

Package ‘ILSM’

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Title Analyze Inter-Layer Structure of Multilayer Ecological Network

Version 1.0.2

Description In view of the analysis of the structural characteristics of the multilayer network has been complete, however, there is still a lack of a unified operation that can quickly obtain the corresponding characteristics of the multilayer network. To solve this insufficiency, 'ILSM' was designed for supporting calculating such metrics of multilayer networks by functions of this R package.

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R topics documented:

build_net	2
Hc	3
igraph_from_matrices	4
Midlayer_role	6
motif_count	8
Multi_motif	10
Node_versatility	11

null_model	13
Prc	15
Psc	16
role_sim	18
subnet_cor	19

Index	22
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build_net	<i>Generating tripartite network</i>
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Description

Generating a network of three layers. All layers of network contain lay_0, lay_1 and lay_2 nodes respectively.

Usage

```
build_net(lay_0, lay_1, lay_2, C_lay, asmatrices = FALSE)
```

Arguments

lay_0	The number of nodes in the first layer.
lay_1	The number of nodes in the second layer.
lay_2	The number of nodes in the third layer.
C_lay	The probability of each node interact with the other one. It ranges from 0 to 1.
asmatrices	Logical. whether to output the overall adjacency matrix of the network and the corresponding interaction matrix of the respective subnetworks. Defaults to FALSE.

Value

Return a tripartite network of direction. From the first layers to the second layer and from the second layer to the third layer.

Examples

```
set.seed(12)
d <- build_net(11,15,16,0.2)
plot(d)

set.seed(12)
N <- build_net(11,15,16,0.2,asmatrices=FALSE)
N
```

Hc

*Counting the degree hub of multilayer network***Description**

This function counts degree hub that the proportion of interconnecting species serving as the core node of the network degree.

Usage

```
Hc(network.or.subnet_mat1, subnet_mat2 = NULL)
```

Arguments

`network.or.subnet_mat1`

Either a multilayer(tripartite) network of 'igraph' class which contains interlayer links and without intralayer links, or a numeric matrix(or data.frame) representing interactions between two groups of species. Each row and column of matrix represents single species in the second and first groups of the tripartite network respectively. Elements of matrix are non-zero numbers if the two groups of species are connected, and 0 otherwise.

`subnet_mat2`

A numeric matrix(or data.frame) representing interactions between two groups of species. Each row and column of matrix represents single species in the second and third groups of the tripartite network respectively. Elements of matrix are non-zero numbers if the two groups of species are connected, and 0 otherwise. If `network.or.subnet_mat1` is "igraph", `subnet_mat2` defaults to NULL.

Details**network.or.subnet_mat1 and subnet_mat2**

There are two types of `network.or.subnet_mat1` that can be processed:

- (1). Input in a network of type "igraph" alone.
- (2). Must be entered as data frame or matrix with `subnet_mat2`.

If the type of inputting is data frame or matrix, please make sure the row of `network.or.subnet_mat1` and `subnet_mat2` correspond with the second group of species that both belong to two subnetworks and interact with other groups of species.

- Try to make the rows of both matrices have the same attributes. Or we default:
- (1). If both matrices have row names, then the function counts all row names to produce two new matrices with the same row names.
- (2). If at most one matrix has row names, the function assigns new row names to both matrices on a row-to-row basis (any extra row names are assigned a new value) and then counts all row names to produce two new matrices with the same row names.

- The two matrices can have different numbers of rows, but read our default handling carefully to make sure the calculation is accurate when using this function!!!

About a network of type "igraph", It can be obtained from the connection matrices of subnetworks by the function `igraph_from_matrices`.

Value

Print a "Hc= ;" and Return a numeric value representing the degree hub of network.

References

Domínguez-García, V., & Kéfi, S. (2021). The structure and robustness of tripartite ecological networks. *bioRxiv*, 2021-10.

Examples

```
set.seed(15)
d <- build_net(11,15,17,0.2)
Hc(d)

md1<-matrix(sample(c(0,1),80,replace=TRUE),8,10)
md2<-matrix(sample(c(0,1),120,replace=TRUE),10,12)
Hc(md1,md2)

mdw1<-matrix(sample(c(rep(0,60),runif(60,0,1))),12,10)
mdw2<-matrix(sample(c(rep(0,40),runif(80,0,1))),10,12)
Hc(mdw1,mdw2)
```

`igraph_from_matrices` *Transforming matrices into network*

Description

Two matrices contain three groups of tropical level species. A multilayer network can be transformed from existing matrices data.

Usage

```
igraph_from_matrices(mat1, mat2, isDirected1 = TRUE, isDirected2 = TRUE)
```

Arguments

`mat1` A numeric matrix(or data.frame) representing interactions between two groups of species.Each row and column of matrix represents single species in the second and first groups of the tripartite network respectively. Elements of matrix are non-zero numbers if the two groups of species are connected, and 0 otherwise.

<code>mat2</code>	A numeric matrix(or data.frame) representing interactions between two groups of species.Each row and column of matrix represents single species in the second and third groups of the tripartite network respectively. Elements of matrix are non-zero numbers if the two groups of species are connected, and 0 otherwise.
<code>isDirected1</code>	Logical. Whether the interaction between the two groups of species in <code>mat1</code> is unidirectional.Default to TRUE, such as Predation and Herbivory. Otherwise it is bidirectional, such as Mutualism.
<code>isDirected2</code>	Logical. Whether the interaction between the two groups of species in <code>mat2</code> is unidirectional.Default to TRUE, such as Predation and Herbivory. Otherwise it is bidirectional, such as Mutualism.

Details

mat1 and **mat2**

The type of inputting is data frame or matrix, please make sure the row of `mat1` and `mat2` correspond with the second group of species that both belong to two subnetworks and interact with other groups of species.

- Try to make the rows of both matrices have the same attributes. Or we default:
- When the two matrices can have different numbers of rows:
 - (1). If both matrices have row names, then the function counts all row names to produce two new matrices with the same row names.
 - (2). If at most one matrix has row names, the function assigns new row names to both matrices on a row-to-row basis (any extra row names are assigned a new value) and then counts all row names to produce two new matrices with the same row names.
- When the two matrices can have the same numbers of rows:
 - No matter how the row names of the two matrices are arranged, as long as the row names are exactly the same; But we don't handle matrices with empty row names (the function will give an error).
- The two matrices can have different numbers of rows, but read our default handling carefully to make sure the calculation is accurate when using this function!!!

The columns of `mat1` and `mat2` could be empty. If empty, the function also defaults to the suggested assignment.

Value

Return a network of type "igraph".

Examples

```
set.seed(12)
MAT <- build_net(11,22,21,0.2,asmatrices=TRUE)
MAT[[1]]

igraph_from_matrices(MAT[[3]],MAT[[4]])
M <- igraph_from_matrices(t(MAT[[3]]),MAT[[4]])
M
```

Midlayer_role

Analyzising role of interconnecting node in motifs

Description

Counting the number of 65 roles about interconnecting species in multilayer network motifs.

Usage

```
Midlayer_role(network.or.subnet_mat1, subnet_mat2 = NULL)
```

Arguments

`network.or.subnet_mat1`

Either a multilayer(tripartite) network of 'igraph' class which contains interlayer links and without intralayer links, or a numeric matrix(or data.frame) representing interactions between two groups of species. Each row and column of matrix represents single species in the second and first groups of the tripartite network respectively. Elements of matrix are non-zero numbers if the two groups of species are connected, and 0 otherwise.

`subnet_mat2`

A numeric matrix(or data.frame) representing interactions between two groups of species. Each row and column of matrix represents single species in the second and third groups of the tripartite network respectively. Elements of matrix are non-zero numbers if the two groups of species are connected, and 0 otherwise. If `network.or.subnet_mat1` is "igraph", `subnet_mat2` defaults to NULL.

Details

network.or.subnet_mat1 and subnet_mat2

There are two types of `network.or.subnet_mat1` that can be processed:

- (1). Input in a network of type "igraph" alone.
- (2). Must be entered as data frame or matrix with `subnet_mat2`.

If the type of inputting is data frame or matrix, please make sure the row of `network.or.subnet_mat1` and `subnet_mat2` correspond with the second group of species that both belong to two subnetworks and interact with other groups of species.

- Try to make the rows of both matrices have the same attributes. Or we default:
- When the two matrices can have different numbers of rows:
 - (1). If both matrices have row names, then the function counts all row names to produce two new matrices with the same row names.
 - (2). If at most one matrix has row names, the function assigns new row names to both matrices on a row-to-row basis (any extra row names are assigned a new value) and then counts all row names to produce two new matrices with the same row names.

- When the two matrices can have the same numbers of rows:
 - No matter how the row names of the two matrices are arranged, as long as the row names are exactly the same; But we don't handle matrices with empty row names (the function will give an error).
- The two matrices can have different numbers of rows, but read our default handling carefully to make sure the calculation is accurate when using this function!!!

About a network of type "igraph", It can be obtained from the connection matrices of subnetworks by the function `igraph_from_matrices`.

Value

Returns a matrix of 65 columns representing the roles of interconnecting species in the motifs. Columns names are Role1, Role2, Role3 ... Role65.

Each row of matrix corresponds to a interconnecting species in the second layer of network. If a interconnecting species is linked to both the second and third level species, the elements in this row are not all zero, otherwise the elements are all zero.

References

Simmons, B. I., Sweering, M. J., Schillinger, M., Dicks, L. V., Sutherland, W. J., & Di Clemente, R. (2019). `bmotif`: A package for motif analyses of bipartite networks. *Methods in Ecology and Evolution*, 10(5), 695-701.

Examples

```
set.seed(12)
d <- build_net(11,22,21,0.2)
Midlayer_role(d)

set.seed(12)
MAT <- build_net(11,22,21,0.2,asmatrices=TRUE)

Midlayer_role(MAT[[3]],MAT[[4]])

md1<-matrix(sample(c(0,1),88,replace=TRUE),8,11)
md2<-matrix(sample(c(0,1),120,replace=TRUE),10,12)
Midlayer_role(md1,md2)

R<-rownames(MAT[[4]][12]
MR<-MAT[[4]][12,]
MAT[[4]]<-MAT[[4]][-12,]
MAT[[4]]<-rbind(MAT[[4]],MR)
rownames(MAT[[4]][22]<-R

Midlayer_role(MAT[[3]],MAT[[4]])
```

 motif_count

Calculating the number of 44 motifs

Description

Calculating the number of 44 motifs from a tripartite interaction network.

Usage

```
motif_count(network.or.subnet_mat1, subnet_mat2 = NULL)
```

Arguments

network.or.subnet_mat1

Either a multilayer(tripartite) network of 'igraph' class which contains interlayer links and without intralayer links, or a numeric matrix(or data.frame) representing interactions between two groups of species. Each row and column of matrix represents single species in the second and first groups of the tripartite network respectively. Elements of matrix are non-zero numbers if the two groups of species are connected, and 0 otherwise.

subnet_mat2

A numeric matrix(or data.frame) representing interactions between two groups of species. Each row and column of matrix represents single species in the second and third groups of the tripartite network respectively. Elements of matrix are non-zero numbers if the two groups of species are connected, and 0 otherwise. If network.or.subnet_mat1 is "igraph", subnet_mat2 defaults to NULL.

Details

network.or.subnet_mat1 and subnet_mat2

There are two types of network.or.subnet_mat1 that can be processed:

- (1). Input in a network of type "igraph" alone.
- (2). Must be entered as data frame or matrix with subnet_mat2.

If the type of inputting is data frame or matrix, please make sure the row of network.or.subnet_mat1 and subnet_mat2 correspond with the second group of species that both belong to two subnetworks and interact with other groups of species.

- Try to make the rows of both matrices have the same attributes. Or we default:
- When the two matrices can have different numbers of rows:
 - (1). If both matrices have row names, then the function counts all row names to produce two new matrices with the same row names.
 - (2). If at most one matrix has row names, the function assigns new row names to both matrices on a row-to-row basis (any extra row names are assigned a new value) and then counts all row names to produce two new matrices with the same row names.

- When the two matrices can have the same numbers of rows:
 - No matter how the row names of the two matrices are arranged, as long as the row names are exactly the same; But we don't handle matrices with empty row names (the function will give an error).
- The two matrices can have different numbers of rows, but read our default handling carefully to make sure the calculation is accurate when using this function!!!

About a network of type "igraph", It can be obtained from the connection matrices of subnetworks by the function `igraph_from_matrices`.

Value

If `subnet_motif = FALSE`, return a numeric vector with the number of 44 motifs: M111, M112, M113, M211, M212, M213, M311, M312, M121_1, M122_1, M122_2, M122_3, M123_1, M123_2, M123_3, M123_4, M123_5, M221_1, M221_2, M221_3, M222_1, M222_2, M222_3, M222_4, M222_5, M222_6, M222_7, M222_8, M321_1, M321_2, M321_3, M321_4, M321_5, M131, M132-1, M132-2, M132-3, M132-4, M132-5, M231-1, M231-2, M231-3, M231-4, M231-5.

References

Pilosof, S., Porter, M. A., Pascual, M., & Kéfi, S. (2017). The multilayer nature of ecological networks. *Nature Ecology & Evolution*, 1(4), 0101.

Simmons, B. I., Sweering, M. J., Schillinger, M., Dicks, L. V., Sutherland, W. J., & Di Clemente, R. (2019). `bmotif`: A package for motif analyses of bipartite networks. *Methods in Ecology and Evolution*, 10(5), 695-701.

Examples

```
set.seed(12)
d <- build_net(11,22,21,0.2)
m <- motif_count(d)
m

set.seed(12)
d <- build_net(11,22,21,0.2,asmatrices=TRUE)

MAT<-d
motif_count(MAT[[3]],MAT[[4]])

md1<-matrix(sample(c(0,1),120,replace=TRUE),8,15)
md2<-matrix(sample(c(0,1),120,replace=TRUE),10,12)
motif_count(md1,md2)

R<-rownames(MAT[[4]])[12]
MR<-MAT[[4]][12,]
MAT[[4]]<-MAT[[4]][-12,]
MAT[[4]]<-rbind(MAT[[4]],MR)
rownames(MAT[[4]])[22]<-R
```

```
motif_count(MAT[[3]],MAT[[4]])
```

Multi_motif

Defined multilayer motifs

Description

Acquiring each or all of 44 motifs of definition of multilayer network.

Usage

```
Multi_motif(
  type = c("M111", "M112", "M113", "M211", "M212", "M213", "M311", "M312", "M121-1",
    "M122-1", "M122-2", "M122-3", "M123-1", "M123-2", "M123-3", "M123-4", "M123-5",
    "M221-1", "M221-2", "M221-3", "M222-1", "M222-2", "M222-3", "M222-4", "M222-5",
    "M222-6", "M222-7", "M222-8", "M321-1", "M321-2", "M321-3", "M321-4", "M321-5",
    "M131", "M132-1", "M132-2", "M132-3", "M132-4", "M132-5", "M231-1", "M231-2",
    "M231-3", "M231-4", "M231-5", "all")
)
```

Arguments

type Character. 45 values representing each and all types of multilayer motifs.

Value

If type is one of 44 motifs of definition, function returns a corresponding motif of "igraph".

If type is "all", function returns a list containing 44 corresponding motifs of "igraph".

Examples

```
type<-c("M111", "M112", "M113", "M211", "M212", "M213", "M311", "M312", "M121-1",
  "M122-1", "M122-2", "M122-3", "M123-1", "M123-2", "M123-3", "M123-4", "M123-5",
  "M221-1", "M221-2", "M221-3", "M222-1", "M222-2", "M222-3", "M222-4", "M222-5",
  "M222-6", "M222-7", "M222-8", "M321-1", "M321-2", "M321-3", "M321-4", "M321-5",
  "M131", "M132-1", "M132-2", "M132-3", "M132-4", "M132-5", "M231-1", "M231-2",
  "M231-3", "M231-4", "M231-5")

m<-Multi_motif("M222-4")
plot(m,main="M222-4")

mr <- par(mfrow=c(6,8),mar=c(1,1,3,1))
for(i in 1:44){
  plot(Multi_motif("all")[[i]],
    vertex.size=30, vertex.label=NA,
    vertex.color="blue",main=type[i])
}
```

```
}
par(mf)
```

Node_versatility *Measuring node versatility of multilayer network*

Description

The versatility of nodes is revealed by several centrality measures that have now been applied to multilayer networks, such as Degree, PageRank, Hub, Authority, Katz, Eigenvector, and Closeness centrality.

Usage

```
Node_versatility(
  network.or.subnet_mat1,
  subnet_mat2 = NULL,
  isDirected1 = TRUE,
  isDirected2 = TRUE,
  type = c("degree", "pagerank", "hub", "authority", "katz", "eigenvector", "closeness",
           "all")
)
```

Arguments

network.or.subnet_mat1	Either a multilayer(tripartite) network of 'igraph' class which contains interlayer links and without intralayer links, or a numeric matrix(or data.frame) representing interactions between two groups of species. Each row and column of matrix represents single species in the second and first groups of the tripartite network respectively. Elements of matrix are non-zero numbers if the two groups of species are connected, and 0 otherwise.
subnet_mat2	A numeric matrix(or data.frame) representing interactions between two groups of species. Each row and column of matrix represents single species in the second and third groups of the tripartite network respectively. Elements of matrix are non-zero numbers if the two groups of species are connected, and 0 otherwise. If network.or.subnet_mat1 is "igraph", subnet_mat2 defaults to NULL.
isDirected1	Logical. Whether the interaction between the two groups of species in mat1 is unidirectional.Default to TRUE, such as Predation and Herbivory. Otherwise it is bidirectional, such as Mutualism.
isDirected2	Logical. Whether the interaction between the two groups of species in mat2 is unidirectional.Default to TRUE, such as Predation and Herbivory. Otherwise it is bidirectional, such as Mutualism.
type	Character. Including "degree", "pagerank", "hub", "authority", "katz", "eigenvector", "closeness", and "all".

Details

network.or.subnet_mat1 and subnet_mat2

There are two types of `network.or.subnet_mat1` that can be processed:

- (1). Input in a network of type "igraph" alone.
- (2). Must be entered as data frame or matrix with `subnet_mat2`.

If the type of inputting is data frame or matrix, please make sure the row of `network.or.subnet_mat1` and `subnet_mat2` correspond with the second group of species that both belong to two subnetworks and interact with other groups of species.

- Try to make the rows of both matrices have the same attributes. Or we default:
- When the two matrices can have different numbers of rows:
 - (1). If both matrices have row names, then the function counts all row names to produce two new matrices with the same row names.
 - (2). If at most one matrix has row names, the function assigns new row names to both matrices on a row-to-row basis (any extra row names are assigned a new value) and then counts all row names to produce two new matrices with the same row names.
- When the two matrices can have the same numbers of rows:
 - No matter how the row names of the two matrices are arranged, as long as the row names are exactly the same; But we don't handle matrices with empty row names (the function will give an error).
- The two matrices can have different numbers of rows, but read our default handling carefully to make sure the calculation is accurate when using this function!!!

About a network of type "igraph", It can be obtained from the connection matrices of subnetworks by the function `igraph_from_matrices`.

type

type "degree", "pagerank", "hub", "authority", "katz", "eigenvector", and "closeness" correspond to Degree, PageRank, Hub, Authority, Katz, Eigenvector, and Closeness centrality. type "all" integrates the above centrality.

Value

Return a data frame with the first row "node" for each node of network representing each species.

- If type is either of "degree", "pagerank", "hub", "authority", "katz", "eigenvector", "closeness", the data frame has two columns, and the second column corresponds to either of "Degree", "PageRank_versatility", "Hub_versatility", "Authority_versatility", "Katz_versatility", "Eigenvector_versatility", "Closeness_versatility".
- If type is "all", the data frame has eight columns, and columns from the second to the eighth correspond to "Degree", "PageRank_versatility", "Hub_versatility", "Authority_versatility", "Katz_versatility", "Eigenvector_versatility", "Closeness_versatility".

References

- De Domenico, M., Nicosia, V., Arenas, A., & Latora, V. (2015). Structural reducibility of multilayer networks. *Nature communications*, 6(1), 6864.
- De Domenico, M., Solé-Ribalta, A., Omodei, E., Gómez, S., & Arenas, A. (2013). Centrality in interconnected multilayer networks. *arXiv preprint arXiv:1311.2906*.
- De Domenico, M. (2022). *Multilayer Networks: Analysis and Visualization*. Introduction to muxViz with R. Cham: Springer.
- Page, L., Brin, S., Motwani, R., & Winograd, T. (1999). The pagerank citation ranking: Bringing order to the web.
- Magnani, M., Micenkova, B., & Rossi, L. (2013). Combinatorial analysis of multiple networks. *arXiv preprint arXiv:1303.4986*.

Examples

```
set.seed(12)
d <- build_net(11,22,21,0.2,asmatrices=TRUE)
d
Node_versatility(d[[1]])

MAT<-d
Node_versatility(MAT[[3]],MAT[[4]])
Node_versatility(t(MAT[[3]]),MAT[[4]])
Node_versatility(MAT[[3]],MAT[[4]],type="pagerank")

Node_versatility(MAT[[3]],MAT[[4]],isDirected2=FALSE)
```

null_model

Null model of multilayer network

Description

The null model could be generated according to different matrix scrambling algorithms for inter-connection patterns in the multilayer network

Usage

```
null_model(
  network,
  number = NULL,
  null_type = c("subnetwork1", "subnetwork2", "all", "Savue")
)
```

Arguments

network	A multilayer(tripartite) network of 'igraph' class. The network contains inter-layer links and without intralayer links.
number	A numeric value. The number of null model. Default to NULL representing number 1.
null_type	Logical. Four matrix scrambling algorithms. If null_type = NULL, default to "all".

Details**null_type**

- For each of the four types of null models, there are corresponding algorithms. The first type, “subnetwork1”, involved scrambling the adjacency matrix of the first and second layers of the multilayer network.
- The second type, “subnetwork2”, focused on scrambling the adjacency matrix of the second and third layers.
- Comprehensively, the third type, “all”, blended the approaches of the first two to disarrange the entire network’s adjacency matrix, achieving a thorough perturbation of the network’s structure.
- The last type named “Savue” that disarranged inherent structure in terms of the groups of species connected by each interconnecting species of every subnetworks, thus exhibiting different interconnection patterns.

network

About a network of type "igraph", It can be obtained from the connection matrices of subnetworks by the function `igraph_from_matrices`

Value

Return a list contains one or more elements. Each element represent a null model of multilayer network.

References

Vázquez, D. P., C. J. Melian, N. M. Williams, N. Blüthgen, B. R. Krasnov, and R. Poulin. 2007. Species abundance and asymmetric interaction strength in ecological networks. *Oikos* 116: 1120-1127.

Sauve, A. M., Thébault, E., Poccock, M. J., & Fontaine, C. (2016). How plants connect pollination and herbivory networks and their contribution to community stability. *Ecology*, 97(4), 908-917.

Examples

```
set.seed(12)
d <- build_net(11,22,21,0.2)
```

```

set.seed(123)
null_model(d)
set.seed(123)
null_model(d,null_type="subnetwork1")
set.seed(123)
null_model(d,null_type="Savue")
set.seed(123)
null_model(d,number=2,null_type="Savue")

```

Prc

Participation ratio of interconnecting code

Description

Counting participation ratio that the difference in the degree of interconnecting nodes within two subnetworks.

Usage

```
Prc(network.or.subnet_mat1, subnet_mat2 = NULL)
```

Arguments

`network.or.subnet_mat1`

Either a multilayer(tripartite) network of 'igraph' class which contains interlayer links and without intralayer links, or a numeric matrix(or data.frame) representing interactions between two groups of species. Each row and column of matrix represents single species in the second and first groups of the tripartite network respectively. Elements of matrix are non-zero numbers if two groups of species are connected, and 0 otherwise.

`subnet_mat2`

A numeric matrix(or data.frame) representing interactions between two groups of species. Each row and column of matrix represents single species in the second and third groups of the tripartite network respectively. Elements of matrix are non-zero numbers if the two groups of species are connected, and 0 otherwise. If `network.or.subnet_mat1` is "igraph", `subnet_mat2` defaults to NULL.

Details

network.or.subnet_mat1 and subnet_mat2

There are two types of `network.or.subnet_mat1` that can be processed:

- (1). Input in a network of type "igraph" alone.
- (2). Must be entered as data frame or matrix with `subnet_mat2`.

If the type of inputting is data frame or matrix, please make sure the row of `network.or.subnet_mat1` and `subnet_mat2` correspond with the second group of species that both belong to two subnetworks and interact with other groups of species.

- Try to make the rows of both matrices have the same attributes. Or we default:
- (1). If both matrices have row names, then the function counts all row names to produce two new matrices with the same row names.
- (2). If at most one matrix has row names, the function assigns new row names to both matrices on a row-to-row basis (any extra row names are assigned a new value) and then counts all row names to produce two new matrices with the same row names.
- The two matrices can have different numbers of rows, but read our default handling carefully to make sure the calculation is accurate when using this function!!!

About a network of type "igraph", It can be obtained from the connection matrices of subnetworks by the function `igraph_from_matrices`.

Value

Print a "PR_C= ;" and Return a numeric value representing difference in the degree of interconnecting nodes within two subnetworks of multialyer network.

References

Domínguez-García, V., & Kéfi, S. (2021). The structure and robustness of tripartite ecological networks. *bioRxiv*, 2021-10.

Examples

```
set.seed(15)
d <- build_net(11,15,17,0.2)
Prc(d)

md1<-matrix(sample(c(0,1),80,replace=TRUE),8,10)
md2<-matrix(sample(c(0,1),120,replace=TRUE),10,12)
Prc(md1,md2)

mdw1<-matrix(sample(c(rep(0,60),runif(60,0,1))),12,10)
mdw2<-matrix(sample(c(rep(0,40),runif(80,0,1))),10,12)
Prc(mdw1,mdw2)
```

Psc

Proportion of interconnection

Description

Calculating the proportion of species sharing with other species of two subnetworks in intermediate layer.

Usage

```
Psc(network.or.subnet_mat1, subnet_mat2 = NULL)
```


Arguments

`network.or.subnet_mat1`

Either a multilayer(tripartite) network of 'igraph' class which contains interlayer links and without intralayer links, or a numeric matrix(or data.frame) representing interactions between two groups of species. Each row and column of matrix represents single species in the second and first groups of the tripartite network respectively. Elements of matrix are non-zero numbers if two groups of species are connected, and 0 otherwise.

`subnet_mat2`

A numeric matrix(or data.frame) representing interactions between two groups of species. Each row and column of matrix represents single species in the second and third groups of the tripartite network respectively. Elements of matrix are non-zero numbers if the two groups of species are connected, and 0 otherwise. If `network.or.subnet_mat1` is "igraph", `subnet_mat2` defaults to NULL.

Details

network.or.subnet_mat1 and **subnet_mat2**

There are two types of `network.or.subnet_mat1` that can be processed:

- (1). Input in a network of type "igraph" alone.
- (2). Must be entered as data frame or matrix with `subnet_mat2`.

If the type of inputting is data frame or matrix, please make sure the row of `network.or.subnet_mat1` and `subnet_mat2` correspond with the second group of species that both belong to two subnetworks and interact with other groups of species.

- Try to make the rows of both matrices have the same attributes. Or we default:
 - (1). If both matrices have row names, then the function counts all row names to produce two new matrices with the same row names.
 - (2). If at most one matrix has row names, the function assigns new row names to both matrices on a row-to-row basis (any extra row names are assigned a new value) and then counts all row names to produce two new matrices with the same row names.
- The two matrices can have different numbers of rows, but read our default handling carefully to make sure the calculation is accurate when using this function!!!

About a network of type "igraph", It can be obtained from the connection matrices of subnetworks by the function `igraph_from_matrices`.

Value

Print a "PS_C=";" and Return a numeric value representing the proportion of sharing species in intermediate layer.

References

Domínguez-García, V., & Kéfi, S. (2021). The structure and robustness of tripartite ecological networks. *bioRxiv*, 2021-10.

Examples

```
set.seed(15)
d <- build_net(11,15,17,0.2)
Psc(d)

md1<-matrix(sample(c(0,1),80,replace=TRUE),8,10)
md2<-matrix(sample(c(0,1),120,replace=TRUE),10,12)
Psc(md1,md2)

mdw1<-matrix(sample(c(rep(0,40),runif(60,0,1))),10,10)
mdw2<-matrix(sample(c(rep(0,40),runif(80,0,1))),10,12)
Psc(mdw1,mdw2)

mdw1<-matrix(sample(c(rep(0,60),runif(60,0,1))),12,10)
mdw2<-matrix(sample(c(rep(0,40),runif(80,0,1))),10,12)
Psc(mdw1,mdw2)
```

role_sim

Similarity of roles of interconnecting species

Description

The average of Similarity of 65 roles of interconnecting species of multilayer network.

Usage

```
role_sim(spe_role_mat)
```

Arguments

spe_role_mat A matrix of 65 columns representing the roles of interconnecting species in the motifs. Columns names are Role1, Role2, Role3 ... Role65.

Details

spe_role_mat

Should acquire from function Midlayer_role.

Value

Return a numeric value.

Examples

```
set.seed(12)
d <- build_net(11,22,21,0.2)
mr <- Midlayer_role(d)
role_sim(mr)

set.seed(1)
D <- build_net(11,22,21,0.2)
role_sim(Midlayer_role(D))
```

 subnet_cor

Correlation of the Structural indices between Subnetworks

Description

Calculating correlation of interconnecting species generalism among Subnetworks ("general_ '~ 'cor") and correlation between similarities of interconnecting species interaction partners in two subnetworks ("similar_ '~ 'cor").

Usage

```
subnet_cor(network.or.subnet_mat1, subnet_mat2 = NULL, weighted = FALSE)
```

Arguments

network.or.subnet_mat1	Either a multilayer(tripartite) network of 'igraph' class which contains interlayer links and without intralayer links, or a numeric matrix(or data.frame) representing interactions between two groups of species. Each row and column of matrix represents single species in the second and first groups of the tripartite network respectively. Elements of matrix are non-zero numbers if the two groups of species are connected, and 0 otherwise.
subnet_mat2	A numeric matrix(or data.frame) representing interactions between two groups of species. Each row and column of matrix represents single species in the second and third groups of the tripartite network respectively. Elements of matrix are non-zero numbers if the two groups of species are connected, and 0 otherwise. If network.or.subnet_mat1 is "igraph", subnet_mat2 defaults to NULL.
weighted	Logical. should elements of matrix be fractional? Default to FALSE. Generally, 'igraph' network represent a spare matrix, so weighted is FALSE. While elements of matrix represent interaction strength, weighted is TRUE.

Details

weighted

If the `weighted = FALSE`, the input for the parameter can be:

- `network.or.subnet_mat1`: input a 'igraph' of network data independently or input sparse matrix together with `subnet_mat2`.

If the `weighted = TRUE`, the input for the parameter can be:

- `network.or.subnet_mat1`: must input matrix(or data.frame) together with `subnet_mat2`. the matrix can be sparse matrix and matrix of interaction strength.

network.or.subnet_mat1 and subnet_mat2

There are two types of `network.or.subnet_mat1` that can be processed:

- (1). Input in a network of type "igraph" alone.
- (2). Must be entered as data frame or matrix with `subnet_mat2`.

If the type of inputting is data frame or matrix, please make sure the row of `network.or.subnet_mat1` and `subnet_mat2` correspond with the second group of species that both belong to two subnetworks and interact with other groups of species.

- Try to make the rows of both matrices have the same attributes. Or we default:
- When the two matrices can have different numbers of rows:
 - (1). If both matrices have row names, then the function counts all row names to produce two new matrices with the same row names.
 - (2). If at most one matrix has row names, the function assigns new row names to both matrices on a row-to-row basis (any extra row names are assigned a new value) and then counts all row names to produce two new matrices with the same row names.
- When the two matrices can have the same numbers of rows:
 - No matter how the row names of the two matrices are arranged, as long as the row names are exactly the same; But we don't handle matrices with empty row names (the function will give an error).
- The two matrices can have different numbers of rows, but read our default handling carefully to make sure the calculation is accurate when using this function!!!

About a network of type "igraph", It can be obtained from the connection matrices of subnetworks by the function `igraph_from_matrices`.

Value

Return a numeric vector of two elements representing correlation of interconnecting species generalism among Subnetworks and correlation between similarities of interconnecting species interaction partners in two subnetworks.

If `weighted = FALSE`, the results will show "general_cor= ;similar_cor= ;" and If `weighted = TRUE`, the results will show "general_weight_cor= ;similar_weight_cor= ;"

References

Sauve, A. M., Thébault, E., Poccock, M. J., & Fontaine, C. (2016). How plants connect pollination and herbivory networks and their contribution to community stability. *Ecology*, 97(4), 908-917.

Examples

```
set.seed(12)
d <- build_net(11,15,17,0.2)
subnet_cor(d)
```

```
md1<-matrix(sample(c(0,1),110,replace=TRUE),10,11)
md2<-matrix(sample(c(0,1),120,replace=TRUE),10,12)
subnet_cor(md1,md2)
subnet_cor(md1,md2,weighted=TRUE)
```

```
md1<-matrix(sample(c(0,1),80,replace=TRUE),8,10)
md2<-matrix(sample(c(0,1),120,replace=TRUE),10,12)
subnet_cor(md1,md2)
```

```
mdw1<-matrix(runif(110,0,1),10,11)
mdw2<-matrix(runif(120,0,1),10,12)
subnet_cor(mdw1,mdw2,weighted=TRUE)
```

```
set.seed(1)
mdw1<-matrix(runif(80,0,1),8,10)
mdw2<-matrix(runif(120,0,1),10,12)
subnet_cor(mdw1,mdw2,weighted=TRUE)
```

Index

[build_net](#), [2](#)

[Hc](#), [3](#)

[igraph_from_matrices](#), [4](#)

[Midlayer_role](#), [6](#)

[motif_count](#), [8](#)

[Multi_motif](#), [10](#)

[Node_versatility](#), [11](#)

[null_model](#), [13](#)

[Prc](#), [15](#)

[Psc](#), [16](#)

[role_sim](#), [18](#)

[subnet_cor](#), [19](#)