and Possingham HP (2016) Solving conservation planning problems with integer linear programming. *Ecological Modelling*, 228: 14–22.

## See Also

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

## Examples

```
# create Marxan problem using Marxan input file
# (note this example requires the data.table package to be installed)
## Not run:
input_file <- system.file("extdata/marxan/input.dat", package = "prioritizr")
p1 <-
  marxan_problem(input_file) %>%
  add_default_solver(verbose = FALSE)

# solve problem
s1 <- solve(p1)

# print solution
head(s1)

# create Marxan problem using data.frames that have been loaded into R
# (note this example also requires the data.table package to be installed)
## load in planning unit data
pu_path <- system.file("extdata/marxan/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/marxan/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/marxan/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/marxan/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) %>%
  add_default_solver(verbose = FALSE)

# 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, blm = 5) %>%
  add_default_solver(verbose = FALSE)

# solve problem
s3 <- solve(p3)

# print solution
head(s3)

## End(Not run)
```

---

new\_waiver

*Waiver*

---

### 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**

A Waiver object.

**Examples**

```
# create new waiver object
w <- new_waiver()

# print object
print(w)
```

---

number_of_features	<i>Number of features</i>
--------------------	---------------------------

---

**Description**

Extract the number of features in an object.

**Usage**

```
number_of_features(x, ...)
```

```
## S3 method for class 'ConservationProblem'
number_of_features(x, ...)
```

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

```
## S3 method for class 'ZonesSpatRaster'
number_of_features(x, ...)
```

```
## S3 method for class 'ZonesRaster'
number_of_features(x, ...)
```

```
## S3 method for class 'ZonesCharacter'
number_of_features(x, ...)
```

**Arguments**

x                    A `problem()`, `optimization_problem()`, or `zones()` object.  
 ...                    not used.

**Value**

An integer number of features.

**Examples**

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_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))

## End(Not run)
```

---

```
number_of_planning_units
  Number of planning units
```

---

**Description**

Extract the number of planning units in an object.

**Usage**

```
number_of_planning_units(x, ...)
```

```
## S3 method for class 'ConservationProblem'
number_of_planning_units(x, ...)
```

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

**Arguments**

x                    `problem()` or `optimization_problem()` object.  
 ...                    not used.

## Details

The planning units for an object corresponds to the number of entries (e.g., rows, cells) for the planning unit data that do not have missing (NA) values for every zone. For example, a single-layer raster dataset might have 90 cells and only two of these cells contain non-missing (NA) values. As such, this dataset would have two planning units.

## Value

An integer number of planning units.

## Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_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))

## End(Not run)
```

---

number\_of\_total\_units *Number of total units*

---

## Description

Extract the number of total units in an object.

## Usage

```
number_of_total_units(x, ...)
```

```
## S3 method for class 'ConservationProblem'
number_of_total_units(x, ...)
```

## Arguments

x                    `problem()` object.  
...                   not used.

## Details

The total units for an object corresponds to the total number of entries (e.g., rows, cells) for the planning unit data. For example, a single-layer raster dataset might have 90 cells and only two of these cells contain non-missing (NA) values. As such, this dataset would have 90 total units and two planning units.

## Value

An integer number of total units.

## Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_features <- get_sim_zones_features()

# 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_zones_pu_raster, sim_zones_features) %>%
  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))

## End(Not run)
```

---

number_of_zones	<i>Number of zones</i>
-----------------	------------------------

---

## Description

Extract the number of zones in an object.

## Usage

```
number_of_zones(x, ...)  
  
## S3 method for class 'ConservationProblem'  
number_of_zones(x, ...)  
  
## S3 method for class 'OptimizationProblem'  
number_of_zones(x, ...)  
  
## S3 method for class 'ZonesRaster'  
number_of_zones(x, ...)  
  
## S3 method for class 'ZonesSpatRaster'  
number_of_zones(x, ...)  
  
## S3 method for class 'ZonesCharacter'  
number_of_zones(x, ...)
```

## Arguments

x                    [problem\(\)](#), [optimization\\_problem\(\)](#), or [zones\(\)](#) object.  
...                    not used.

## Value

An integer number of zones.

## Examples

```
## Not run:  
# load data  
sim_zones_pu_raster <- get_sim_zones_pu_raster()  
sim_zones_features <- get_sim_zones_features()  
  
# print number of zones in a Zones object  
print(number_of_zones(sim_zones_features))  
# create problem with multiple zones  
p <-  
  problem(sim_zones_pu_raster, sim_zones_features) %>%  
  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))

## End(Not run)

```

---

Objective-class	<i>Objective class</i>
-----------------	------------------------

---

### Description

This class is used to represent the objective function used in optimization. **Only experts should use the fields and methods for this class directly.**

### Super class

`prioritizr::ConservationModifier` -> Objective

### Methods

#### Public methods:

- `Objective$default_weights()`
- `Objective$apply()`
- `Objective$clone()`

**Method** `default_weights()`: Specify default values for weights.

*Usage:*

`Objective$default_weights(x)`

*Arguments:*

x `problem()` object.

*Returns:* Invisible TRUE.

**Method** `apply()`: Update an optimization problem formulation.

*Usage:*

`Objective$apply(x)`

*Arguments:*

x `optimization_problem()` object.

*Returns:* Invisible TRUE.

**Method** `clone()`: The objects of this class are cloneable with this method.

*Usage:*

`Objective$clone(deep = FALSE)`

*Arguments:*

deep Whether to make a deep clone.

**See Also**

Other classes: [ConservationModifier-class](#), [ConservationProblem-class](#), [Constraint-class](#), [Decision-class](#), [OptimizationProblem-class](#), [Penalty-class](#), [Portfolio-class](#), [Solver-class](#), [Target-class](#)

---

objectives

*Add an objective*

---

**Description**

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 all conservation planning problems formulated using the `prioritizr` package require an objective function, and attempting to solve a problem without an objective will result in 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 overall (weighted sum) shortfall for as many targets as possible while ensuring that the cost of the solution does not exceed a budget.

`add_min_largest_shortfall_objective()` Minimize the largest (maximum) shortfall among all targets 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()` Maximize the weighted sum of the features represented by the solution subject to a budget.

`add_min_penalties_objective()` Minimize the penalties associated with a problem as much as possible subject to a budget. This is mainly used when performing hierarchical multi-objective optimization.

**See Also**

Other overviews: [constraints](#), [decisions](#), [importance](#), [penalties](#), [portfolios](#), [solvers](#), [summaries](#), [targets](#)

**Examples**

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()
sim_phylogeny <- get_sim_phylogeny()

# create base problem
p <-
  problem(sim_pu_raster, sim_features) %>%
    add_relative_targets(0.1) %>%
    add_binary_decisions() %>%
    add_default_solver(verbose = FALSE)

# 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 minimum largest shortfall objective
p5 <- p %>% add_min_largest_shortfall_objective(1900)

# create problem with added maximum phylogenetic diversity objective
p6 <- p %>% add_max_phylo_div_objective(1900, sim_phylogeny)

# create problem with added maximum phylogenetic diversity objective
p7 <- p %>% add_max_phylo_end_objective(1900, sim_phylogeny)

# create problem with added maximum utility objective
# note that this objective does not use targets
p8 <- p %>% add_max_utility_objective(1900)

# solve problems
s <- c(
  solve(p1), solve(p2), solve(p3), solve(p4), solve(p5), solve(p6),
  solve(p7), solve(p8)
)
names(s) <- c(
  "min set", "max coverage", "max features", "min shortfall",
```



```

    "min largest shortfall", "max phylogenetic diversity",
    "max phylogenetic endemism", "max utility"
)
# plot solutions
plot(s, axes = FALSE)

## End(Not run)

```

---

OptimizationProblem-class

*Optimization problem class*

---

## Description

This class is used to represent an optimization problem. It stores the information needed to generate a solution using an exact algorithm solver. Most users should use `compile()` to generate new optimization problem objects, and the functions distributed with the package to interact with them (e.g., `base::as.list()`). **Only experts should use the fields and methods for this class directly.**

## Public fields

`ptr` A Rcpp::Xptr external pointer. Create a new optimization problem object.

## Methods

### Public methods:

- `OptimizationProblem$new()`
- `OptimizationProblem$print()`
- `OptimizationProblem$show()`
- `OptimizationProblem$ncol()`
- `OptimizationProblem$nrow()`
- `OptimizationProblem$ncell()`
- `OptimizationProblem$model sense()`
- `OptimizationProblem$vtype()`
- `OptimizationProblem$obj()`
- `OptimizationProblem$A()`
- `OptimizationProblem$rhs()`
- `OptimizationProblem$sense()`
- `OptimizationProblem$lb()`
- `OptimizationProblem$sub()`
- `OptimizationProblem$number_of_features()`
- `OptimizationProblem$number_of_planning_units()`
- `OptimizationProblem$number_of_zones()`
- `OptimizationProblem$col_ids()`

- `OptimizationProblem$row_ids()`
- `OptimizationProblem$compressed_formulation()`
- `OptimizationProblem$shuffle_columns()`
- `OptimizationProblem$copy()`
- `OptimizationProblem$clone()`

**Method** `new()`:

*Usage:*

`OptimizationProblem$new(ptr)`

*Arguments:*

`ptr Rcpp::Xptr` external pointer.

*Returns:* A new `OptimizationProblem` object.

**Method** `print()`: Print concise information about the object.

*Usage:*

`OptimizationProblem$print()`

*Returns:* Invisible TRUE.

**Method** `show()`: Print concise information about the object.

*Usage:*

`OptimizationProblem$show()`

*Returns:* Invisible TRUE.

**Method** `ncol()`: Obtain the number of columns in the problem formulation.

*Usage:*

`OptimizationProblem$ncol()`

*Returns:* A numeric value.

**Method** `nrow()`: Obtain the number of rows in the problem formulation.

*Usage:*

`OptimizationProblem$nrow()`

*Returns:* A numeric value.

**Method** `ncell()`: Obtain the number of cells in the problem formulation.

*Usage:*

`OptimizationProblem$ncell()`

*Returns:* A numeric value.

**Method** `modelsense()`: Obtain the model sense.

*Usage:*

`OptimizationProblem$modelsense()`

*Returns:* A character value.

**Method** `vtype()`: Obtain the decision variable types.

*Usage:*

```
OptimizationProblem$vtype()
```

*Returns:* A character vector.

**Method** `obj()`: Obtain the objective function.

*Usage:*

```
OptimizationProblem$obj()
```

*Returns:* A numeric vector.

**Method** `A()`: Obtain the constraint matrix.

*Usage:*

```
OptimizationProblem$A()
```

*Returns:* A `Matrix::sparseMatrix()` object.

**Method** `rhs()`: Obtain the right-hand-side constraint values.

*Usage:*

```
OptimizationProblem$rhs()
```

*Returns:* A numeric vector.

**Method** `sense()`: Obtain the constraint senses.

*Usage:*

```
OptimizationProblem$sense()
```

*Returns:* A character vector.

**Method** `lb()`: Obtain the lower bounds for the decision variables.

*Usage:*

```
OptimizationProblem$lb()
```

*Returns:* A numeric vector.

**Method** `ub()`: Obtain the upper bounds for the decision variables.

*Usage:*

```
OptimizationProblem$ub()
```

*Returns:* A numeric vector.

**Method** `number_of_features()`: Obtain the number of features.

*Usage:*

```
OptimizationProblem$number_of_features()
```

*Returns:* A numeric value.

**Method** `number_of_planning_units()`: Obtain the number of planning units.

*Usage:*

```
OptimizationProblem$number_of_planning_units()
```

*Returns:* A numeric value.

**Method** `number_of_zones()`: Obtain the number of zones.

*Usage:*

`OptimizationProblem$number_of_zones()`

*Returns:* A numeric value.

**Method** `col_ids()`: Obtain the identifiers for the columns.

*Usage:*

`OptimizationProblem$col_ids()`

*Returns:* A character value.

**Method** `row_ids()`: Obtain the identifiers for the rows.

*Usage:*

`OptimizationProblem$row_ids()`

*Returns:* A character value.

**Method** `compressed_formulation()`: Is the problem formulation compressed?

*Usage:*

`OptimizationProblem$compressed_formulation()`

*Returns:* A logical value.

**Method** `shuffle_columns()`: Shuffle the order of the columns in the optimization problem.

*Usage:*

`OptimizationProblem$shuffle_columns(order)`

*Arguments:*

`order` integer vector with new order.

*Returns:* An integer vector with indices to un-shuffle the problem.

**Method** `copy()`: Create a copy of the optimization problem.

*Usage:*

`OptimizationProblem$copy()`

*Returns:* A new `OptimizationProblem` object.

**Method** `clone()`: The objects of this class are cloneable with this method.

*Usage:*

`OptimizationProblem$clone(deep = FALSE)`

*Arguments:*

`deep` Whether to make a deep clone.

### See Also

Other classes: [ConservationModifier-class](#), [ConservationProblem-class](#), [Constraint-class](#), [Decision-class](#), [Objective-class](#), [Penalty-class](#), [Portfolio-class](#), [Solver-class](#), [Target-class](#)

---

OptimizationProblem-methods  
*Optimization problem methods*

---

**Description**

These functions are used to access data from a `optimization_problem()`.

**Usage**

```
## S4 method for signature 'OptimizationProblem'  
nrow(x)  
  
## S4 method for signature 'OptimizationProblem'  
ncol(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 `optimization_problem()` 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** `Matrix::dgCMatrix` 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 (" $\leq$ ", " $\geq$ ", "=").

**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

A `Matrix::dgCMatrix`, numeric vector, numeric vector, or scalar integer depending on the method used.

---

optimization\_problem    *Optimization problem*

---

### Description

Create a new optimization problem.

### Usage

```
optimization_problem(x = NULL)
```

### Arguments

**x**                    A NULL or list object. See Details for more information. Defaults to NULL.

### Details

The argument to `x` can be a NULL or a list. If `x` is a NULL, then an empty optimization problem is created. Alternately, if a `x` is a list then a fully formulated optimization problem is created. Specifically, the list should contain 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.

**Value**

An [OptimizationProblem](#) object.

**See Also**

[OptimizationProblem-methods](#).

**Examples**

```
# create new empty object
x1 <- optimization_problem()

# print new empty object
print(x1)

# create list with optimization problem
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, 1),
  rhs = c(2, 10),
  compressed_formulation = TRUE,
  sense = c(">=", ">="),
  vtype = c("B", "B", "B"),
  row_ids = c("spp_target", "spp_target"),
  col_ids = c("pu", "pu", "pu")
)

# create fully formulated object based on lists
x2 <- optimization_problem(l)

# print fully formulated object
print(x2)
```

---

penalties

*Add a penalty*

---

**Description**

A penalty can be applied to a conservation planning problem to penalize solutions according to a specific metric. They directly trade-off with the primary objective of a problem (e.g., the primary objective when using [add\\_min\\_set\\_objective\(\)](#) is to minimize solution cost). If you want to



generate a prioritization that only focusses on minimizing a particular penalty, then the minimum penalties objective should be used (i.e., `add_min_penalties_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 primary 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_asym_connectivity_penalties()` Add penalties to a conservation problem to account for asymmetric connectivity.

`add_connectivity_penalties()` Add penalties to a conservation problem to account for symmetric connectivity.

`add_linear_penalties()` Add penalties to a conservation problem to favor solutions that avoid selecting planning units based on a certain variable (e.g., anthropogenic pressure).

## See Also

Other overviews: [constraints](#), [decisions](#), [importance](#), [objectives](#), [portfolios](#), [solvers](#), [summaries](#), [targets](#)

## Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()

# create basic problem
p1 <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_default_solver(verbose = FALSE)

# create problem with boundary penalties
p2 <- p1 %>% add_boundary_penalties(5, 1)

# create connectivity matrix based on spatial proximity
scm <- terra::as.data.frame(sim_pu_raster, xy = TRUE, na.rm = FALSE)
scm <- 1 / (as.matrix(dist(as.matrix(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)

# create asymmetric connectivity data by randomly simulating values
acm <- matrix(runif(ncell(sim_pu_raster) ^ 2), ncol = ncell(sim_pu_raster))
acm[acm < 0.85] <- 0

# create problem with asymmetric connectivity penalties
p4 <- p1 %>% add_asym_connectivity_penalties(1, data = acm)

# create problem with linear penalties,
# here the penalties will be based on random numbers to keep it simple

# simulate penalty data
sim_penalty_raster <- simulate_cost(sim_pu_raster)

# plot penalty data
plot(sim_penalty_raster, main = "penalty data", axes = FALSE)

# create problem with linear penalties, with a penalty scaling factor of 100
p5 <- p1 %>% add_linear_penalties(100, data = sim_penalty_raster)

# solve problems
s <- c(solve(p1), solve(p2), solve(p3), solve(p4), solve(p5))
names(s) <- c(
  "basic solution", "boundary penalties", "connectivity penalties",
  "asymmetric penalties", "linear penalties"
)

# plot solutions
plot(s, axes = FALSE)

## End(Not run)

```

---

 Penalty-class

*Penalty class*


---

## Description

This class is used to represent penalties used in optimization. **Only experts should use the fields and methods for this class directly.**

## Super class

[prioritizr::ConservationModifier](#) -> Penalty

## Methods

### Public methods:

- [Penalty\\$apply\(\)](#)

- [Penalty\\$clone\(\)](#)

**Method** `apply()`: Update an optimization problem formulation.

*Usage:*

`Penalty$apply(x)`

*Arguments:*

x [optimization\\_problem\(\)](#) object.

*Returns:* Invisible TRUE.

**Method** `clone()`: The objects of this class are cloneable with this method.

*Usage:*

`Penalty$clone(deep = FALSE)`

*Arguments:*

deep Whether to make a deep clone.

### See Also

Other classes: [ConservationModifier-class](#), [ConservationProblem-class](#), [Constraint-class](#), [Decision-class](#), [Objective-class](#), [OptimizationProblem-class](#), [Portfolio-class](#), [Solver-class](#), [Target-class](#)

---

Portfolio-class

*Portfolio class*

---

### Description

This class is used to represent portfolios used in optimization. **Only experts should use the fields and methods for this class directly.**

### Super class

[prioritizr::ConservationModifier](#) -> Portfolio

### Methods

#### Public methods:

- [Portfolio\\$run\(\)](#)
- [Portfolio\\$clone\(\)](#)

**Method** `run()`: Run the portfolio to generate solutions.

*Usage:*

`Portfolio$run(x, solver)`

*Arguments:*

x [optimization\\_problem\(\)](#) object.

solver [Solver](#) object.

*Returns:* list of solutions.

**Method** `clone()`: The objects of this class are cloneable with this method.

*Usage:*

```
Portfolio$clone(deep = FALSE)
```

*Arguments:*

`deep` Whether to make a deep clone.

### See Also

Other classes: [ConservationModifier-class](#), [ConservationProblem-class](#), [Constraint-class](#), [Decision-class](#), [Objective-class](#), [OptimizationProblem-class](#), [Penalty-class](#), [Solver-class](#), [Target-class](#)

---

portfolios

*Add portfolios*

---

### Description

Conservation planning exercises rarely have access to all the data needed to identify the *truly* perfect solution. This is because available data may lack important details (e.g., land acquisition costs may be unavailable), contain errors (e.g., species presence/absence data may have false positives), or key objectives may not be formally incorporated into the prioritization process (e.g., future land use requirements). As such, conservation planners can help decision makers by providing them with a portfolio of solutions to inform their decision.

### Details

The following portfolios can be added to a conservation planning `problem()`. Note that all methods for generating portfolios return solutions that are within the specified optimality gap.

`add_default_portfolio()` Generate a portfolio containing a single solution. This portfolio method is added to `problem()` objects by default.

`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

Other overviews: [constraints](#), [decisions](#), [importance](#), [objectives](#), [penalties](#), [solvers](#), [summaries](#), [targets](#)

### Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_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 default portfolio
p1 <- p %>% add_default_portfolio()

# create problem with cuts portfolio with 4 solutions
p2 <- p %>% add_cuts_portfolio(4)

# create problem with shuffle portfolio with 4 solutions
p3 <- p %>% add_shuffle_portfolio(4)

# create problem with extra portfolio
p4 <- p %>% add_extra_portfolio()

# create problem with top portfolio with 4 solutions
p5 <- p %>% add_top_portfolio(4)

# create problem with gap portfolio with 4 solutions within 50% of optimality
p6 <- p %>% add_gap_portfolio(4, 0.5)

# solve problems to obtain solution portfolios
s <- list(solve(p1), solve(p2), solve(p3), solve(p4), solve(p5), solve(p6))
```

```

# plot solution from default portfolio
plot(terra::rast(s[[1]]), axes = FALSE)

# plot solutions from cuts portfolio
plot(terra::rast(s[[2]]), axes = FALSE)

# plot solutions from shuffle portfolio
plot(terra::rast(s[[3]]), axes = FALSE)

# plot solutions from extra portfolio
plot(terra::rast(s[[4]]), axes = FALSE)

# plot solutions from top portfolio
plot(terra::rast(s[[5]]), axes = FALSE)

# plot solutions from gap portfolio
plot(terra::rast(s[[6]]), axes = FALSE)

## End(Not run)

```

---

presolve\_check

*Presolve check*


---

## 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

```

presolve_check(x, warn = TRUE)

## S3 method for class 'ConservationProblem'
presolve_check(x, warn = TRUE)

## S3 method for class 'OptimizationProblem'
presolve_check(x, warn = TRUE)

```

## Arguments

x [problem\(\)](#) or [optimization\\_problem\(\)](#) object.

warn logical should a warning be thrown if the presolve checks fail? Defaults to TRUE.

## 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

A logical value indicating if all checks passed successfully.

### See Also

`problem()`, `solve()`, <http://www.gurobi.cn/download/GuNum.pdf>.

### Examples

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_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)

## End(Not run)

```

---

prioritizr

*prioritizr: Systematic Conservation Prioritization in R*

---

## Description

The **prioritizr R** package uses mixed integer linear programming (MILP) techniques to provide a flexible interface for building and solving conservation planning problems (Hanson *et al.* 2024). 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 (e.g., Rodrigues *et al.* 2000; Billionnet 2013). 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 (Schuster *et al.*

2020). 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 Hanson *et al.* (2024) and the [online code repository](#) for more information.

## Details

This package contains several vignettes that are designed to showcase its functionality. To view them, please use the code `vignette("name", package = "prioritizr")` where "name" is the name of the desired vignette (e.g., "gurobi\_installation").

**prioritizr** Brief introduction to systematic conservation planning and demonstration of the main package features.

**package\_overview** Comprehensive introduction to systematic conservation planning and detailed overview of the package features.

**calibrating\_trade-offs\_tutorial** Examples of balancing different criteria to identify candidate prioritizations.

**connectivity\_tutorial** Examples of incorporating and evaluating connectivity in prioritizations using a range of approaches.

**management\_zones\_tutorial** Tutorial on using multiple management actions or zones to create detailed prioritizations.

**gurobi\_installation** Instructions for installing and setting up the *Gurobi* optimization software for use with the package.

**solver\_benchmark** Reports run times for solving conservation planning problems of varying size and complexity using different solvers.

**publication\_record** List of publications that have cited the package.

## Citation

Please cite the *prioritizr* R package when using it in publications. To cite the package, please use: Hanson JO, Schuster R, Strimas-Mackey M, Morrell N, Edwards BPM, Arcese P, Bennett JR, and Possingham HP (2024) Systematic conservation prioritization with the prioritizr R package. *Conservation Biology*, In press: [doi:10.1111/cobi.14376](https://doi.org/10.1111/cobi.14376).

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## References

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Beyer HL, Dujardin Y, Watts ME, and Possingham HP (2016) Solving conservation planning problems with integer linear programming. *Ecological Modelling*, 228: 14–22.

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Hanson JO, Schuster R, Strimas-Mackey M, Morrell N, Edwards BPM, Arcese P, Bennett JR, and Possingham HP (2024) Systematic conservation prioritization with the prioritizr R package. *Conservation Biology*, In press: [doi:10.1111/cobi.14376](https://doi.org/10.1111/cobi.14376).

Rodrigues AS, Cerdeira OJ, and Gaston KJ (2000) Flexibility, efficiency, and accountability: adapting reserve selection algorithms to more complex conservation problems. *Ecography*, 23: 565–574.

Schuster R, Hanson JO, Strimas-Mackey M, and Bennett JR (2020) Exact integer linear programming solvers outperform simulated annealing for solving conservation planning problems. *PeerJ* 8: e9258

## See Also

Useful links:

- Package website (<https://prioritizr.net>)
- Source code repository (<https://github.com/prioritizr/prioritizr>)
- Report bugs (<https://github.com/prioritizr/prioritizr/issues>)

---

prioritizr-deprecated *Deprecation notice*

---

## Description

The functions listed here are deprecated. This means that they once existed in earlier versions of the of the **prioritizr** package, but they have since been removed entirely, replaced by other functions, or renamed as other functions in newer versions. To help make it easier to transition to new versions of the **prioritizr** package, we have listed alternatives for deprecated the functions (where applicable). If a function is described as being renamed, then this means that only the name of the function has changed (i.e., the inputs, outputs, and underlying code remain the same).

**Usage**

`add_connected_constraints(...)`  
`add_corridor_constraints(...)`  
`set_number_of_threads(...)`  
`get_number_of_threads(...)`  
`is.parallel(...)`  
`add_pool_portfolio(...)`  
`connected_matrix(...)`  
`feature_representation(...)`  
`replacement_cost(...)`  
`rarity_weighted_richness(...)`  
`ferrier_score(...)`  
`distribute_load(...)`  
`new_optimization_problem(...)`  
`predefined_optimization_problem(...)`

**Arguments**

... not used.

**Details**

The following functions have been deprecated:

`add_connected_constraints()` renamed as the `add_contiguity_constraints()` function.

`add_corridor_constraints()` replaced by the `add_feature_contiguity_constraints()` function.

`set_number_of_threads()` no longer needed due to improved data extraction methods.

`get_number_of_threads()` no longer needed due to improved data extraction methods.

`is.parallel()` no longer needed due to improved data extraction methods.

`add_pool_portfolio()` replaced by the `add_extra_portfolio()` and `add_top_portfolio()`.

`connected_matrix()` renamed as the `adjacency_matrix()` function.

`feature_representation()` replaced by the `eval_feature_representation_summary()` function for consistency with other functions.

`replacement_cost()` renamed as the `eval_replacement_importance()` function for consistency with other functions for evaluating solutions.

`rarity_weighted_richness()` renamed as the `eval_rare_richness_importance()` function for consistency with other functions for evaluating solutions.

`ferrier_score()` renamed as the `eval_ferrier_importance()` function for consistency with other functions for evaluating solutions.

`distribute_load()` has been removed because it is no longer used. See `parallel::splitIndices()` for equivalent functionality.

`new_optimization_problem()` replaced by `optimization_problem()`.

`predefined_optimization_problem()` replaced by `optimization_problem()`.

---

problem	<i>Conservation planning problem</i>
---------	--------------------------------------

---

## 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 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

```
problem(x, features, ...)

## S4 method for signature 'SpatRaster,SpatRaster'
problem(x, features, run_checks, ...)

## S4 method for signature 'SpatRaster,ZonesSpatRaster'
problem(x, features, run_checks, ...)

## S4 method for signature 'data.frame,character'
problem(x, features, cost_column, ...)

## S4 method for signature 'data.frame,ZonesCharacter'
problem(x, features, cost_column, ...)

## S4 method for signature 'data.frame,data.frame'
problem(x, features, rij, cost_column, zones, ...)

## S4 method for signature 'numeric,data.frame'
problem(x, features, rij_matrix, ...)

## S4 method for signature 'matrix,data.frame'
```

```

problem(x, features, rij_matrix, ...)

## S4 method for signature 'sf,SpatRaster'
problem(x, features, cost_column, run_checks, ...)

## S4 method for signature 'sf,ZonesSpatRaster'
problem(x, features, cost_column, run_checks, ...)

## S4 method for signature 'sf,character'
problem(x, features, cost_column, ...)

## S4 method for signature 'sf,ZonesCharacter'
problem(x, features, cost_column, ...)

## 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, ...)

## S4 method for signature 'Spatial,ZonesRaster'
problem(x, features, cost_column, run_checks, ...)

## S4 method for signature 'Spatial,character'
problem(x, features, cost_column, ...)

## S4 method for signature 'Spatial,ZonesCharacter'
problem(x, features, cost_column, ...)

## S4 method for signature 'sf,Raster'
problem(x, features, cost_column, run_checks, ...)

## S4 method for signature 'sf,ZonesRaster'
problem(x, features, cost_column, run_checks, ...)

```

## Arguments

- |          |   |
|----------|---|
| x        | <a href="#">terra::rast()</a> , <a href="#">sf::st_sf()</a> , data.frame, matrix, or numeric vector 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 <a href="#">add_locked_out_constraints()</a> 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 **has** `terra::rast()` or `sf::st_sf()` **planning units** The argument to features can be a `terra::rast()` 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 **has** `sf::st_sf()` or `data.frame` **planning units** The argument to features can be a character vector with column names (from x) 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 **has** `data.frame`, `matrix`, or numeric **vector planning units** The argument to features can be a `data.frame` object containing the names of the features. Note that if this type of argument is supplied to features then the argument `rij` or `rij_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 `rij`.
  - 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 **has** `terra::rast()` or `sf::st_sf()` **planning units** The argument to features can be a `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 **has** `sf::st_sf()` or `data.frame` **planning units** The argument to features can be a `ZonesCharacter` object with column names (from x) that correspond to the abundance or occurrence of different features in each planning unit in different zones.

...	not used.
<code>run_checks</code>	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 datasets they may increase run time. If it is taking a prohibitively long time to create the prioritization problem, try setting <code>run_checks</code> to <code>FALSE</code> .
<code>cost_column</code>	character name or integer indicating the column(s) with the cost data. This argument must be supplied when the argument to x is a <code>sf::st_sf()</code> or <code>data.frame</code> 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 <code>cost_column</code> as a single column name.

<code>rij</code>	<p><code>data.frame</code> containing information on the amount of each feature in each planning unit assuming each management zone. Similar to <code>data.frame</code> arguments for features, the <code>data.frame</code> objects must follow the conventions used by <i>Marxan</i>. Note that the "zone" column is not needed for problems involving a single management zone. Specifically, the argument should contain the following columns:</p> <p><b>pu</b> integer planning unit identifier.  <b>species</b> integer feature identifier.  <b>zone</b> integer zone identifier (optional for problems involving a single zone).  <b>amount</b> numeric amount of the feature in the planning unit.</p>
<code>zones</code>	<p><code>data.frame</code> containing information on the zones. This argument is only used when argument to <code>x</code> and <code>features</code> are both <code>data.frame</code> objects and the problem being built contains multiple zones. Following conventions used in <i>MarZone</i>, this argument should contain the following columns: columns:</p> <p><b>id</b> integer zone identifier.  <b>name</b> character zone name.</p>
<code>rij_matrix</code>	<p>list of <code>matrix</code> or <code>Matrix::dgMatrix</code> 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 <code>rij_matrix</code> can be a single <code>matrix</code> or <code>Matrix::dgMatrix</code> when specifying a problem with a single management zone. This argument is only used when the argument to <code>x</code> is a numeric or <code>matrix</code> object.</p>

## Details

A systematic conservation planning exercise leverages data to help inform conservation decision making. To help ensure that the data – and resulting prioritizations – are relevant to the over-arching goals of the exercise, you should decide on the management action (or set of actions) that need be considered in the exercise. For example, these actions could include establishing protected areas, selecting land for conservation easements, restoring habitat, planting trees for carbon sequestration, eradicating invasive species, or some combination of the previous actions. If the exercise involves multiple different actions, they can be incorporated by using multiple zones (see the Management Zones vignette for details). After deciding on the management action(s), you can compile the following data.

First, you will need to create a set of planning units (i.e., discrete spatial areas) to inform decision making. Planning units are often created by subdividing a study region into a set of square or hexagonal cells. They can also be created using administrative boundaries (e.g., provinces), land management boundaries (e.g., property boundaries derived from cadastral data), or ecological boundaries (e.g., based on ecosystem classification data). The size (i.e., spatial grain) of the planning units is often determined based on a compromise between the scale needed to inform decision making, the spatial accuracy (resolution) of available datasets, and the computational resources available for generating prioritizations (e.g., RAM and number of CPU cores on your computer).

Second, you will need data to quantify the cost of implementing each management action within each planning unit. Critically, the cost data should reflect the management action(s) considered in the exercise. For example, costs are often specified using data that reflect economic expenditure



(e.g., land acquisition cost), socioeconomic conditions (e.g., human population density), opportunity costs of foregone commercial activities (e.g., logging or agriculture), or opportunity costs of foregone recreational activities (e.g., recreational fishing). In some cases – depending on the management action(s) considered – it can make sense to use a constant cost value (e.g., all planning units are assigned a cost value equal to one) or use a cost value based on spatial extent (e.g., each planning unit is assigned a cost value based on its total area). Also, in most cases, you want to avoid negative cost values. This is because a negative value means that a place is *desirable* for implementing a management action, and such places will almost always be selected for prioritization even if they provide no benefit.

Third, you will need data to quantify the benefits of implementing management actions within planning units. To achieve this, you will need to select a set of conservation features that relate to the over-arching goals of the exercise. For example, conservation features often include species (e.g., Clouded Leopard), habitats (e.g., mangroves or cloud forest), or ecosystems. The benefit that each feature derives from a planning unit can take a variety of forms, but is typically occupancy (i.e., presence or absence), area of occurrence within each planning unit (e.g., based on species' geographic range data), or a measure of habitat suitability (e.g., estimated using a statistical model). After compiling these data, you have the minimal data needed to generate a prioritization.

A systematic conservation planning exercise involves prioritizing a set of management actions to be implemented within certain planning units. Critically, this prioritization should ideally optimize the trade-off between benefits and costs. To accomplish this, the **prioritizr** package uses input data to formulate optimization problems (see Optimization section for details). Broadly speaking, the goal of an optimization problem is to minimize (or maximize) an objective function over a set of decision variables, subject to a series of constraints. Here, an objective function specifies the metric for evaluating conservation plans. The decision variables are what we control, and usually there is one binary variable for each planning unit to specify whether that unit is selected or not (but other approaches are available, see [decisions](#)). The constraints can be thought of as rules that must be followed. For example, constraints can be used to ensure a prioritization must stay within a certain budget. These constraints can also leverage additional data to help ensure that prioritizations meet the over-arching goals of the exercise. For example, to account for existing conservation efforts, you could obtain data delineating the extent of existing protected areas and use constraints to lock in planning units that are covered by them (see [add\\_locked\\_in\\_constraints](#)).

## Value

A new `problem()` ([ConservationProblem](#)) object.

## Optimization

The **prioritizr** package uses exact algorithms to solve reserve design problems (see [solvers](#) for details). To achieve this, it internally formulates mathematical optimization problems using mixed integer linear programming (MILP). The general form of such problems can be expressed in matrix notation using the following equation.

$$\text{Minimize } \mathbf{c}^T \mathbf{x} \text{ subject to } \mathbf{A}\mathbf{x} \geq \text{ or } \leq \mathbf{b}$$

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  $j$ . If you wish to see exactly how a conservation planning problem is formulated as mixed integer linear programming problem, you can use the `write_problem()` function to save the optimization problem to a plain-text file on your computer and then view it using a standard text editor (e.g., Notepad).

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()` function). As a consequence, it can take a while to initialize large-scale conservation planning problems that involve millions of planning units.

### See Also

See `solve()` for details on solving a problem to generate solutions. Also, see [objectives](#), [penalties](#), [targets](#), [constraints](#), [decisions](#), [portfolios](#), [solvers](#) for information on customizing problems. Additionally, see [summaries](#) and [importance](#) for information on evaluating solutions.

### Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_pu_polygons <- get_sim_pu_polygons()
sim_pu_points <- get_sim_pu_points()
sim_pu_lines <- get_sim_pu_lines()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_pu_polygons <- get_sim_zones_pu_polygons()
sim_zones_features <- get_sim_zones_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() %>%
  add_default_solver(verbose = FALSE)

# create problem using polygon planning unit data
p2 <-
  problem(sim_pu_polygons, sim_features, "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# create problem using line planning unit data
p3 <-
  problem(sim_pu_lines, sim_features, "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
```

```

    add_binary_decisions() %>%
    add_default_solver(verbose = FALSE)

# create problem using point planning unit data
p4 <-
  problem(sim_pu_points, sim_features, "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# since geo-processing can be slow for large spatial vector datasets
# (e.g., polygons, lines, points), it can be worthwhile to pre-process the
# planning unit data so that it contains columns indicating the amount of
# each feature inside each planning unit
# (i.e., each column corresponds to a different feature)

# calculate the amount of each species within each planning unit
pre_proc_data <- rij_matrix(sim_pu_polygons, sim_features)

# add extra columns to the polygon planning unit data
# to indicate the amount of each species within each planning unit
pre_proc_data <- as.data.frame(t(as.matrix(pre_proc_data)))
names(pre_proc_data) <- names(sim_features)
sim_pu_polygons <- cbind(sim_pu_polygons, pre_proc_data)

# create problem using the polygon planning unit data
# with the pre-processed columns
p5 <-
  problem(sim_pu_polygons, features = names(pre_proc_data), "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# in addition to spatially explicit data, pre-processed aspatial data
# can also be used to create a problem
# (e.g., data created using external spreadsheet software)
costs <- sim_pu_polygons$cost
features <- data.frame(
  id = seq_len(terra::nlyr(sim_features)),
  name = names(sim_features)
)
rij_mat <- rij_matrix(sim_pu_polygons, sim_features)
p6 <-
  problem(costs, features, rij_matrix = rij_mat) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.2) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problems
s1 <- solve(p1)

```

```

s2 <- solve(p2)
s3 <- solve(p3)
s4 <- solve(p4)
s5 <- solve(p5)
s6 <- solve(p6)

# plot solutions for problems associated with spatial data
plot(s1, main = "raster data", axes = FALSE)
plot(s2[, "solution_1"], main = "polygon data")
plot(s3[, "solution_1"], main = "line data")
plot(s4[, "solution_1"], main = "point data")
plot(s5[, "solution_1"], main = "preprocessed data (polygon data)")

# show solutions for problems associated with aspatial data
str(s6)

# 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_zones_features),
  ncol = number_of_zones(sim_zones_features),
  dimnames = list(
    feature_names(sim_zones_features), zone_names(sim_zones_features)
  )
)

# print targets
print(targets)

# create a multi-zone problem with raster data
p7 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_min_set_objective() %>%
  add_absolute_targets(targets) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s7 <- solve(p7)

# 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(s7, main = c("zone 1", "zone 2", "zone 3"), axes = 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(s7), axes = FALSE)

# create a multi-zone problem with polygon data
p8 <-
  problem(
    sim_zones_pu_polygons, sim_zones_features,
    cost_column = c("cost_1", "cost_2", "cost_3")
  ) %>%
  add_min_set_objective() %>%
  add_absolute_targets(targets) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s8 <- solve(p8)

# create column containing the zone id for which each planning unit was
# allocated to in the solution
s8$solution <- category_vector(sf::st_drop_geometry(
  s8[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
))
s8$solution <- factor(s8$solution)

# plot solution
plot(s8[, "solution"], axes = FALSE)

# create a multi-zone problem with polygon planning unit data
# and where columns correspond to feature abundances

# to begin with, we will add columns to the planning unit data
# that indicate the amount of each feature in each zone
sim_zones_pu_polygons$spp1_z1 <- rpois(nrow(sim_zones_pu_polygons), 1)
sim_zones_pu_polygons$spp2_z1 <- rpois(nrow(sim_zones_pu_polygons), 1)
sim_zones_pu_polygons$spp3_z1 <- rpois(nrow(sim_zones_pu_polygons), 1)
sim_zones_pu_polygons$spp1_z2 <- rpois(nrow(sim_zones_pu_polygons), 1)
sim_zones_pu_polygons$spp2_z2 <- rpois(nrow(sim_zones_pu_polygons), 1)
sim_zones_pu_polygons$spp3_z2 <- rpois(nrow(sim_zones_pu_polygons), 1)

# create problem with polygon planning unit data and use column 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
p9 <-
  problem(
    sim_zones_pu_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() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s9 <- solve(p9)

# plot solution
plot(s9[, c("solution_1_z1", "solution_1_z2")], axes = FALSE)

## End(Not run)

```

---

proximity_matrix	<i>Proximity matrix</i>
------------------	-------------------------

---

## 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 'SpatRaster'
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	<a href="#">terra::rast()</a> or <a href="#">sf::sf()</a> 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 [sf::st\\_is\\_within\\_distance\(\)](#).

**Value**

A [Matrix::dsCMatrix](#) symmetric sparse matrix object. 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 [terra::rast\(\)](#) object, then cells with missing (NA) values are set to zero too.

**See Also**

Proximity matrix data might need rescaling to improve optimization performance, see [rescale\\_matrix\(\)](#) to perform these calculations.

**Examples**

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_pu_polygons <- get_sim_pu_polygons()
sim_pu_lines <- get_sim_pu_lines()
sim_pu_points <- get_sim_pu_points()

# create proximity matrix using raster data
## crop raster to 9 cells to provide a small example
r <- terra::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 data
## subset 9 polygons to provide a small example
ply <- sim_pu_polygons[c(1:3, 11:13, 20:22), ]

## make proximity matrix using a distance threshold of 2
cm_ply <- proximity_matrix(ply, distance = 2)

# create proximity matrix using line data
## subset 9 lines to provide a small example
lns <- sim_pu_lines[c(1:3, 11:13, 20:22), ]

## make proximity matrix
cm_lns <- proximity_matrix(lns, distance = 2)
```

```

## create proximity matrix using point data
## subset 9 points to provide a small example
pts <- sim_pu_points[c(1:3, 11:13, 20:22), ]

# make proximity matrix
cm_pts <- proximity_matrix(pts, distance = 2)

## plot raster and proximity matrix
plot(r, main = "raster", axes = FALSE)
Matrix::image(cm_raster, main = "proximity matrix")

## plot polygons and proximity matrix
plot(ply[, 1], main = "polygons", axes = FALSE)
Matrix::image(cm_ply, main = "proximity matrix")

## plot lines and proximity matrix
plot(lns[, 1], main = "lines", axes = FALSE)
Matrix::image(cm_lns, main = "proximity matrix")

## plot points and proximity matrix
plot(pts[, 1], main = "points", axes = FALSE)
Matrix::image(cm_pts, main = "proximity matrix")

## End(Not run)

```

---

rescale\_matrix

*Rescale a matrix*


---

### Description

Linearly rescale a matrix. Specifically, the values in the matrix are rescaled so that the maximum value in the matrix is equal to a new user-specified maximum value.

### Usage

```
rescale_matrix(x, max = 1000)
```

### Arguments

x	matrix, array, <code>Matrix::Matrix</code> object.
max	numeric new maximum value in matrix. Defaults to 1000.

### Details

This function is particularly useful for rescaling data prior to optimization to avoid numerical issues. For example, boundary length (e.g., generated using `boundary_matrix()`) or connectivity data (e.g., generated using `connectivity_matrix()`) can contain very large values (e.g., values



greater than 1,000,000) and such large values can, in turn, degrade the performance of exact algorithm solvers (see Details section in [presolve\\_check\(\)](#) for more information on numerical issues). By using this function to rescale boundary length or connectivity data prior to optimization (e.g., before using [add\\_boundary\\_penalties\(\)](#) or [add\\_connectivity\\_penalties\(\)](#)), this can help avoid numerical issues during optimization.

### Value

A [matrix](#), [array](#), or [Matrix::Matrix](#) object. The returned object is the same class as the argument to `x`.

### See Also

See [boundary\\_matrix\(\)](#) and [connectivity\\_matrix\(\)](#) for details on creating boundary length and connectivity data. Also, see [presolve\\_check\(\)](#) for information on numerical issues.

### Examples

```
# TODO
```

---

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 'SpatRaster,SpatRaster'
rij_matrix(x, y, memory, idx, ...)
```

```
## S4 method for signature 'sf,SpatRaster'
rij_matrix(x, y, fun, memory, idx, ...)
```

```
## S4 method for signature 'Raster,Raster'
rij_matrix(x, y, memory, idx, ...)
```

```
## S4 method for signature 'sf,Raster'
rij_matrix(x, y, fun, memory, idx, ...)
```

```
## S4 method for signature 'Spatial,Raster'
rij_matrix(x, y, fun, memory, idx, ...)
```

**Arguments**

x	<code>terra::rast()</code> or <code>sf::sf()</code> object representing planning units.
y	<code>terra::rast()</code> object.
...	not used.
memory	logical should calculations be performed using a method that prioritizes reduced memory consumption over speed? This is useful when processing particularly large raster datasets. If TRUE, then calculations are performed by processing each raster layer in y in a sequential manner. If FALSE, then calculations are performed by processing all raster layers in y together. If NA, then the memory requirements will be estimated and, if required, processing will be performed using the method that reduces memory consumption. Defaults to NA.
idx	integer vector containing planning unit indices. Defaults to NULL such that the indices are computed automatically based on x.
fun	character for summarizing values inside each planning unit. This parameter is only used when the argument to x is a <code>sf::sf()</code> object. Defaults to "sum".

**Details**

Generally, processing `sf::st_sf()` data takes much longer to process than `terra::rast()` data. As such, it is recommended to use `terra::rast()` data for planning units where possible. The performance of this function for large `terra::rast()` datasets can be improved by increasing the GDAL cache size. The default cache size is 25 MB. For example, the following code can be used to set the cache size to 4 GB.

```
terra::gdalCache(size = 4000)
```

**Value**

A `Matrix::dgCMatrix` sparse matrix object. The sparse matrix represents the spatial intersection between the planning units and the features. Rows correspond to features, and columns correspond to planning units. Values correspond to the amount (or presence/absence) 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**

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_pu_polygons <- get_sim_pu_polygons()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_features <- get_sim_features()

# 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 planning units
```

```
rij_polygons <- rij_matrix(sim_pu_polygons, sim_features)
print(rij_polygons)

# create rij matrix using raster planning units with multiple zones
rij_zones_raster <- rij_matrix(sim_zones_pu_raster, sim_features)
print(rij_zones_raster)

## End(Not run)
```

---

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                    `problem()` object.

## Details

This function is used for the effect of modifying the input `ConservationProblem` object. As such, it does not return anything. To use this function with `pipe()` operators, use the `%T>%` operator and not the `%>%` operator.

## Value

An invisible TRUE indicating success.

## Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()

# 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) %>%
add_binary_decisions() %>%
add_default_solver(verbose = FALSE)

# 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) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE) %T>%
  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 time by running the preliminary
# calculations before making copies of the problem with slightly
# different constraints. Although the time saved in this example
# is rather small, this is because the example data are very small.
# We would expect larger time savings for larger datasets.

## End(Not run)

```

---

show	<i>Show</i>
------	-------------

---

**Description**

Display information about an object.

**Usage**

```
## S4 method for signature 'ConservationModifier'  
show(x)
```

```
## S4 method for signature 'ConservationProblem'  
show(x)
```

```
## S4 method for signature 'OptimizationProblem'  
show(x)
```

```
## S4 method for signature 'Solver'  
show(x)
```

**Arguments**

x            Any object.

**Value**

None.

**See Also**

[methods::show\(\)](#).

---

simulate_cost	<i>Simulate cost data</i>
---------------	---------------------------

---

**Description**

Generates simulated cost data using Gaussian random fields.

**Usage**

```
simulate_cost(x, n, intensity, sd, scale)

## S3 method for class 'Raster'
simulate_cost(x, n = 1, intensity = 100, sd = 20, scale = 2.5)

## S3 method for class 'SpatRaster'
simulate_cost(x, n = 1, intensity = 100, sd = 20, scale = 2.5)
```

**Arguments**

x	<a href="#">terra::rast()</a> object to use as a template.
n	integer number of layers to simulate. Defaults to 1.
intensity	numeric average value of simulated data. Defaults to 100.
sd	numeric standard deviation of simulated data. Defaults to 20.
scale	numeric parameter to control level of spatial auto-correlation in the simulated data. Defaults to 2.5.

**Value**

A [terra::rast\(\)](#) object with integer values greater than zero.

**See Also**

Other simulations: [simulate\\_data\(\)](#), [simulate\\_species\(\)](#)

**Examples**

```
## Not run:
# create raster
r <- terra::rast(
  ncols = 10, nrows = 10, xmin = 0, xmax = 1, ymin = 0, ymax = 1, vals = 1
)

# simulate data
cost <- simulate_cost(r)

# plot simulated species
plot(cost, main = "simulated cost data", axes = FALSE)

## End(Not run)
```

---

simulate_data	<i>Simulate data</i>
---------------	----------------------

---

### Description

Simulate spatially auto-correlated data using Gaussian random fields.

### Usage

```
simulate_data(x, n, scale, intensity, sd, transform)
```

```
## S3 method for class 'Raster'
```

```
simulate_data(  
  x,  
  n = 1,  
  scale = 0.5,  
  intensity = 0,  
  sd = 1,  
  transform = identity  
)
```

```
## S3 method for class 'SpatRaster'
```

```
simulate_data(  
  x,  
  n = 1,  
  scale = 0.5,  
  intensity = 0,  
  sd = 1,  
  transform = identity  
)
```

### Arguments

x	<code>terra::rast()</code> object to use as a template.
n	integer number of layers to simulate. Defaults to 1.
scale	numeric parameter to control level of spatial auto-correlation in the simulated data. Defaults to 0.5.
intensity	numeric average value of simulated data. Defaults to 0.
sd	numeric standard deviation of simulated data. Defaults to 1.
transform	function transform values output from the simulation. Defaults to the <code>identity()</code> function such that values remain the same following transformation.

### Value

A `terra::rast()` object.

## See Also

Other simulations: [simulate\\_cost\(\)](#), [simulate\\_species\(\)](#)

## Examples

```
## Not run:
# create raster
r <- terra::rast(
  ncols = 10, nrows = 10, xmin = 0, xmax = 1, ymin = 0, ymax = 1, vals = 1
)

# simulate data using a Gaussian field
x <- simulate_data(r, n = 1, scale = 0.2)

# plot simulated data
plot(x, main = "simulated data", axes = FALSE)

## End(Not run)
```

---

simulate_species	<i>Simulate species habitat suitability data</i>
------------------	--

---

## Description

Generates simulated species data using Gaussian random fields.

## Usage

```
simulate_species(x, n, scale)

## S3 method for class 'Raster'
simulate_species(x, n = 1, scale = 0.5)

## S3 method for class 'SpatRaster'
simulate_species(x, n = 1, scale = 0.5)
```

## Arguments

x	<a href="#">terra::rast()</a> object to use as a template.
n	integer number of layers to simulate. Defaults to 1.
scale	numeric parameter to control level of spatial auto-correlation in the simulated data. Defaults to 0.5.

## Value

A [terra::rast\(\)](#) object with values between zero and one.



**See Also**

Other simulations: [simulate\\_cost\(\)](#), [simulate\\_data\(\)](#)

**Examples**

```
## Not run:
# create raster
r <- terra::rast(
  ncols = 10, nrows = 10, xmin = 0, xmax = 1, ymin = 0, ymax = 1, vals = 1
)

# simulate data for 4 species
spp <- simulate_species(r, 4)

# plot simulated species
plot(spp, main = "simulated species distributions", axes = FALSE)

## End(Not run)
```

---

sim\_data

*Get simulated conservation planning data*

---

**Description**

A set of functions are available for importing simulated datasets. These datasets are designed for creating small example spatial prioritizations.

**Usage**

```
get_sim_pu_polygons()
get_sim_zones_pu_polygons()
get_sim_pu_lines()
get_sim_pu_points()
get_sim_pu_raster()
get_sim_locked_in_raster()
get_sim_locked_out_raster()
get_sim_zones_pu_raster()
get_sim_features()
```

```
get_sim_zones_features()
```

```
get_sim_phylogeny()
```

### Format

```
get_sim_pu_polygons() sf::st_sf() object.
get_sim_zones_pu_polygons() sf::st_sf() object.
get_sim_pu_lines() sf::st_sf() object.
get_sim_pu_points() sf::st_sf() object.
get_sim_pu_raster() terra::rast() object.
get_sim_zones_pu_raster() terra::rast() object.
get_sim_locked_in_raster() terra::rast() object.
get_sim_locked_out_raster() terra::rast() object.
get_sim_features() terra::rast() object.
get_sim_zones_features() ZonesRaster() object.
get_sim_phylogeny() terra::rast() object.
```

### Single zone datasets

The following functions are provided for generating spatial prioritizations that only contain a single management zone.

```
get_sim_pu_raster() Import planning unit data that are stored in raster format. Here, cell values indicate planning unit cost and missing (NA) values indicate that a cell is not a planning unit.
get_sim_locked_in_raster() Import planning unit data that are stored in raster format. Here, cell values are binary and indicate if planning units should be locked in to a solution.
get_sim_locked_out_raster() Import planning unit data that are stored in raster format. Here, cell values are binary and indicate if planning units should be locked out from a solution.
get_sim_pu_polygons() Import planning unit data stored in vector format. Here, planning units are represented using spatial polygons (e.g., each polygon corresponds to a different management areas). The data contains columns indicating the expenditure required for prioritizing each planning unit ("cost" column), if the planning units should be selected in the solution ("locked_in" column), and if the planning units should never be selected in the solution ("locked_out" column).
get_sim_pu_points() Import planning unit data stored in vector format. Here, planning units are represented using spatial lines (e.g., each line corresponds to a different section along a river) . The attribute table follows the same conventions as for sim_pu_polygons.
get_sim_pu_lines() Import planning unit data stored in vector format. Here, planning units are represented using spatial points (e.g., each point corresponds to a different site) . The attribute table follows the same conventions as for sim_pu_polygons.
get_sim_features() Import feature data stored in raster format. Here, data describe the spatial distribution of five species. Each layer corresponds to a different species, and cell values indicate habitat suitability.
get_sim_phylogeny() Import phylogenetic tree for the ten species.
```

### Multiple zone datasets

The following functions are provided for generating spatial prioritizations that contain multiple management zones.

`get_sim_zones_pu_raster()` Import planning unit data for multiple management zones that are stored in raster format. Here, each layer indicates the cost for a different management zone. Cells with NA values in a given zone indicate that a planning unit cannot be allocated to that zone in a solution. Additionally, cells with NA values in all layers are not a planning unit.

`get_sim_zones_pu_polygons()` Import planning unit data for multiple management zones stored in vector format. Here, planning units are represented using spatial polygons. The data contains columns indicating the expenditure required for prioritizing each planning unit under different management zones ("cost\_1", "cost\_2", and "cost\_3" columns), and a series of columns indicating the value that each planning unit that should be assigned in the solution ("locked\_1", "locked\_2", "locked\_3" columns). In these locked columns, planning units that should not be locked to a specific value are assigned a missing (NA) value.

`get_sim_zones_features()` Import feature data for multiple management zones stored in raster format. Here, data describe the spatial distribution of ten species under three different management zones.

### Examples

```
# load data
sim_pu_polygons <- get_sim_pu_polygons()
sim_zones_pu_polygons <- get_sim_zones_pu_polygons()
sim_pu_lines <- get_sim_pu_lines()
sim_pu_points <- get_sim_pu_points()
sim_pu_raster <- get_sim_pu_raster()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_locked_in_raster <- get_sim_locked_in_raster()
sim_locked_out_raster <- get_sim_locked_out_raster()
sim_phylogeny <- get_sim_phylogeny()
sim_features <- get_sim_features()
sim_zones_features <- get_sim_zones_features()

# plot raster data
## Not run:
par(mfrow = c(2, 2))
plot(sim_pu_raster, main = "planning units (raster)", axes = FALSE)
plot(sim_locked_in_raster, main = "locked in units (raster)", axes = FALSE)
plot(sim_locked_out_raster, main = "locked out units (raster)", axes = FALSE)

# plot vector planning unit data
par(mfrow = c(1, 1))
plot(sim_pu_polygons)
plot(sim_pu_lines)
plot(sim_pu_points)

# plot vector planning unit data for multiple management zones
plot(sim_zones_pu_polygons)
```

```

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

# plot feature data
par(mfrow = c(1, 1))
plot(sim_features, axes = FALSE)

# plot cost data for multiple management zones
par(mfrow = c(1, 1))
plot(sim_zones_pu_raster, axes = FALSE)

# plot feature data for multiple management zones
plot_names <- paste0(
  "Species ",
  rep(
    seq_len(number_of_zones(sim_zones_features)),
    number_of_features(sim_zones_features)
  ),
  " (zone ",
  rep(
    seq_len(number_of_features(sim_zones_features)),
    each = number_of_zones(sim_zones_features)
  ),
  ")"
)
plot(
  terra::rast(as.list(sim_zones_features)),
  main = plot_names, axes = FALSE
)

## End(Not run)

```

---

solve

*Solve*

---

### Description

Solve a conservation planning problem.

### Usage

```

## S3 method for class 'ConservationProblem'
solve(a, b, ..., run_checks = TRUE, force = FALSE)

```

### Arguments

a                    [problem\(\)](#) object.  
b                    missing.

...	arguments passed to <code>compile()</code> .
<code>run_checks</code>	logical flag indicating whether presolve checks should be run prior solving the problem. These checks are performed using the <code>presolve_check()</code> function. Defaults to TRUE. Skipping these checks may reduce run time for large problems.
<code>force</code>	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.

### Details

After formulating a conservation planning `problem()`, it can be solved using an exact algorithm solver (see `solvers` for available solvers). If no solver has been explicitly specified, then the best available exact algorithm solver will be used by default (see `add_default_solver()`). Although these exact algorithm solvers will often display a lot of information that isn't really that helpful (e.g., nodes, cutting planes), they do display information about the progress they are making on solving the problem (e.g., the performance of the best solution found at a given point in time). If potential issues were detected during the presolve checks (see `presolve_check()`) and the problem is being forcibly solved (i.e., with `force = TRUE`), then it is also worth checking for any warnings displayed by the solver to see if these potential issues are actually causing issues (e.g., *Gurobi* can display warnings that include "Warning: Model contains large matrix coefficient range" and "Warning: Model contains large rhs").

### Value

A numeric, matrix, data.frame, `sf::st_sf()`, or `terra::rast()` object containing the solution to the problem. Additionally, the returned object has attributes that describe optimization process or solution (see below for examples on accessing these attributes). These attributes provide the following information.

- `objective` numeric mathematical objective value for the solution used to evaluate the prioritization during optimization.
- `runtime` numeric total amount of time elapsed while during the optimization process (reported in seconds). Note that this measure of time does not include any data pre-processing or post-processing steps.
- `status` character status of the optimization process. This status typically describes the reason why the optimization process terminated. For example, it might indicate that the optimization process terminated because an optimal solution was found, or because a pre-specified time limit was reached. These status values are (mostly) obtained directly from the solver software, and so we recommend consulting the solver's documentation for further information on what particular status values mean. Note that some solvers (e.g., Gurobi and HiGHS) will return an "OPTIMAL" status when the solver has found a solution within the pre-specified optimality gap (e.g., it has found a solution within 10% of optimality), even though the solution itself may not be strictly optimal.
- `gap` numeric optimality of the solution. This gap value provides an upper bound of how far the solution is from optimality. For example, you might specify a 10% optimality gap for the optimization process (e.g., using `add_highs_solver(gap = 0.1)`), and this might produce a solution that is actually 5% from optimality. As such, the solution might have a gap value of 0.05 (corresponding to 5%). Because this value represents an upper bound, it is also possible

that the solution in this example – even though it is actually 5% from optimality – might have a gap value of 7% (i.e., 0.07). Note that only some solvers are able to provide this information (i.e., the *Gurobi* and *HiGHS* solvers), and the gap value for other solvers will contain missing (NA) values.

### Output format

This function will output solutions in a similar format to the planning units associated with a. Specifically, it will return solutions based on the following types of planning units.

- a **has numeric planning units** The solution will be returned as a numeric vector. Here, each element in the vector corresponds to a different planning unit. Note that if a portfolio is used to generate multiple solutions, then a list of such numeric vectors will be returned.
- a **has matrix planning units** The solution will be returned as a matrix object. Here, rows correspond to different planning units, and columns correspond to different management zones. Note that if a portfolio is used to generate multiple solutions, then a list of such matrix objects will be returned.
- a **has terra::rast() planning units** The solution will be returned as a `terra::rast()` object. If the argument to `x` contains multiple zones, then the object will have a different layer for each management zone. Note that if a portfolio is used to generate multiple solutions, then a list of `terra::rast()` objects will be returned.
- a **has sf::sf(), or data.frame planning units** The solution will be returned in the same data format as the planning units. Here, each row corresponds to a different planning unit, and columns contain solutions. If the argument to `a` contains a single zone, then the solution object will contain columns named by solution. Specifically, the column names containing the solution values will be named as "solution\_XXX" where "XXX" corresponds to a solution identifier (e.g., "solution\_1"). If the argument to `a` contains multiple zones, then the columns containing solutions will be named as "solution\_XXX\_YYY" where "XXX" corresponds to the solution identifier and "YYY" is the name of the management zone (e.g., "solution\_1\_zone1").

### See Also

See `problem()` to create conservation planning problems, and `presolve_check()` to check problems for potential issues. Also, see the `category_layer()` and `category_vector()` function to reformat solutions that contain multiple zones.

### Examples

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_raster <- get_sim_pu_raster()
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()
sim_zones_pu_raster <- get_sim_zones_pu_raster()
sim_zones_pu_polygons <- get_sim_zones_pu_polygons()
sim_zones_features <- get_sim_zones_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(verbose = FALSE)

# solve the problem
s1 <- solve(p1)

# print solution
print(s1)

# print attributes describing the optimization process and the solution
print(attr(s1, "objective"))
print(attr(s1, "runtime"))
print(attr(s1, "status"))
print(attr(s1, "gap"))

# calculate feature representation in the solution
r1 <- eval_feature_representation_summary(p1, s1)
print(r1)

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

# build minimal conservation problem with polygon data
p2 <-
  problem(sim_pu_polygons, sim_features, cost_column = "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve the problem
s2 <- solve(p2)

# print solution
print(s2)

# calculate feature representation in the solution
r2 <- eval_feature_representation_summary(p2, s2[, "solution_1"])
print(r2)

# plot solution
plot(s2[, "solution_1"], main = "solution", axes = FALSE)

# build multi-zone conservation problem with raster data
p3 <-
  problem(sim_zones_pu_raster, sim_zones_features) %>%
  add_min_set_objective() %>%
```

```

add_relative_targets(matrix(runif(15, 0.1, 0.2), nrow = 5, ncol = 3)) %>%
add_binary_decisions() %>%
add_default_solver(verbose = FALSE)

# solve the problem
s3 <- solve(p3)

# print solution
print(s3)

# calculate feature representation in the solution
r3 <- eval_feature_representation_summary(p3, s3)
print(r3)

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

# build multi-zone conservation problem with polygon data
p4 <-
  problem(
    sim_zones_pu_polygons, sim_zones_features,
    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() %>%
  add_default_solver(verbose = FALSE)

# solve the problem
s4 <- solve(p4)

# print solution
print(s4)

# calculate feature representation in the solution
r4 <- eval_feature_representation_summary(
  p4, s4[, c("solution_1_zone_1", "solution_1_zone_2", "solution_1_zone_3")]
)
print(r4)

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

# plot solution
plot(s4[, "solution"])

## End(Not run)

```



---

Solver-class

*Solver class*

---

## Description

This class is used to represent solvers for optimization. **Only experts should use the fields and methods for this class directly.**

## Super class

`prioritizr::ConservationModifier` -> Solver

## Methods

### Public methods:

- `Solver$run()`
- `Solver$calculate()`
- `Solver$set_variable_ub()`
- `Solver$set_variable_lb()`
- `Solver$set_constraint_rhs()`
- `Solver$set_start_solution()`
- `Solver$solve()`
- `Solver$clone()`

**Method** `run()`: Run the solver to generate a solution.

*Usage:*

`Solver$run()`

*Returns:* list of solutions.

**Method** `calculate()`: Perform computations that need to be completed before applying the object.

*Usage:*

`Solver$calculate(...)`

*Arguments:*

... Additional arguments.

x `optimization_problem()` object.

*Returns:* Invisible TRUE.

**Method** `set_variable_ub()`: Set the upper bound for a decision variable.

*Usage:*

`Solver$set_variable_ub(index, value)`

*Arguments:*

index integer value indicating the index of the decision variable.

value numeric new bound value.

*Details:* Note that this method should only be run after `$calculate()`. It can be used to overwrite values after ingesting an `optimization_problem()` object. It is designed to be used in `portfolios` and `importance` functions.

*Returns:* Invisible TRUE.

**Method** `set_variable_lb()`: Set the lower bound for a decision variable.

*Usage:*

```
Solver$set_variable_lb(index, value)
```

*Arguments:*

index integer value indicating the index of the decision variable.

value numeric new bound value.

*Details:* Note that this method should only be run after `$calculate()`. It can be used to overwrite values after ingesting an `optimization_problem()` object. It is designed to be used in `portfolios` and `importance` functions.

*Returns:* Invisible TRUE.

**Method** `set_constraint_rhs()`: Set the right-hand-side coefficient bound for a constraint.

*Usage:*

```
Solver$set_constraint_rhs(index, value)
```

*Arguments:*

index integer value indicating the index of the decision variable.

value numeric new value.

*Details:* Note that this method should only be run after `$calculate()`. It can be used to overwrite values after ingesting an `optimization_problem()` object. It is designed to be used in `portfolios` and `importance` functions.

*Returns:* Invisible TRUE.

**Method** `set_start_solution()`: Set the starting solution.

*Usage:*

```
Solver$set_start_solution(value)
```

*Arguments:*

value numeric new value.

*Details:* Note that this method should only be run after `$calculate()`. It can be used to overwrite values after ingesting an `optimization_problem()` object. It is designed to be used in `portfolios` and `importance` functions.

*Returns:* Invisible TRUE.

**Method** `solve()`: Solve an optimization problem.

*Usage:*

```
Solver$solve(x, ...)
```

*Arguments:*

x `optimization_problem()` object.  
 ... Additional arguments passed to the `calculate()` method.

*Returns:* Invisible TRUE.

**Method** `clone()`: The objects of this class are cloneable with this method.

*Usage:*

```
Solver$clone(deep = FALSE)
```

*Arguments:*

`deep` Whether to make a deep clone.

### See Also

Other classes: [ConservationModifier-class](#), [ConservationProblem-class](#), [Constraint-class](#), [Decision-class](#), [Objective-class](#), [OptimizationProblem-class](#), [Penalty-class](#), [Portfolio-class](#), [Target-class](#)

---

solvers

*Add solvers*

---

### 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. For information on the performance of different solvers, please see Schuster *et al.* (2020) for benchmarks comparing the run time and solution quality of some of these solvers when applied to different sized datasets.

### 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. We recommend using this solver if at all possible. It is by far the fastest of the solvers available for generating prioritizations, however, it 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_cplex_solver()` *IBM CPLEX* is a commercial optimization software. It is faster than the open source solvers available for generating prioritizations, however, it is not freely available. Similar to the *Gurobi* software, licenses are available to academics at no cost. This solver uses the **cplexAPI** package to solve problems using *IBM CPLEX*.

`add_cbc_solver()` *CBC* is an open-source mixed integer programming solver that is part of the Computational Infrastructure for Operations Research (COIN-OR) project. Preliminary benchmarks indicate that it is the fastest open source solver currently supported. We recommend using this solver if both *Gurobi* and *IBM CPLEX* are unavailable. It requires the **rcbc** package, which is currently only available on [GitHub](#).

`add_highs_solver()` *HIGHS* is an open source optimization software. Although this solver can have comparable performance to the *CBC* solver for particular problems and is generally faster than the *SYMPHONY* based solvers (see below), it sometimes can take much longer than the *CBC* solver for particular problems.

`add_lpsymphony_solver()` *SYMPHONY* is an open-source mixed integer programming solver that is also part of the COIN-OR project. Although both *SYMPHONY* and *CBC* are part of the COIN-OR project, they are different software. The **lpsymphony** package provides an interface to the *SYMPHONY* software, and is distributed through **Bioconductor**. We recommend using this solver if the *CBC* and *HiGHS* solvers cannot be installed. This solver can use parallel processing to solve problems, so it is faster than **Rsymphony** package interface (see below).

`add_rsymphony_solver()` This solver provides an alternative interface to the *SYMPHONY* solver using the **Rsymphony** package. Unlike other solvers, the **Rsymphony** package can be installed directly from the Comprehensive R Archive Network (CRAN). It is also the slowest of the available solvers.

## References

Schuster R, Hanson JO, Strimas-Mackey M, and Bennett JR (2020). Exact integer linear programming solvers outperform simulated annealing for solving conservation planning problems. *PeerJ*, 8: e9258.

## See Also

Other overviews: [constraints](#), [decisions](#), [importance](#), [objectives](#), [penalties](#), [portfolios](#), [summaries](#), [targets](#)

## Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()

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

# create vector to store plot names
n <- c()

# create empty list to store solutions
s <- c()

# if gurobi is installed: create problem with added gurobi solver
if (require("gurobi")) {
  p1 <- p %>% add_gurobi_solver(verbose = FALSE)
```

```
n <- c(n, "gurobi")
s <- c(s, solve(p1))
}

# if cplexAPI is installed: create problem with added CPLEX solver
if (require("cplexAPI")) {
  p2 <- p %>% add_cplex_solver(verbose = FALSE)
  n <- c(n, "CPLEX")
  s <- c(s, solve(p2))
}

# if rcbc is installed: create problem with added CBC solver
if (require("rcbc")) {
  p3 <- p %>% add_cbc_solver(verbose = FALSE)
  n <- c(n, "CBC")
  s <- c(s, solve(p3))
}

# if highs is installed: create problem with added HiGHS solver
if (require("highs")) {
  p4 <- p %>% add_highs_solver(verbose = FALSE)
  n <- c(n, "HiGHS")
  s <- c(s, solve(p4))
}

# create problem with added rsymphony solver
if (require("Rsymphony")) {
  p5 <- p %>% add_rsymphony_solver(verbose = FALSE)
  n <- c(n, "Rsymphony")
  s <- c(s, solve(p5))
}

# if lpsymphony is installed: create problem with added lpsymphony solver
if (require("lpsymphony")) {
  p6 <- p %>% add_lpsymphony_solver(verbose = FALSE)
  n <- c(n, "lpsymphony")
  s <- c(s, solve(p6))
}

# plot solutions
names(s) <- n
plot(terra::rast(s), axes = FALSE)

## End(Not run)
```

## Description

After generating a solution to a conservation planning problem, it can be useful to evaluate how well it performs. These functions can be used to evaluate a solution according to various different summary statistics.

## Details

The following functions can be used to summarize the performance of a solution to a conservation planning `problem()`:

`eval_n_summary()` Calculate the number of planning units selected within a solution.

`eval_cost_summary()` Calculate the total cost of a solution.

`eval_feature_representation_summary()` Calculate how well features are represented by a solution. This function can be used for all problems.

`eval_target_coverage_summary()` Calculate how well feature representation `targets` are met by a solution. This function can only be used with problems that contain `targets`.

`eval_boundary_summary()` Calculate the exposed boundary length (perimeter) associated with a solution.

`eval_connectivity_summary()` Calculate the connectivity held within a solution using symmetric data.

`eval_asym_connectivity_summary()` Calculate the connectivity held within a solution using asymmetric data.

## See Also

Other overviews: [constraints](#), [decisions](#), [importance](#), [objectives](#), [penalties](#), [portfolios](#), [solvers](#), [targets](#)

## Examples

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()

# create a minimal problem
p <-
  problem(sim_pu_raster, sim_features) %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions() %>%
  add_default_solver(verbose = FALSE)

# solve problem
s <- solve(p)

# evaluate number of selected planning units in solution
eval_n_summary(p, s)
```

```

# evaluate solution cost
eval_cost_summary(p, s)

# evaluate feature representation by solution
eval_feature_representation_summary(p, s)

# evaluate target coverage by solution
eval_target_coverage_summary(p, s)

# evaluate exposed boundary (perimeter) length by solution
eval_boundary_summary(p, s)

# create a symmetric connectivity matrix to describe pair-wise connectivity
# values between combinations of planning units,
# see ?connectivity_matrix for more information

# for brevity, we will do this using the cost data
# cost values have high connectivity between them
cm <- connectivity_matrix(sim_pu_raster, sim_pu_raster)

# evaluate connectivity of solution using symmetric data
eval_connectivity_summary(p, s, data = cm)

# create an asymmetric connectivity matrix to describe pair-wise
# connectivity values between combinations of planning units

# for brevity, we will just generate a matrix with random values
acm <- matrix(
  runif(ncell(sim_pu_raster) ^ 2),
  ncol = terra::ncell(sim_pu_raster)
)

# evaluate connectivity of solution using asymmetric data
eval_asym_connectivity_summary(p, s, data = acm)

## End(Not run)

```

---

Target-class

*Target class*


---

### Description

This class is used to represent targets for optimization. **Only experts should use the fields and methods for this class directly.**

### Super class

[prioritizr::ConservationModifier](#) -> Target

**Methods****Public methods:**

- [Target\\$output\(\)](#)
- [Target\\$clone\(\)](#)

**Method** `output()`: Output the targets.

*Usage:*

`Target$output()`

*Returns:* `tibble::tibble()` data frame.

**Method** `clone()`: The objects of this class are cloneable with this method.

*Usage:*

`Target$clone(deep = FALSE)`

*Arguments:*

`deep` Whether to make a deep clone.

**See Also**

Other classes: [ConservationModifier-class](#), [ConservationProblem-class](#), [Constraint-class](#), [Decision-class](#), [Objective-class](#), [OptimizationProblem-class](#), [Penalty-class](#), [Portfolio-class](#), [Solver-class](#)

---

targets

*Add representation targets*

---

**Description**

Targets are used to specify the minimum amount or proportion of a feature's distribution that should (ideally) be covered (represented) by a 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 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**

Other overviews: [constraints](#), [decisions](#), [importance](#), [objectives](#), [penalties](#), [portfolios](#), [solvers](#), [summaries](#)

**Examples**

```
## Not run:
# load data
sim_pu_raster <- get_sim_pu_raster()
sim_features <- get_sim_features()

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

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

# create problem with added absolute targets
p2 <- p %>% add_absolute_targets(3)

# create problem with added loglinear targets
p3 <- p %>% add_loglinear_targets(10, 0.9, 100, 0.2)

# create problem with manual targets that equate to 10% relative targets
targs <- data.frame(
  feature = names(sim_features),
  target = 0.1,
  type = "relative"
)

p4 <- p %>% add_manual_targets(targs)

# solve problem
s <- c(solve(p1), solve(p2), solve(p3), solve(p4))
names(s) <- c(
  "relative targets", "absolute targets", "loglinear targets",
  "manual targets"
)

# plot solution
plot(s, axes = FALSE)

## End(Not run)
```

## Description

Assorted functions for manipulating `tibble::tibble()` objects.

## Usage

```
## S4 method for signature 'tbl_df'  
nrow(x)  
  
## S4 method for signature 'tbl_df'  
ncol(x)  
  
## S4 method for signature 'tbl_df'  
as.list(x)
```

## Arguments

x `tibble::tibble()` object.

## Details

The following methods are provided from manipulating `tibble::tibble()` objects.

**nrow** integer number of rows.

**ncol** 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)
```

---

write_problem	<i>Write problem</i>
---------------	----------------------

---

### Description

Save the mathematical formulation for a conservation planning problem to a file for mixed integer programming solvers. Note that this function requires either the **Rsymphony** or **gurobi** package to be installed.

### Usage

```
write_problem(x, path, solver = NULL)
```

### Arguments

x	<code>problem()</code> object.
path	character file path to save the problem formulation. The argument should contain a ".lp" or ".mps" file extension to specify whether the problem formulation will be saved in the <b>LP</b> or <b>MPS</b> format (respectively).
solver	character name of optimization solver to write the problem to disk. Available options include: "rsymphony", "gurobi", or NULL. Note that using the Gurobi solver is much faster, because the Rsymphony solver requires attempting to solve the problem before it can be written. Defaults to NULL, such that the best available solver is used.

### Value

An invisible TRUE indicating success.

### Examples

```
## Not run:
# set seed for reproducibility
set.seed(500)

# load data
sim_pu_polygons <- get_sim_pu_polygons()
sim_features <- get_sim_features()

# subset data to extract first four planning units
sim_pu_polygons <- sim_pu_polygons[1:4, ]

# create minimal problem
p <-
  problem(sim_pu_polygons, sim_features, cost_column = "cost") %>%
  add_min_set_objective() %>%
  add_relative_targets(0.1) %>%
  add_binary_decisions()
```

```

# specify file path to save problem formulation
path <- file.path(tempdir(), "model.lp")
print(path)

# save problem to file
## note that either the gurobi or Rsymphony package needs to be installed
write_problem(p, path)

# print model file
cat(readLines(path), sep = "\n")

## End(Not run)

```

---

zones

*Management zones*

---

## Description

Organize data for multiple features for multiple management zones. Specifically, the data should describe the expected amount of each feature within each planning unit given each management zone. For example, the data could describe the occupancy (e.g., presence/absence), probability of occurrence, or abundance expected for each feature when each planning unit is allocated to a different zone.

## Usage

```
zones(..., zone_names = NULL, feature_names = NULL)
```

## Arguments

...	<a href="#">terra::rast()</a> or character objects that pertain to the biodiversity data. See <a href="#">Details</a> 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 depends on the type of planning unit data used when building the conservation planning [problem\(\)](#).

`problem()` will have `terra::rast()` or `sf::st_sf()` **planning units** `terra::rast()` object can be supplied to specify the expected amount of each feature within each planning unit under each management zone. Data for each zone should be specified as separate arguments, and the data for each feature in a given zone are specified in separate layers in a `terra::rast()` object. Note that all layers for a given zone must have missing (NA) values in exactly the same cells.

`problem()` will have `sf::st_sf()` or `data.frame` **planning units** character vector containing column names can be supplied to specify the expected amount of each feature under each zone. Note that these columns must not contain any missing (NA) values.

`problem()` will have `sf::st_sf()`, `data.frame`, or `matrix` **planning units** `data.frame` object can be supplied to specify the expected amount of each feature under each zone. Following conventions used in *Marxan*, the `data.frame` object should contain the following 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 should correspond to a single zone. Also, note that data are not required for all combinations of planning units, features, and zones. The expected amount of features in planning units under management zones that are missing from the table are assumed to be zero.

## Value

A `Zones` object containing data for each zone, and the feature and zone names.

## See Also

See `problem()` for information on using this function to generate a prioritization with multiple management zones.

## Examples

```
## Not run:
# load planning unit data
sim_pu_raster <- get_sim_pu_raster()

zone_1 <- simulate_species(sim_pu_raster, 3)
zone_2 <- simulate_species(sim_pu_raster, 3)

# create zones using two SpatRaster 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)
```

```

# plot the rasters for the first zone in the Zones object
plot(
  z[[1]],
  main = c("Zone 1 feature 1", "Zone 1 feature 2", "Zone 1 feature 3")
)

# 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 corresponding to column names
# of 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)

## End(Not run)

```

---

zone\_names

*Zone names*


---

## Description

Extract the names of zones in an object.

## Usage

```
zone_names(x, ...)
```

```
## S3 method for class 'ConservationProblem'
zone_names(x, ...)
```

```
## S3 method for class 'ZonesRaster'
zone_names(x, ...)
```

```
## S3 method for class 'ZonesSpatRaster'
zone_names(x, ...)
```

```
## S3 method for class 'ZonesCharacter'  
zone_names(x, ...)
```

### Arguments

x                    [problem\(\)](#) or [zones\(\)](#) object.  
...                  not used.

### Value

A character vector of zone names.

### Examples

```
## Not run:  
# load data  
sim_zones_pu_raster <- get_sim_zones_pu_raster()  
sim_zones_features <- get_sim_zones_features()  
  
# print names of zones in a Zones object  
print(zone_names(sim_zones_features))  
# create problem with multiple zones  
p <-  
  problem(sim_zones_pu_raster, sim_zones_features) %>%  
  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))  
  
## End(Not run)
```

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