

# Package ‘match2C’

February 17, 2021

**Type** Package

**Title** Match One Sample using Two Criteria

**Version** 1.1.0

**Description** Multivariate matching in observational studies typically has two goals: 1. to construct treated and control groups that have similar distribution of observed covariates and 2. to produce matched pairs or sets that are homogeneous in a few priority variables. This packages implements a network-flow-based method built around a tripartite graph that can simultaneously achieve both goals. A detailed explanation of the workflow and numerous examples are given in the vignette.

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**Encoding** UTF-8

**LazyData** true

**RoxygenNote** 7.1.1

**Imports** ggplot2, mvnfast, rbalance, Rcpp, stats, utils

**Suggests** dplyr, knitr, optmatch, RIttools, rmarkdown

**LinkingTo** Rcpp

**VignetteBuilder** knitr

**NeedsCompilation** yes

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**Repository** CRAN

**Date/Publication** 2021-02-17 10:10:03 UTC

## R topics documented:

NewPackage-package . . . . .	2
check_balance . . . . .	3
construct_outcome . . . . .	3
create_list_from_mat . . . . .	4

create_list_from_scratch . . . . .	5
create_list_from_scratch_overall . . . . .	7
dt_Rouse . . . . .	8
match_2C . . . . .	9
match_2C_list . . . . .	10
match_2C_mat . . . . .	11
revert_dist_list_cpp . . . . .	13
solve_network_flow . . . . .	14
stitch_two_nets . . . . .	14
treated_control_net . . . . .	15

<b>Index</b>	<b>16</b>
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NewPackage-package      *A short title line describing what the package does*

---

## Description

A more detailed description of what the package does. A length of about one to five lines is recommended.

## Details

This section should provide a more detailed overview of how to use the package, including the most important functions.

## Author(s)

Your Name, email optional.

Maintainer: Your Name <your@email.com>

## References

This optional section can contain literature or other references for background information.

## See Also

Optional links to other man pages

## Examples

```
## Not run:
## Optional simple examples of the most important functions
## These can be in \dontrun{} and \donttest{} blocks.

## End(Not run)
```

---

check_balance	<i>Check balance after matching.</i>
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---

**Description**

This function checks the overall balance after statistical matching.

**Usage**

```
check_balance(Z, match_object, cov_list, plot_propens, propens)
```

**Arguments**

Z	A vector of treatment indicator.
match_object	An object returned by <code>match_2C</code> or <code>match_2C_mat</code> or <code>match_2C_list</code> .
cov_list	A vector of names of covariates as appeared in the original dataset.
plot_propens	Post-matching distribution of the estimated propensity scores in two groups is plotted if TRUE; FALSE by default.
propens	NULL by default. If <code>plot_propens = TRUE</code> , then a vector of estimated propensity scores satisfying <code>length(propens) = length(Z)</code> needs to be supplied.

**Value**

This function returns a data frame of the overall balance after statistical matching. We tabulate the mean of each covariate in the `cov_list` in the treated group and control groups after matching, and calculate their standardized differences, which is defined as the mean difference divided by the pooled standard error before matching.

---

construct_outcome	<i>Construct an output for matching.</i>
-------------------	--

---

**Description**

This function constructs the output given the relaxsolution to the associated network flow problem and the original dataset.

**Usage**

```
construct_outcome(res, dist_list_1, Z, dataset, controls = 1)
```

**Arguments**

res	A callrelax output.
dist_list_1	A possibly sparse representation of the first distance matrix.
Z	A vector of treatment status.
dataset	The original dataset.
controls	Number of controls matched to each treated.

**Value**

This function returns a list of three objects: 1) feasible: 0/1 depending on the feasibility of the matching problem; 2) data\_with\_matched\_set\_ind: a dataframe that is the same as the original dataframe, except that a column called “matched\_set” and a column called “distance” are added to it. “matched\_set” column assigns 1,2,...,n<sub>t</sub> to each matched set, and NA to those not matched to any treated. Variable “distance” records the distance (as specified in the left network) between each matched control and the treated, and assigns NA to all treated and controls that are left unmatched. If matching is not feasible, NULL will be returned; 3) matched\_data\_in\_order: a dataframe organized in the order of matched sets and otherwise the same as data\_with\_matched\_set\_ind. Note that the matched\_set column assigns 1,2,...,n<sub>t</sub> for as indices for matched sets, and NA for those controls that are not paired. Null will be returned if the matching is infeasible.

---

create\_list\_from\_mat *Create a list representation of a distance matrix.*

---

**Description**

This function creates a “list representations” of a treatment-by-control distance matrix.

**Usage**

```
create_list_from_mat(
  Z,
  dist_mat,
  p = NULL,
  caliper = NULL,
  k = NULL,
  penalty = Inf
)
```

**Arguments**

Z	A length (n = n <sub>t</sub> + n <sub>c</sub> ) vector of treatment indicators.
dist_mat	A treatment-by-control (n <sub>t</sub> -by-n <sub>c</sub> ) distance matrix.
p	A vector of length (n <sub>t</sub> + n <sub>c</sub> ) on which caliper applies (e.g. propensity scores)
caliper	Size of the caliper.
k	Connect each treated to the nearest k controls
penalty	Penalty for violating the caliper. Set to Inf by default.

## Details

This function creates a list representation of a treatment-by-control network. The list representation can be made sparse using a user-specified caliper. A list representation of a treatment-by-control distance matrix consists of the following arguments:

- `start_n`: a vector containing the node numbers of the start nodes of each arc in the network.
- `end_n`: a vector containing the node numbers of the end nodes of each arc in the network.
- `d`: a vector containing the integer cost of each arc in the network.

Node 1,2,...,n<sub>t</sub> are n<sub>t</sub> treatment nodes; n<sub>t</sub> + 1, n<sub>t</sub> + 2, ..., n<sub>t</sub> + n<sub>c</sub> are n<sub>c</sub> control nodes. `start_n`, `end_n`, and `d` should have the same lengths, all of which equal to the number of edges.

There are two options for users to make a network sparse. First, `caliper` is a value applied to the vector `p` to avoid connecting treated to controls whose covariate/propensity score defined by `p` is outside `p +/- caliper`. Second, within a specified caliper, sometimes there are too many controls connected to the treated, and we can further trim down this number up to `k` with restricting attention to the `k` nearest (in `p`) to each treated.

## Value

This function returns a list that consists of three arguments: `start_n`, `end_n`, and `d`, as described above.

---

`create_list_from_scratch`

*Create a sparse list representation of treatment-to-control distance matrix with a caliper.*

---

## Description

This function takes in a n-by-p matrix of observed covariates, a length-n vector of treatment indicator, a caliper, and construct a possibly sparse list representation of the distance matrix.

## Usage

```
create_list_from_scratch(
  Z,
  X,
  exact = NULL,
  soft_exact = FALSE,
  p = NULL,
  caliper_low = NULL,
  caliper_high = NULL,
  k = NULL,
  alpha = 1,
  penalty = Inf,
  method = "maha",
  dist_func = NULL
)
```

**Arguments**

Z	A length-n vector of treatment indicator.
X	A n-by-p matrix of covariates.
exact	A vector of strings indicating which variables need to be exactly matched.
soft_exact	If set to TRUE, the exact constraint is enforced up to a large penalty.
p	A length-n vector on which a caliper applies, e.g. a vector of propensity score.
caliper_low	Size of caliper low.
caliper_high	Size of caliper high.
k	Connect each treated to the nearest k controls. See details section.
alpha	Tuning parameter.
penalty	Penalty for violating the caliper. Set to Inf by default.
method	Method used to compute treated-control distance
dist_func	A user-specified function that compute treat-control distance. See details section.

**Details**

Currently, there are 4 methods implemented in this function: 'maha' (Mahalanobis distance), 'robust maha' (robust Mahalanobis distance), '0/1' (distance = 0 if and only if covariates are the same), 'Hamming' (Hamming distance).

User can also supply their own distance function by setting method = 'other' and using the argument "dist\_func". "dist\_func" is a user-supplied distance function in the following format: dist\_func(controls, treated), where treated is a length-p vector of covariates and controls is a n\_c-by-p matrix of covariates. The output of function dist\_func is a length-n\_c vector of distance between each control and the treated.

There are two options for users to make a network sparse. First, caliper is a value applied to the vector p to avoid connecting treated to controls whose covariate/propensity score defined by p is outside p +/- caliper. Second, within a specified caliper, sometimes there are too many controls connected to the treated, and we can further trim down this number up to k with restricting attention to the k nearest (in p) to each treated.

**Value**

This function returns a list of three objects: start\_n, end\_n, and d. See documentation of function "create\_list\_from\_mat" for more details.

**Examples**

```
# We first prepare the input X, Z, propensity score

attach(dt_Rouse)
X = cbind(female,black,bytest,dadeduc,momeduc,fincome)
Z = IV
propensity = glm(IV~female+black+bytest+dadeduc+momeduc+fincome,
                 family=binomial)$fitted.values
```

```

detach(dt_Rouse)

# Create distance lists with built-in options.

# Mahalanobis distance with propensity score caliper = 0.05
# and k = 100.

dist_list_pscore_maha = create_list_from_scratch(Z, X, p = propensity,
                                                caliper_low = 0.05, k = 100, method = 'maha')

# More examples, including how to use a user-supplied
# distance function, can be found in the vignette.

```

---

```
create_list_from_scratch_overall
```

*Create a sparse list representation of treated-to-control distance matrix with a fixed number caliper with L1-distance.*

---

## Description

This function takes in a n-by-p matrix of observed covariates, a length-n vector of treatment indicator, a caliper, and construct a possibly sparse list representation of the distance matrix with Mahalanobis distance. Note that this function is of limited interest to most users.

## Usage

```

create_list_from_scratch_overall(
  Z,
  X,
  exact = NULL,
  soft_exact = FALSE,
  p = NULL,
  caliper_low = NULL,
  caliper_high = NULL,
  k = NULL,
  penalty = Inf,
  dist_func = NULL
)

```

## Arguments

Z	A length-n vector of treatment indicator.
X	A n-by-p matrix of covariates.
exact	A vector of strings indicating which variables are to be exactly matched.
soft_exact	If set to TRUE, the exact constraint is enforced up to a large penalty.

p	A length-n vector on which a caliper applies, e.g. a vector of propensity score.
caliper_low	Size of caliper_inf.
caliper_high	Size of caliper_sup.
k	Connect each treated to the nearest k controls
penalty	Penalty for violating the caliper. Set to Inf by default.
dist_func	A function used to calculate distance

### Value

This function returns a list of three objects: start\_n, end\_n, and d. See documentation of function “create\_list\_from\_mat” for more details.

---

dt_Rouse	<i>Rouse (1995) dataset</i>
----------	-----------------------------

---

### Description

Variables of the dataset is as follows:

**educ86** Years of education since 1986.

**twoyr** Attending a two-year college immediately after high school.

**female** Gender: 1 if female and 0 otherwise.

**black** Race: 1 if African American and 0 otherwise.

**hispanic** Race: 1 if Hispanic and 0 otherwise.

**bytest** Test score.

**fincome** Family income.

**finmiss** Missingness indicator for family income.

**IV** Instrumental variable: encouragement to attend a two-year college.

**dadeduc** Dad’s education: College - 2; Some college - 1; Neither - 0.

**momeduc** Mom’s education: College - 2; Some college - 1; Neither - 0.

### Usage

```
data(dt_Rouse)
```

### Format

A data frame with 3037 rows, 8 observed variables, 1 binary instrumental variable, 1 treatment, and 1 continuous response.

### Source

SS



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 match\_2C

*Optimal Matching with Two Criteria.*


---

### Description

This function perform an optimal statistical matching that sequentially balances the nominal levels (near-fine balance), the marginal distribution of the propensity score, and the total within-matched-pair Mahalanibis distance.

### Usage

```
match_2C(
  Z,
  X,
  propensity,
  dataset,
  exact = NULL,
  caliper_left = 1,
  caliper_right = 1,
  k_left = NULL,
  k_right = NULL,
  fb_var = NULL,
  controls = 1
)
```

### Arguments

Z	A length-n vector of treatment indicator.
X	A n-by-p matrix of covariates with column names.
propensity	A vector of estimated propensity score ( $\text{length}(\text{propensity}) = \text{length}(Z)$ ).
dataset	Dataset to be matched.
exact	A vector of strings indicating which variables need to be exactly matched.
caliper_left	Size of caliper on the left network.
caliper_right	Size of caliper on the right network.
k_left	Connect each treated to k_left controls closest in the propensity score in the left network.
k_right	Connect each treated to k_right controls closest in the propensity score in the right network.
fb_var	A vector giving names of variables in matrix X to be finely balanced.
controls	Number of controls matched to each treated. Default is 1.

### Value

This function returns a list of three objects including the feasibility of the matching problem and the matched controls organized in different formats. See the documentation of the function `construct_outcome` or the tutorial for more details.

**Examples**

```
# We first prepare the input X, Z, propensity score

attach(dt_Rouse)
X = cbind(female,black,bytest,dadeduc,momeduc,fincome)
Z = IV
propensity = glm(IV~female+black+bytest+dadeduc+momeduc+fincome,
                 family=binomial)$fitted.values
detach(dt_Rouse)

matching_output_double_calipers = match_2C(Z = Z, X = X,
propensity = propensity,
caliper_left = 0.05, caliper_right = 0.05,
k_left = 100, k_right = 100,
dataset = dt_Rouse)

# Please refer to the vignette for more examples.
```

---

match_2C_list	<i>Perform a pair matching using two user-specified list representations of distance matrices.</i>
---------------	--

---

**Description**

This function performs a pair-matching using (at most) two user-specified distance matrices in their (possibly sparse) list representations. For more details on “list representations” of a treatment-by-control distance matrix, see the documentation of the function “create\_list\_from\_mat”.

**Usage**

```
match_2C_list(
  Z,
  dataset,
  dist_list_1,
  dist_list_2 = NULL,
  lambda = 1000,
  controls = 1,
  overflow = FALSE
)
```

**Arguments**

Z	A length-n vector of treatment indicator.
dataset	dataset to be matched.
dist_list_1	A (possibly sparse) list representation of treatment-by-control distance matrix.

dist_list_2	A second (possibly sparse) list representation of treatment-by-control distance matrix.
lambda	A penalty that does a trade-off between two parts of the network.
controls	Number of controls matched to each treated. Default is set to 1.
overflow	A logical value indicating if overflow protection is turned on.

## Details

This function is designed for more experienced and sophisticated R users. Instead of providing possibly dense treatment-by-control distance matrices that take up a lot of memories, users may simply provide two lists that specifies informations of edges: their starting points, ending points, capacity, and cost. For more information on list representations of a distance matrix, see the documentation of the function “create\_list\_from\_mat” and “create\_list\_from\_scratch”. Note that by setting `dist_list_2 = NULL`, the usual matching framework is restored.

## Value

This function returns the same object as function `match_2C_mat`.

---

match_2C_mat	<i>Perform a pair matching using two user-specified distance matrices.</i>
--------------	--

---

## Description

This function performs a pair-matching using two user-specified distance matrices and two calipers. Typically one distance matrix is used to minimize matched-pair differences, and a second distance matrix is used to enforce constraints on marginal distributions of certain variables.

## Usage

```
match_2C_mat(
  Z,
  dataset,
  dist_mat_1,
  dist_mat_2,
  lambda,
  controls = 1,
  p_1 = NULL,
  caliper_1 = NULL,
  k_1 = NULL,
  p_2 = NULL,
  caliper_2 = NULL,
  k_2 = NULL,
  penalty = Inf,
  overflow = FALSE
)
```

**Arguments**

Z	A length-n vector of treatment indicator.
dataset	The original dataset.
dist_mat_1	A user-specified treatment-by-control (n_t-by-n_c) distance matrix.
dist_mat_2	A second user-specified treatment-by-control (n_t-by-n_c) distance matrix.
lambda	A penalty that controls the trade-off between two parts of the network.
controls	Number of controls matched to each treated.
p_1	A length-n vector on which caliper_1 applies, e.g. a vector of propensity score.
caliper_1	Size of caliper_1.
k_1	Maximum number of controls each treated is connected to in the first network.
p_2	A length-n vector on which caliper_2 applies, e.g. a vector of propensity score.
caliper_2	Size of caliper_2.
k_2	Maximum number of controls each treated is connected to in the second network.
penalty	Penalty for violating the caliper. Set to Inf by default.
overflow	A logical value indicating if overflow protection is turned on.

**Details**

This function performs a pair matching via a two-part network. The first part is a network whose treatment-to-control distance matrix is supplied by `dist_mat_1`. The second part of the network is constructed using distance matrix specified by `dist_mat_2`. Often, the first part of the network is used to minimize total treated-to-control matched pair distances, and the second part is used to enforce certain marginal constraints.

The function constructs two list representations of distance matrices, possibly using the caliper. `caliper_1` is applied to `p_1` (`caliper_2` applied to `p_2`) in order to construct sparse list representations. For instance, a caliper equal to 0.2 (`caliper_1 = 0.2`) applied to the propensity score (`p_1`).

`lambda` is a penalty, or a tuning parameter, that balances these two objectives. When `lambda` is very large, the network will first minimize the second part of network and then the first part.

**Value**

This function returns a list of three objects including the feasibility of the matching problem and the matched controls organized in different formats. See the documentation of the function `construct_outcome` or the tutorial for more details.

**Examples**

```
## Not run:
To run the following code, one needs to first install
and load the package optmatch.

# We first prepare the input X, Z, propensity score
```

```

#attach(dt_Rouse)
#X = cbind(female,black,bytest,dadeduc,momeduc,fincome)
#Z = IV
#propensity = glm(IV~female+black+bytest+dadeduc+momeduc+fincome,
#family=binomial)$fitted.values
#n_t = sum(Z)
#n_c = length(Z) - n_t
#dt_Rouse$propensity = propensity
#detach(dt_Rouse)

# Next, we use the match_on function in optmatch
to create two treated-by-control distance matrices.

#library(optmatch)
# dist_mat_1 = match_on(IV~female+black+bytest+dadeduc+momeduc+fincome,
# method = 'mahalanobis', data = dt_Rouse)

# dist_mat_2 = match_on(IV ~ female, method = 'euclidean', data = dt_Rouse)

# Feed two distance matrices to the function match_2C_mat without caliper
# and a large penalty lambda to enforce (near-)fine balance.

#matching_output = match_2C_mat(Z, dt_Rouse, dist_mat_1, dist_mat_2,
#                               lambda = 10000, p_1 = NULL, p_2 = NULL)

# For more examples, please consult the RMarkdown tutorial.

## End(Not run)

```

---

revert\_dist\_list\_cpp *Revert a treated-to-control distance list.*

---

## Description

Revert a treated-to-control distance list.

## Usage

```
revert_dist_list_cpp(n_t, n_c, startn, endn, d)
```

## Arguments

n_t	Number of treated units
n_c	Number of control units
startn	Vector of starting nodes of edges
endn	Vector of ending nodes of edges
d	Vector of cost associated with edges

---

`solve_network_flow`      *Solve a network flow problem.*

---

### Description

This function solves network flow optimization problems by calling the RELAX-IV algorithm implemented in FORTRAN by Dimitri Bertsekas and Paul Tseng, and made available by Sam Pimentel in the package rcbalance.

### Usage

```
solve_network_flow(net)
```

### Arguments

`net`                      A list of five vectors: startn, endn, ucap, cost, b.

### Details

This function is of limited interest to users.

### Value

If the problem is feasible, function returns a list with the following elements: `crash`: an integer, equal to zero if the algorithm ran correctly and equal to 1 if it crashed. `feasible`: an integer, equal to zero if the problem is not feasible. `x`: a vector equal in length to the number of arcs in argument problem `net`, giving in each coordinate the number of units of flow passing across the corresponding edge in the optimal network flow. If the problem is not feasible, it returns "Not feasible."

---

`stitch_two_nets`              *Stitch two treated-to-control networks into one two-part networks.*

---

### Description

This function takes as inputs two networks and one penalty `lambda`, and constructs one two-part network out of them.

### Usage

```
stitch_two_nets(net1, net2, lambda, controls = 1, overflow = FALSE)
```

**Arguments**

net1	A list of five vectors: startn, endn, ucap, cost, b.
net2	A list of five vectors: startn, endn, ucap, cost, b.
lambda	A penalty.
controls	Number of controls matched to each treated.
overflow	A logical value indicating if overflow protection is turned on.

**Details**

This function is of limited interest to users. Once overflow is set to TRUE, each control in the first network will be directly connected to the sink at a large cost, so that the network flow problem is feasible as long as the first part is feasible.

**Value**

This function returns a list of five vectors: startn, endn, ucap, cost, b.

---

treated_control_net	<i>Create a treat-to-control network to be solved via a network flow algorithm.</i>
---------------------	---

---

**Description**

This function takes in a list representation of distance matrix and create a network structure to be solved.

**Usage**

```
treated_control_net(n_t, n_c, dist_list, controls = 1)
```

**Arguments**

n_t	Number of treated subjects.
n_c	Number of controls.
dist_list	A list representation of the distance matrix.
controls	Number of controls matched to each treated.

**Details**

dist\_list is a list consisting of the following three elements: start\_n: the starting nodes for all edges, end\_n: the ending nodes for all edges, d: distance of all treated-control edges. Function create\_dist\_list in this package constructs such a list representation given a user-specified distance function.

**Value**

This function returns a list of five vectors: startn, endn, ucap, cost, b.

# Index

\* **datasets**

dt\_Rouse, [8](#)

\* **package**

NewPackage-package, [2](#)

check\_balance, [3](#)

construct\_outcome, [3](#)

create\_list\_from\_mat, [4](#)

create\_list\_from\_scratch, [5](#)

create\_list\_from\_scratch\_overall, [7](#)

dt\_Rouse, [8](#)

match\_2C, [9](#)

match\_2C\_list, [10](#)

match\_2C\_mat, [11](#)

NewPackage (NewPackage-package), [2](#)

NewPackage-package, [2](#)

revert\_dist\_list\_cpp, [13](#)

solve\_network\_flow, [14](#)

stitch\_two\_nets, [14](#)

treated\_control\_net, [15](#)