Signed networks in ecology: new challenges for understanding ecological communities

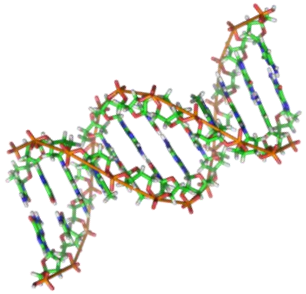
NetSci 2015
Complex networks in Ecology

Hugo Saiz, Jesús Gómez-Gardeñes, Paloma Nuche-Gálvez,
Andrea Girón, Yolanda Pueyo, Concepción L. Alados

Universidad Zaragoza

Prologue: simmilarities

Ecologists



Computer scientists

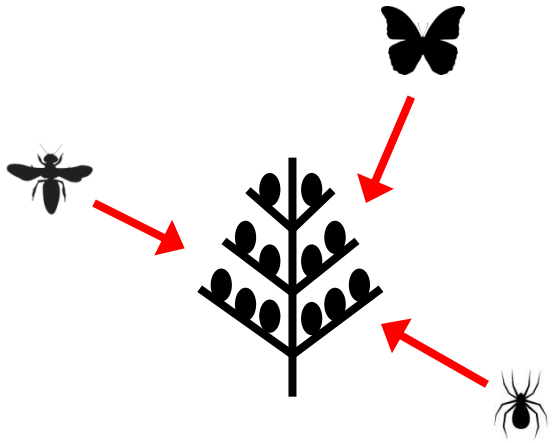
```
/**
 * Simple HelloButton() method.
 * @version 1.0
 * @author john doe <doe.j@example.com>
 */
HelloButton()
{
  JButton hello = new JButton( "Hello, wor
  hello.addActionListener( new HelloBtnList

  // use the JFrame type until support for t
  // new component is finished
  JFrame frame = new JFrame( "Hello Button"
  Container pane = frame.getContentPane();
  pane.add( hello );
  frame.pack();
  frame.show();           // display the fra
}
```

http://es.wikipedia.org/wiki/%C3%81cido_desoxirribonucleico; http://en.wikipedia.org/wiki/Source_code

Prologue: simmilarities

Ecologists



Computer scientists

http://es.wikipedia.org/wiki/%C3%81cido_desoxirribonucleico; *http://en.wikipedia.org/wiki/Source_code*
http://es.wikipedia.org/wiki/Servidor; *http://linuxitomex.blogspot.fr/2009/08/aplicaciones-libres-utiles.html*

Prologue: differences

Ecologists

WHERE DIVERSITY COMES?

Niche processes
Neutral processes
…

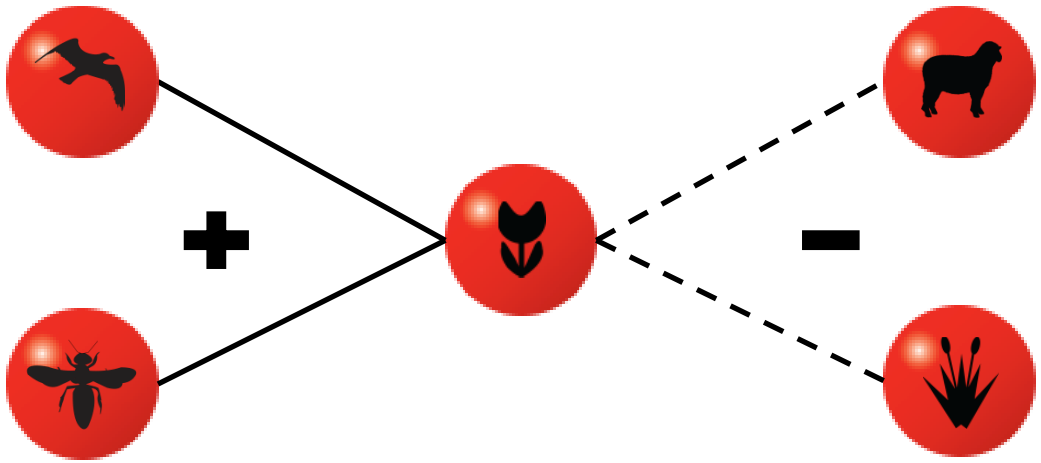
Computer scientists

HOW USE DIVERSITY?

Software diversification
Services diversification
…

Biotic interactions and networks

Species interact with other species.



Biotic interactions and networks

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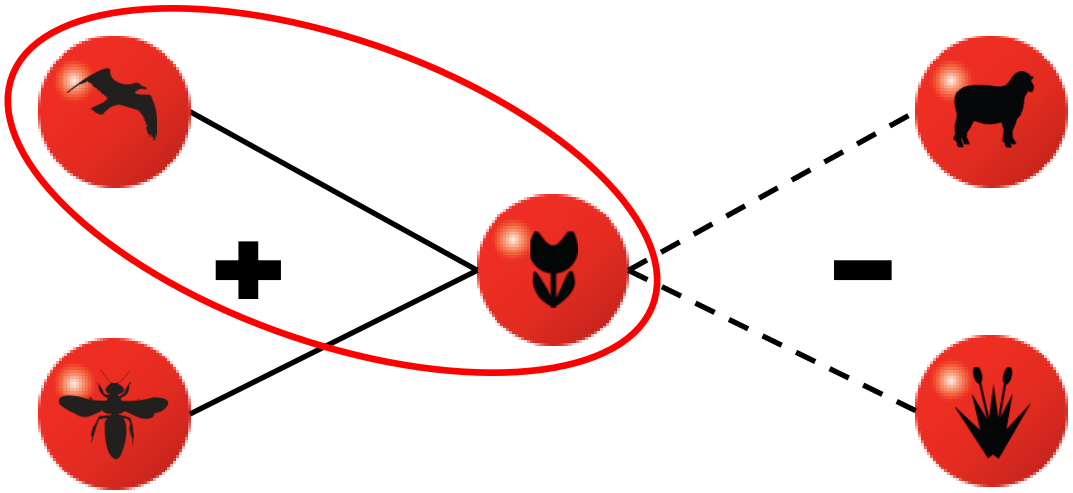

Signed networks are not common in ecology.

Ecology needs signed networks

Oikos 118: 122–130, 2009
doi: 10.1111/j.1600-0706.2008.16751.x,
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Subject Editor: Jonathan Shurin. Accepted 4 July 2008

Melián et al. 2009

Diversity in a complex ecological network with two interaction types

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Fontaine et al. 2011

ECOLOGY LETTERS
Ecology Letters, (2011) **14**: 1170–1181 doi: 10.1111/j.1461-0248.2011.01688.x

REVIEW AND SYNTHESIS

The ecological and evolutionary implications of merging different types of networks

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IDEA AND PERSPECTIVE

More than a meal… integrating non-feeding interactions into food webs

Kéfi et al. 2012

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IDEA AND PERSPECTIVE

More than a meal… integrating non-feeding interactions into food webs

Kéfi et al. 2012

Pocock et al. 2012

The Robustness and Restoration of a Network of Ecological Networks

Michael J. O. Pocock,*† Darren M. Evans,‡ Jane Memmott

Ecology needs signed networks

Special issue in *Population Ecology* 57 (2015)

Popul Ecol
DOI 10.1007/s10144-014-0473-y

THE SOCIETY OF POPULATION ECOLOGY

SPECIAL FEATURE: ORIGINAL ARTICLE — Unravelling ecological networks

Comparing the conservatism of ecological interactions in plant–pollinator and plant–herbivore networks

Colin Fontaine · Elisa Thébault

Popul Ecol (2015) 57:21–27
DOI 10.1007/s10144-014-0475-9

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Interaction-type diversity hypothesis and interaction strength: the condition for the positive complexity-stability effect to arise

Michio Kondoh · Akihiko Mougi

Popul Ecol (2015) 57:3–19
DOI 10.1007/s10144-015-0482-5

THE SOCIETY OF POPULATION ECOLOGY

SPECIAL FEATURE: PREFACE — Unravelling ecological networks

Multi-faceted approaches toward unravelling complex ecological networks

Toshiyuki Namba[1]

Popul Ecol
DOI 10.1007/s10144-014-0471-0

THE SOCIETY OF POPULATION ECOLOGY

SPECIAL FEATURE: REVIEW — Unravelling ecological networks

The stability–complexity relationship at age 40: a random matrix perspective

Stefano Allesina · Si Tang

The road until now

- Compare different networks (*Cagnolo et al. 2011, J Anim Ecol*)

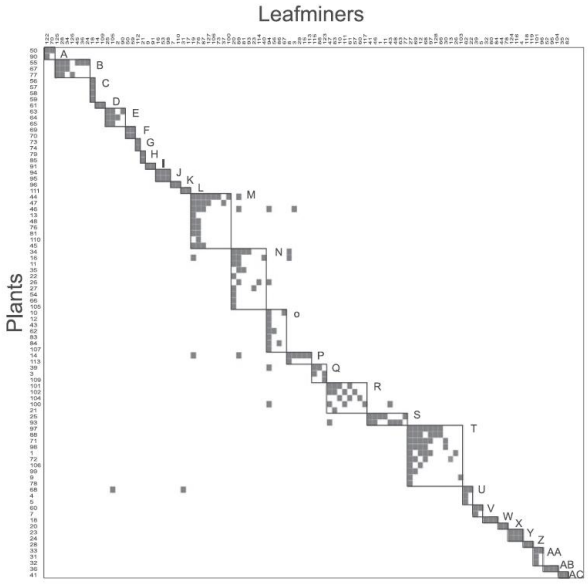


Fig. 1. Plant-leafminer food web of the Chaco Serrano forest from Central Argentina. Row and column numbers are codes for species names given in Supporting Information. Compartments are outlined and uppercase letters are compartment names. Isolated pairwise interactions were removed from the figure for clarity.

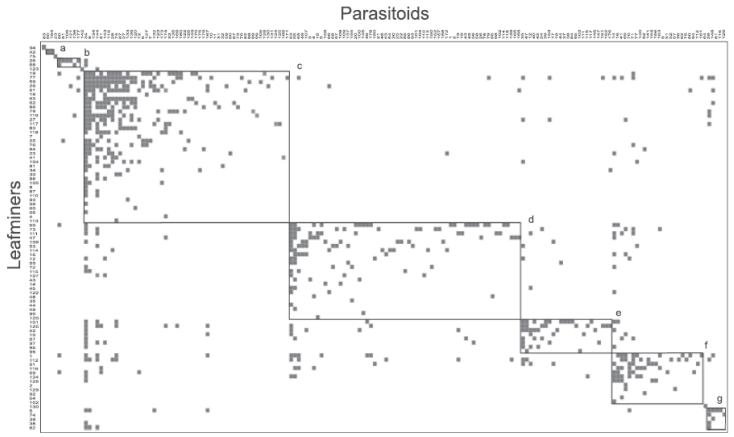
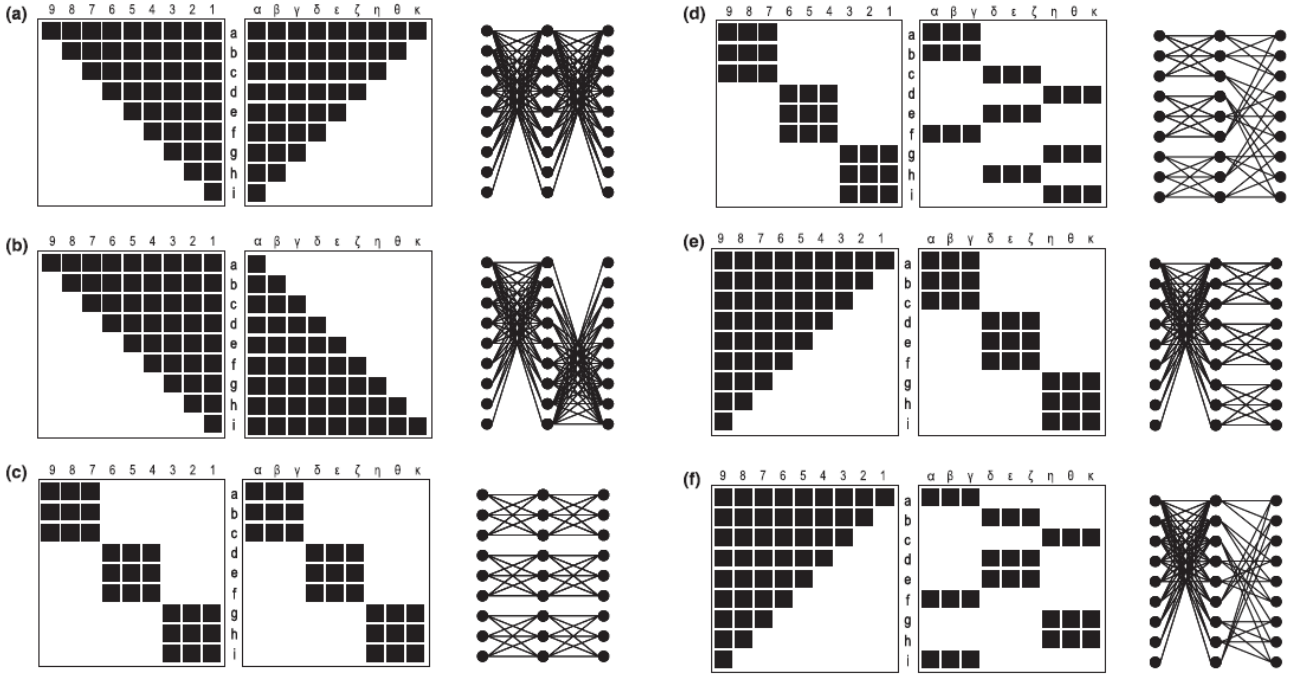


Fig. 2. Leafminer-parasitoid food web of the Chaco Serrano forest from central Argentina. Row and column numbers are codes for species names given in Supporting Information. Compartments are outlined and lowercase letters are compartment names.

The road until now

- Build networks of networks (*Fontaine et al. 2011, Ecol Let*)



The road until now

- Build networks of networks (*Pocock et al. 2012, Science*)

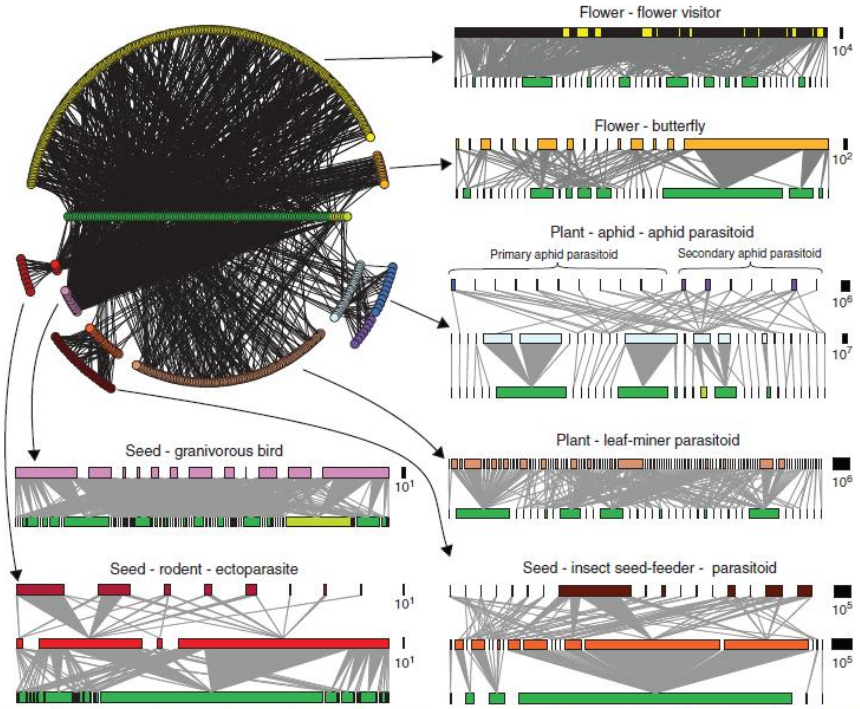


Fig. 1. Species' interaction networks at Norwood Farm, Somerset, UK. The entire network of networks is shown at top left (in which each circle represents one species), and quantitative visualizations are shown for each of the seven quantified individual networks (in which each block is a species, and the width of blocks of each color represents relative abundance). Details of the networks are given in table S1 and (*14*). Dark green and light green circles and blocks indicate noncrop and crop plants, respectively, whereas other colors indicate animal groups. Scale bars indicate the abundance of animal taxa. Plants are scaled in proportion to their interactions with animals in each network.

The road until now

- Networks with different interactions (*Kefi et al. 2015, Ecology*)

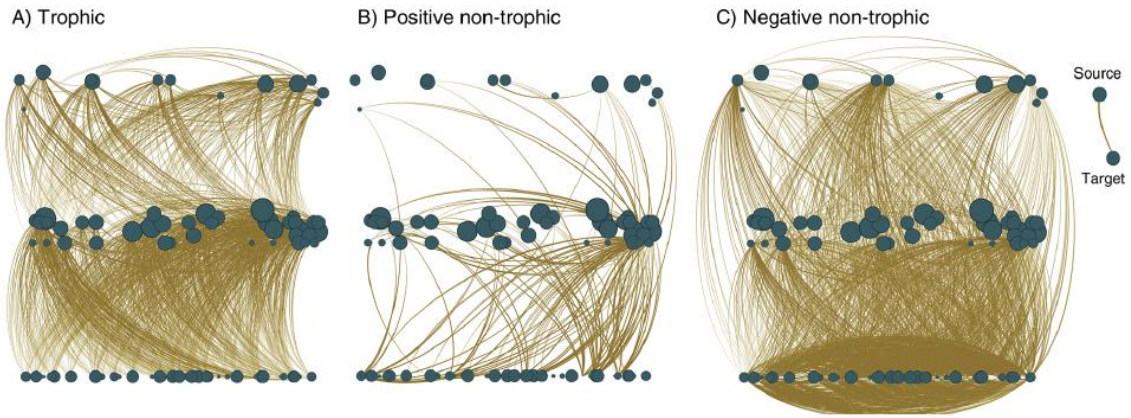
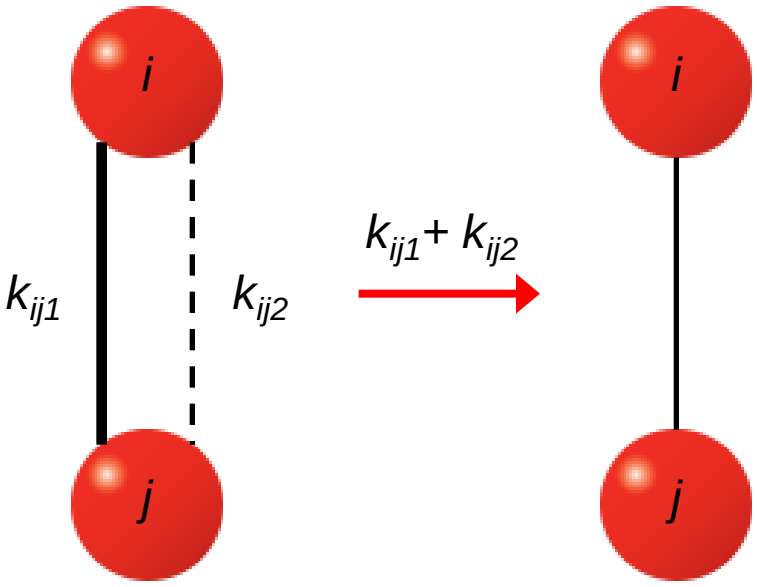
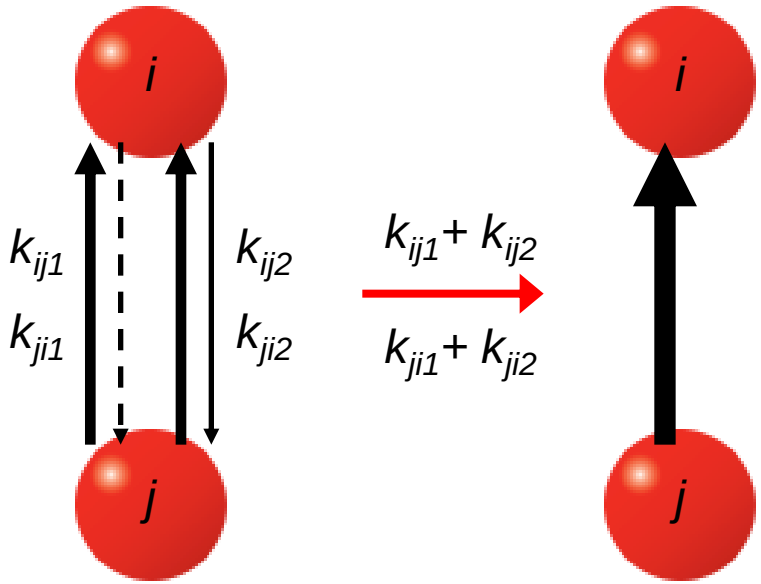


FIG. 1. Networks of trophic and non-trophic interactions between the 104 species of the Chilean intertidal ecosystem: (A) trophic network, (B) network of positive non-trophic interactions, and (C) network of negative non-trophic interactions. Each node indicates a species. The vertical position is the trophic level (basal species at the bottom and top predators at the top). The horizontal position within each level is random. The curvature of lines between the nodes indicates directionality of influence, with lines arcing counterclockwise from source to target species (as shown on the key on the right of panel C). The networks were plotted with Mappr, Vibrant Data's cloud-based visualization software (*available online*: http://vibrantdata.is). Among the 99 species that had at least one non-trophic interaction, 66 species had at least one positive non-trophic interaction, and 77 had at least one negative non-trophic interaction. The non-trophic connectance was 0.34, and the trophic connectance 0.13.

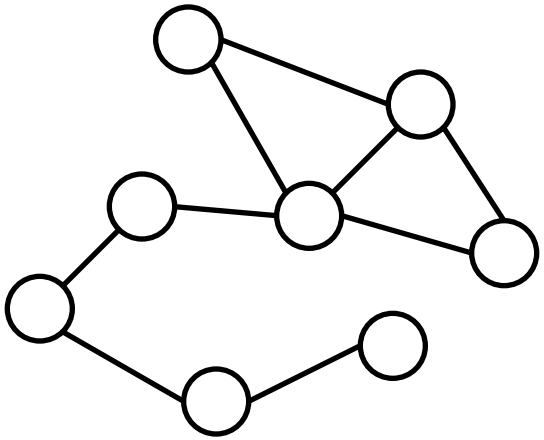
Problems merging links

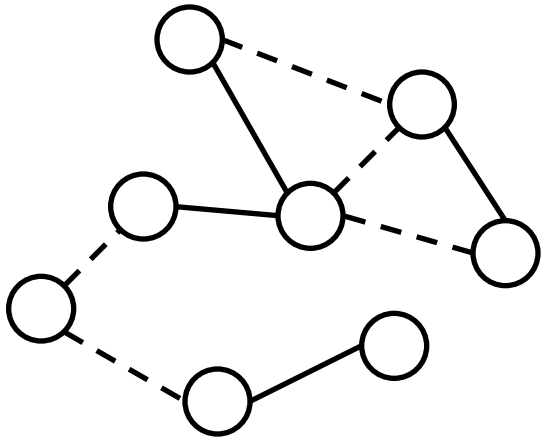


Problems merging links



Analyzing signed networks





$K = 9$

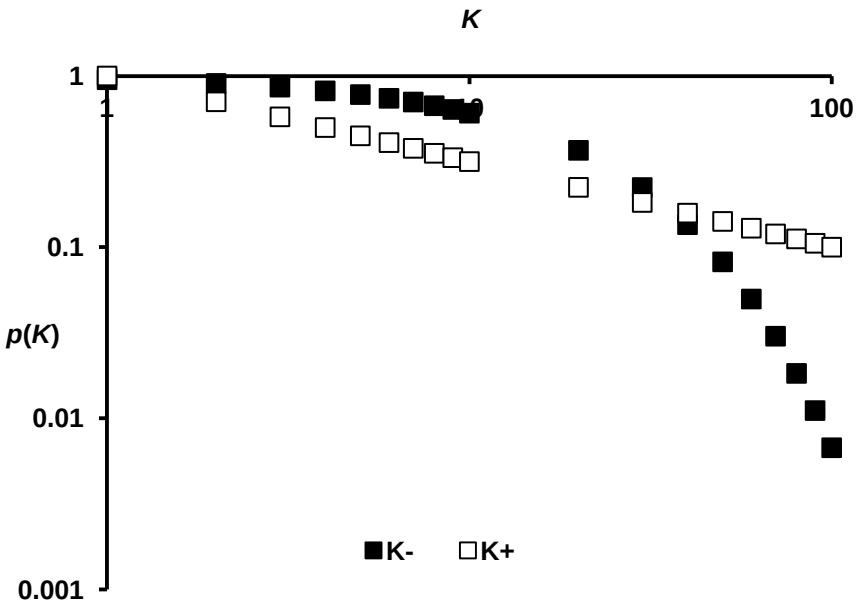
$K^+ = 4$ $K^- = 5$

$K = |K| = K^+ + K^- = 9$

Connectance, clustering, betweenness…

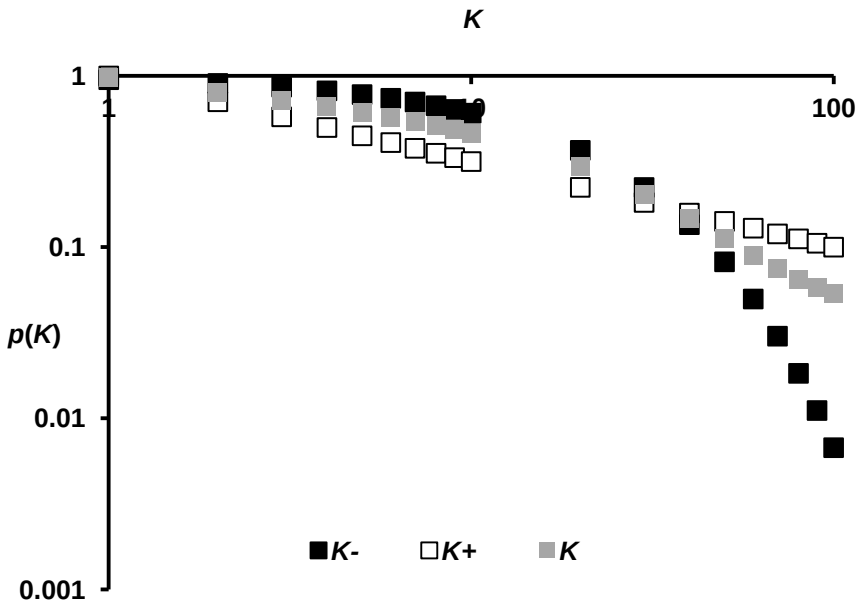
Structure of signed networks

Degree distribution



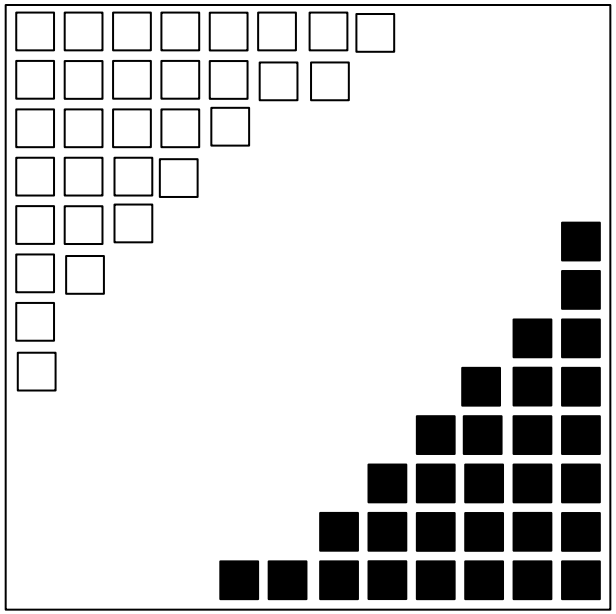
Structure of signed networks

Degree distribution



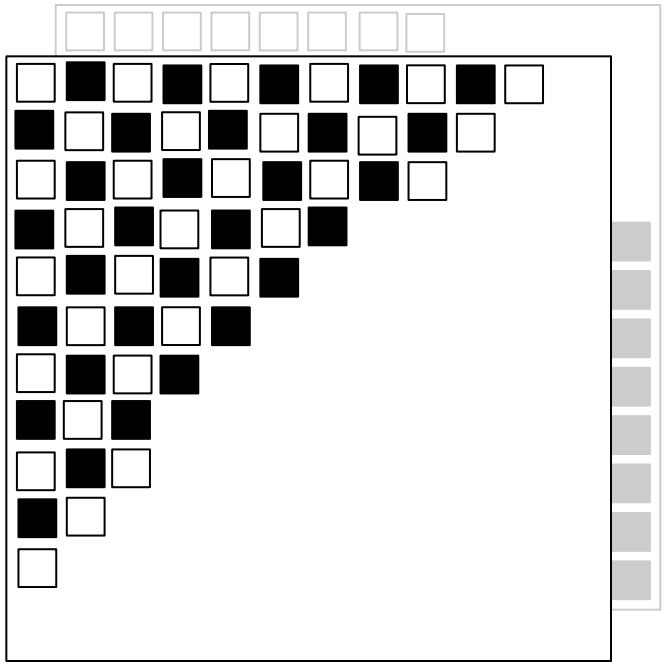
Structure of signed networks

Nestedness



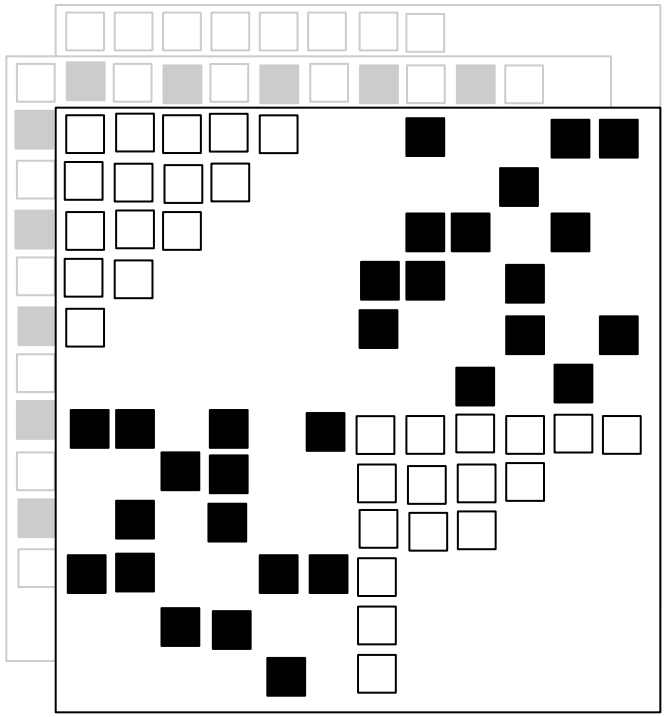
Structure of signed networks

Nestedness



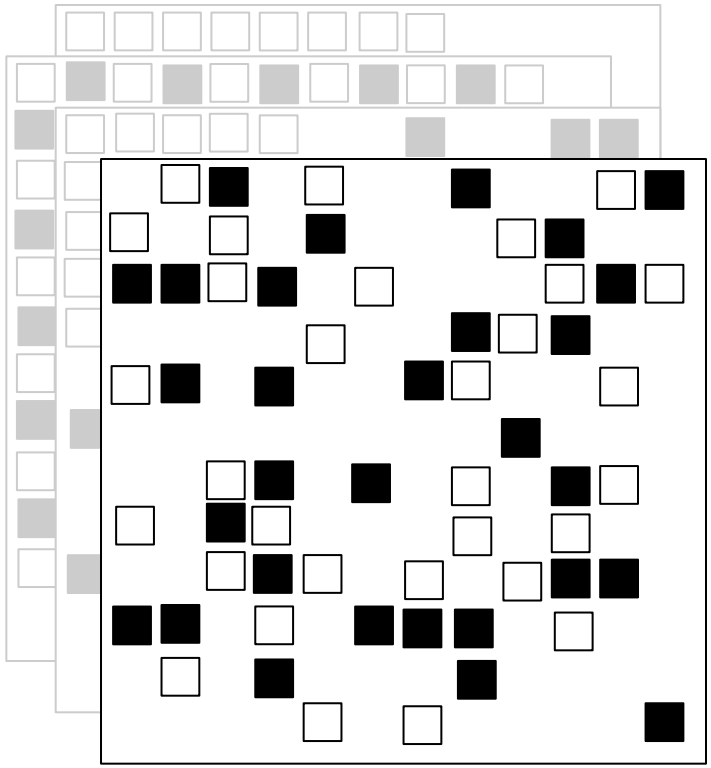
Structure of signed networks

Nestedness



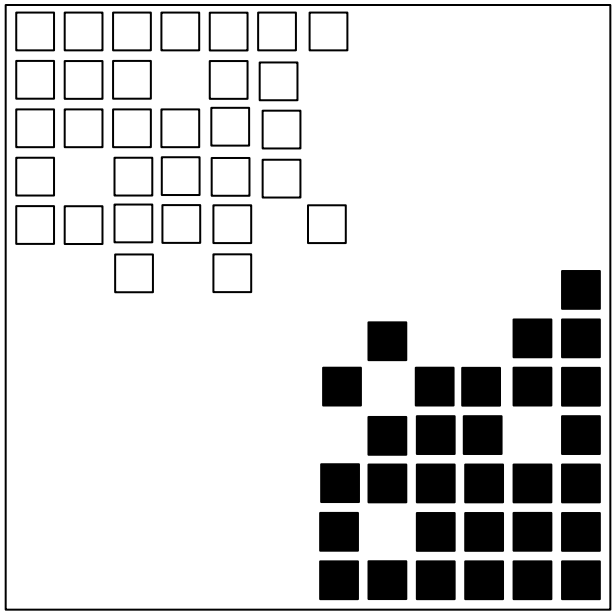
Structure of signed networks

Nestedness



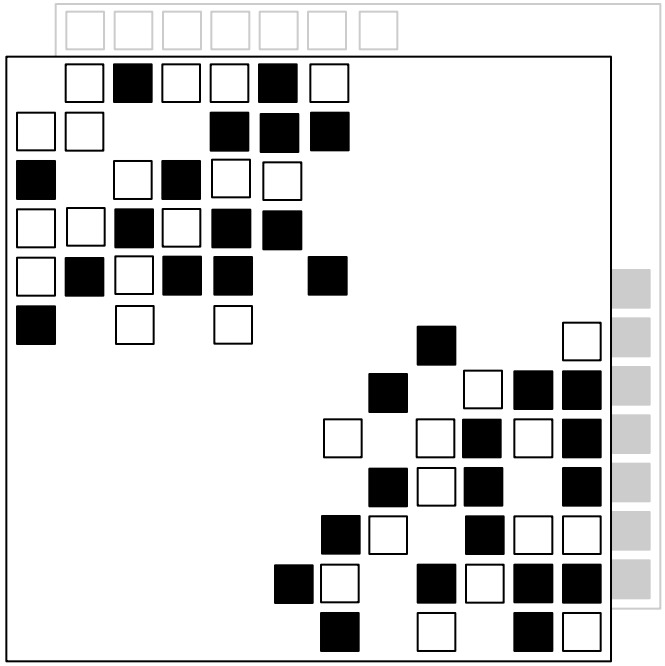
Structure of signed networks

Modularity



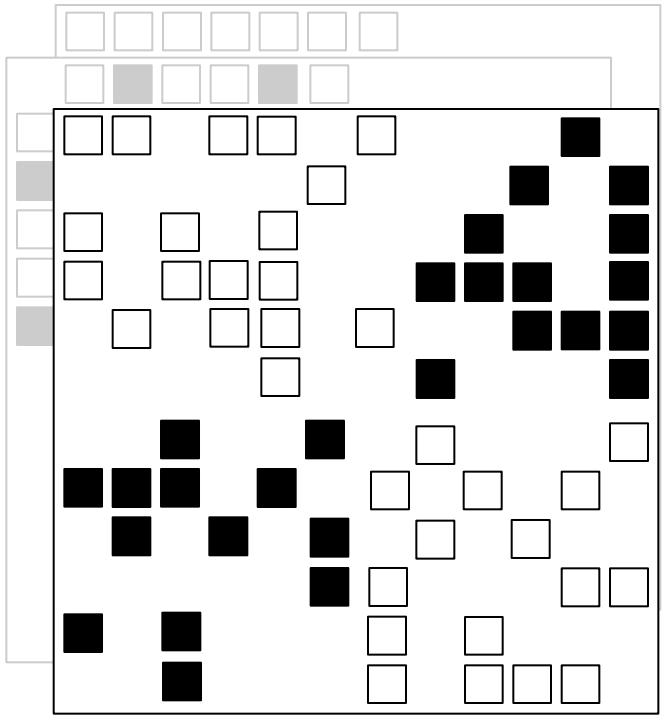
Structure of signed networks

Modularity



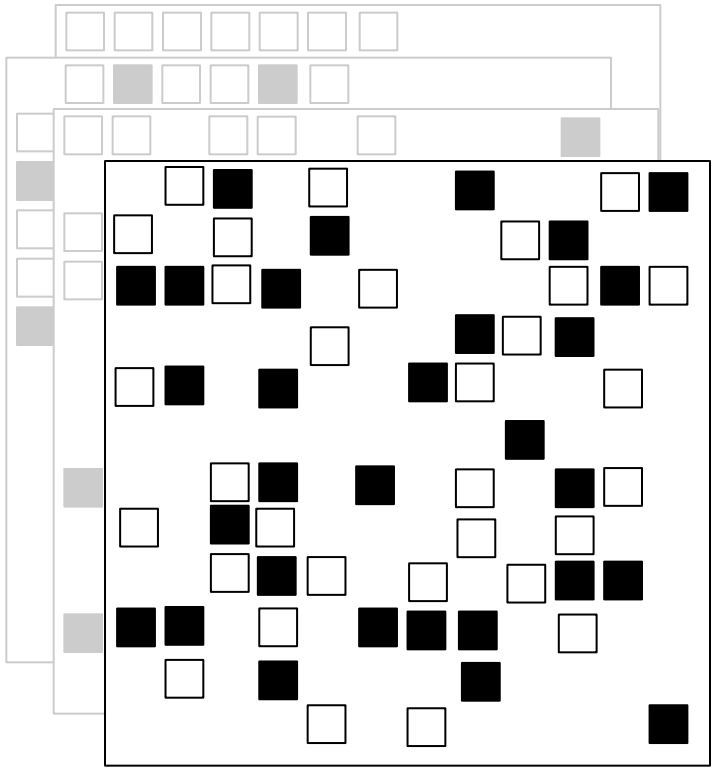
Structure of signed networks

Modularity



Structure of signed networks

Modularity



Signed network measures

Ecological sense ?

Structural balance

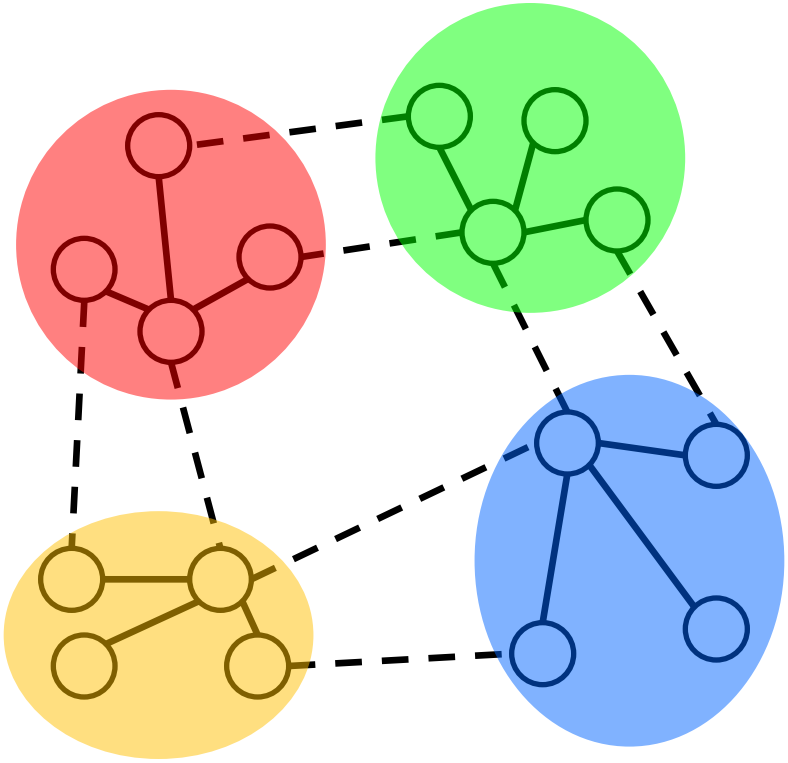
Doreian & Mrvar 2009

Structural balance

- Within a block → Links are positive
- Between blocks → Links are negative

Structural balance

Network

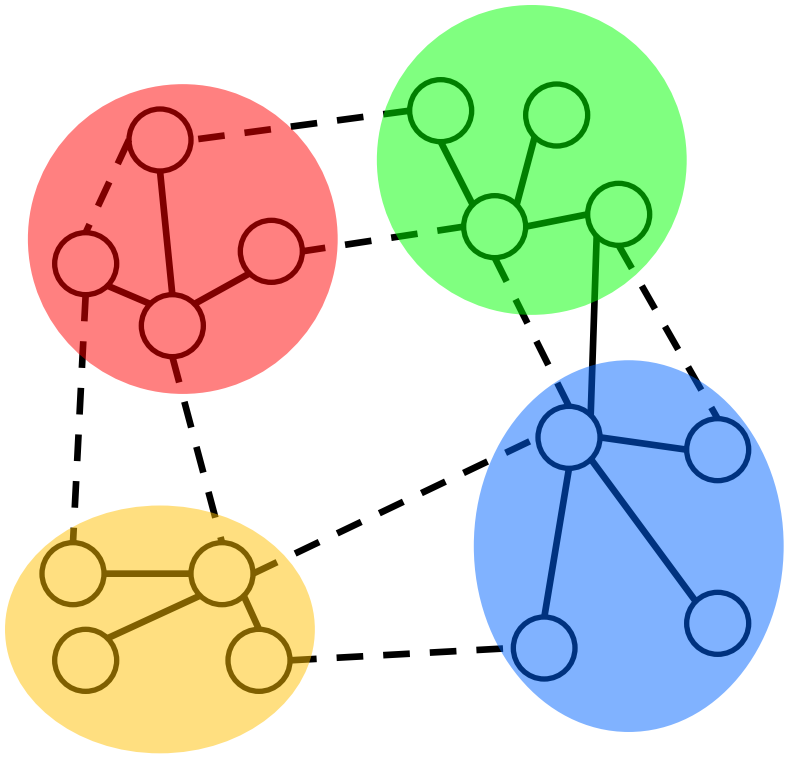


Adjacency matrix

+	-	-	
-	+		-
-		+	-
	-	-	+

Imperfect balanced

Networks can be unbalanced.



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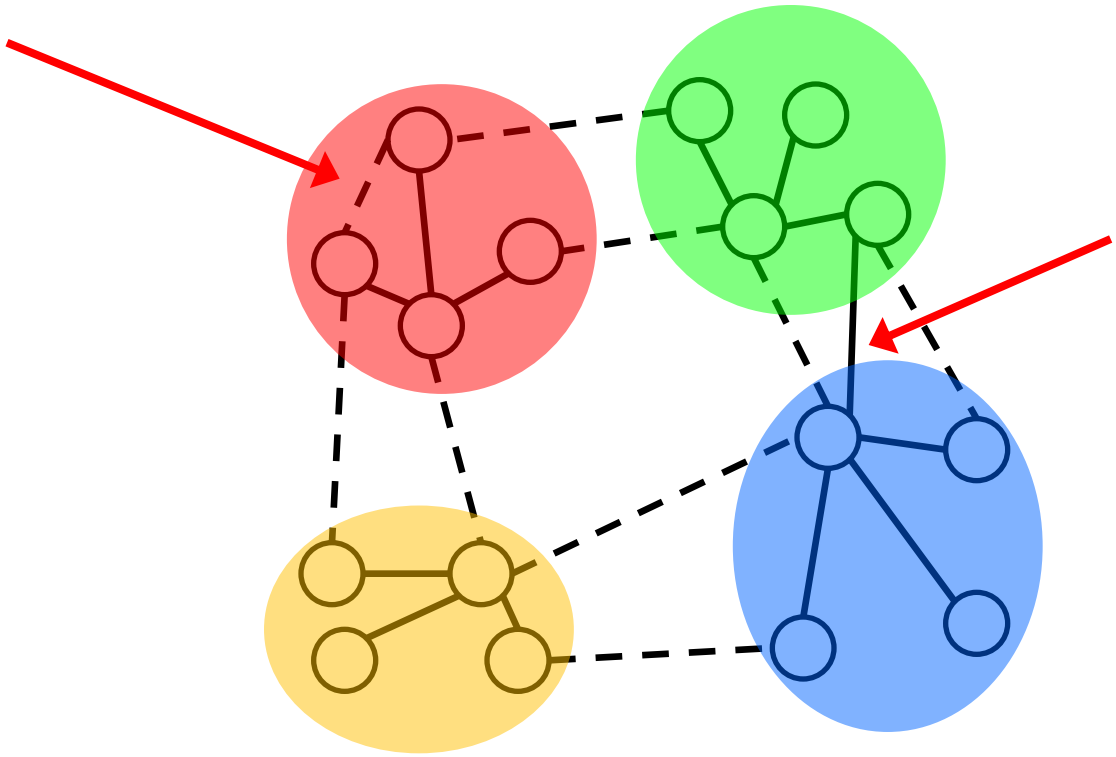
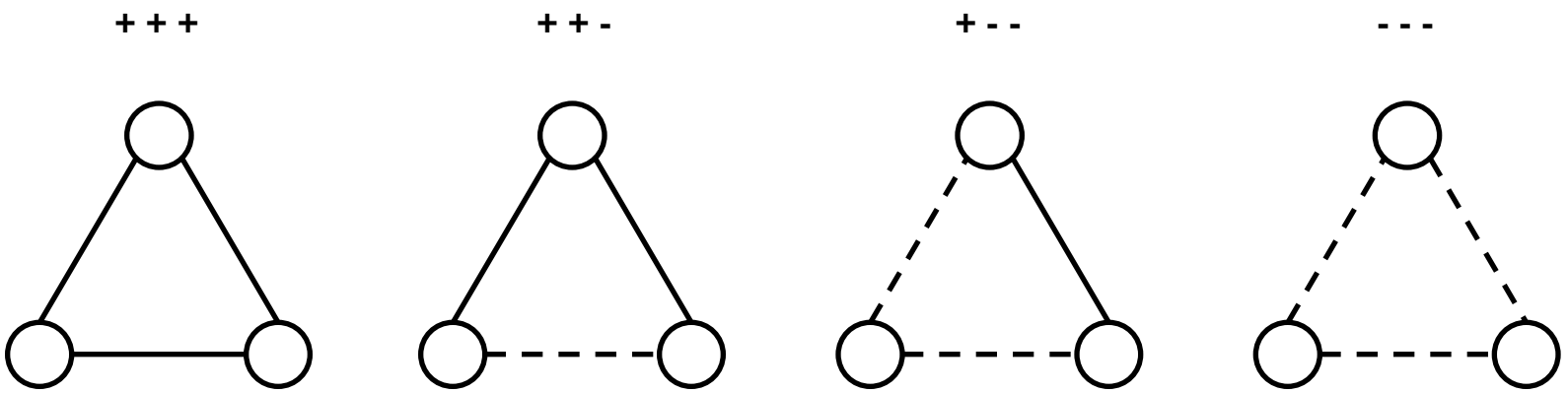


The number of links that are not in balance is the **Frustration** of the network.

Imperfect balanced

Local balance: Triads



Imperfect balanced

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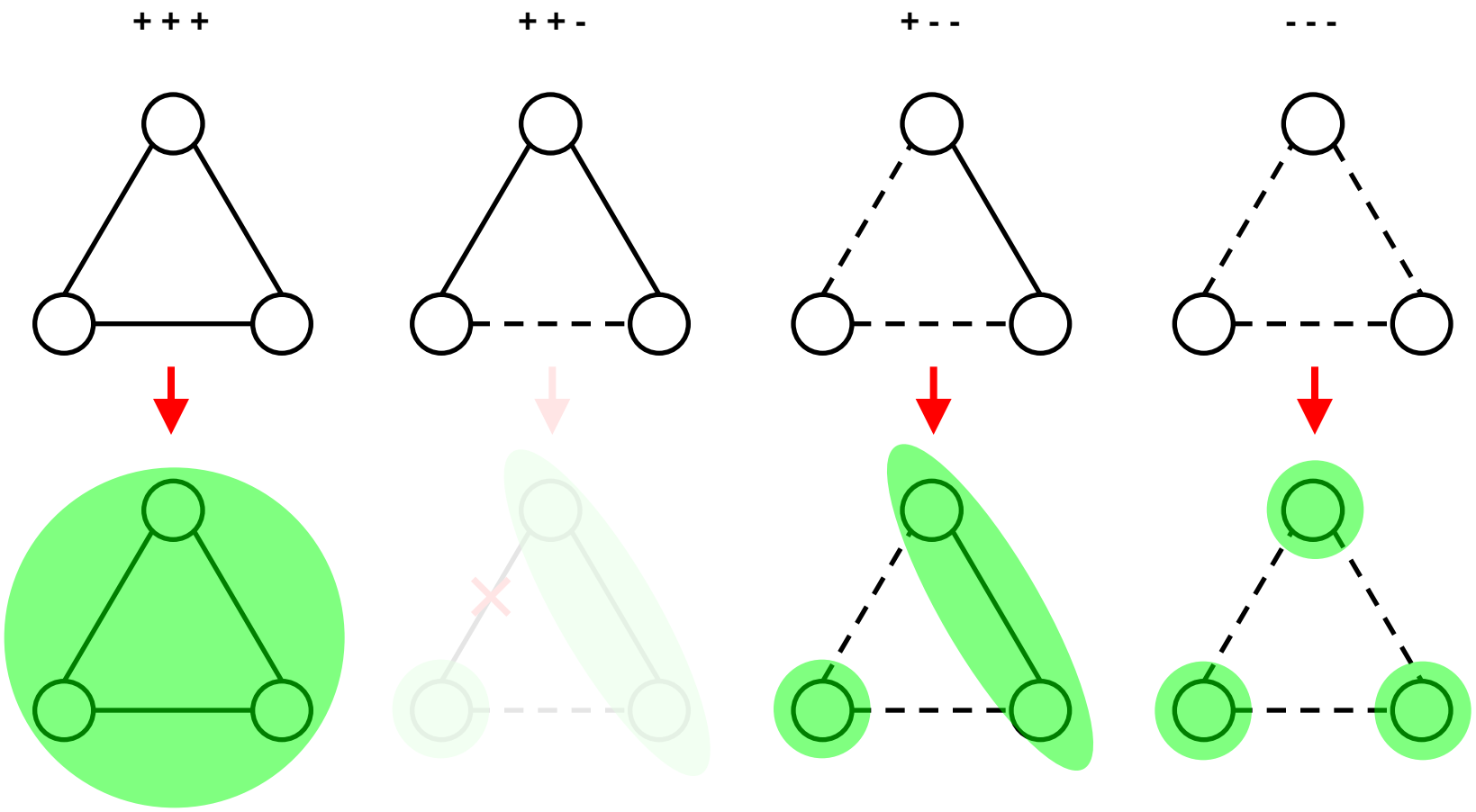
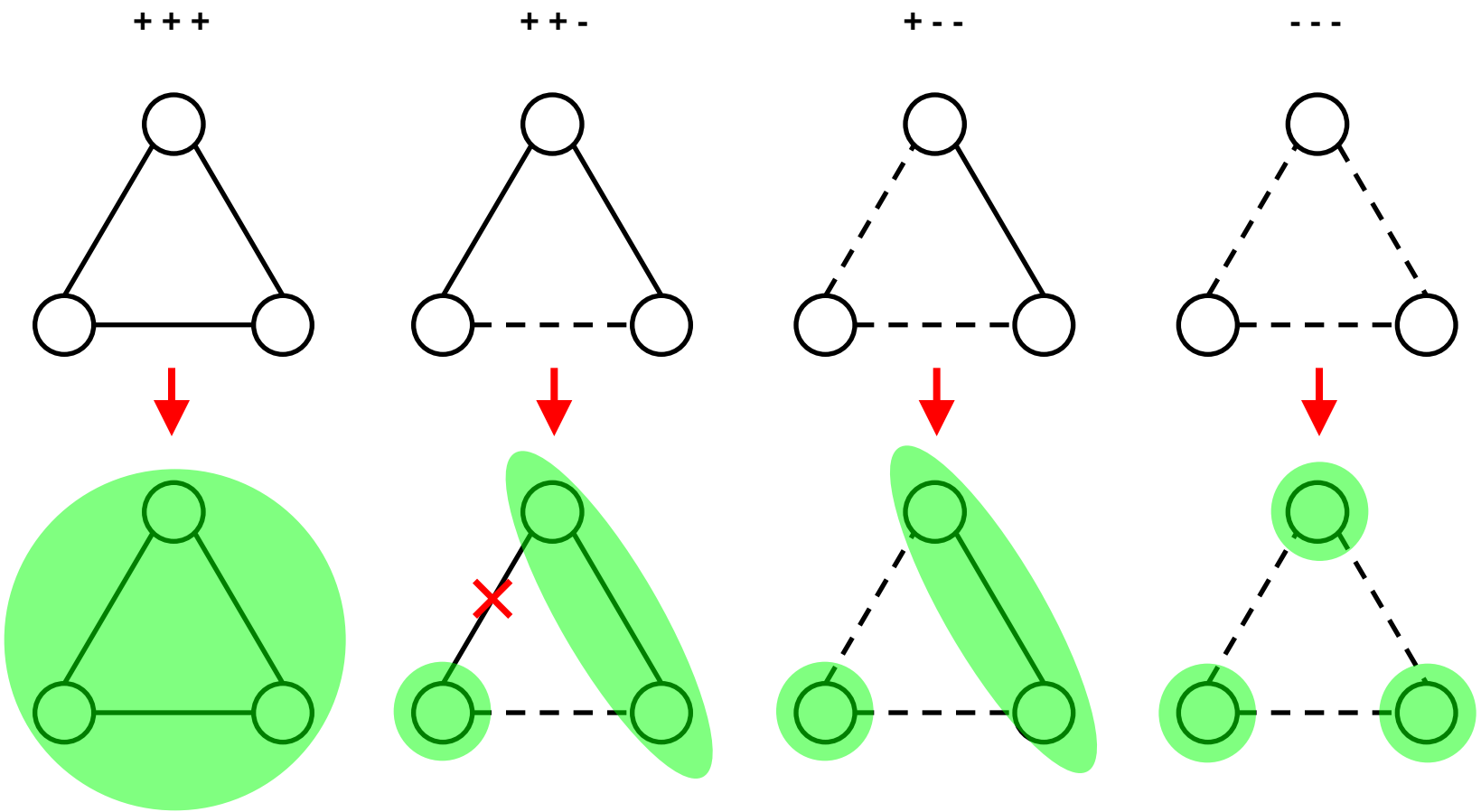
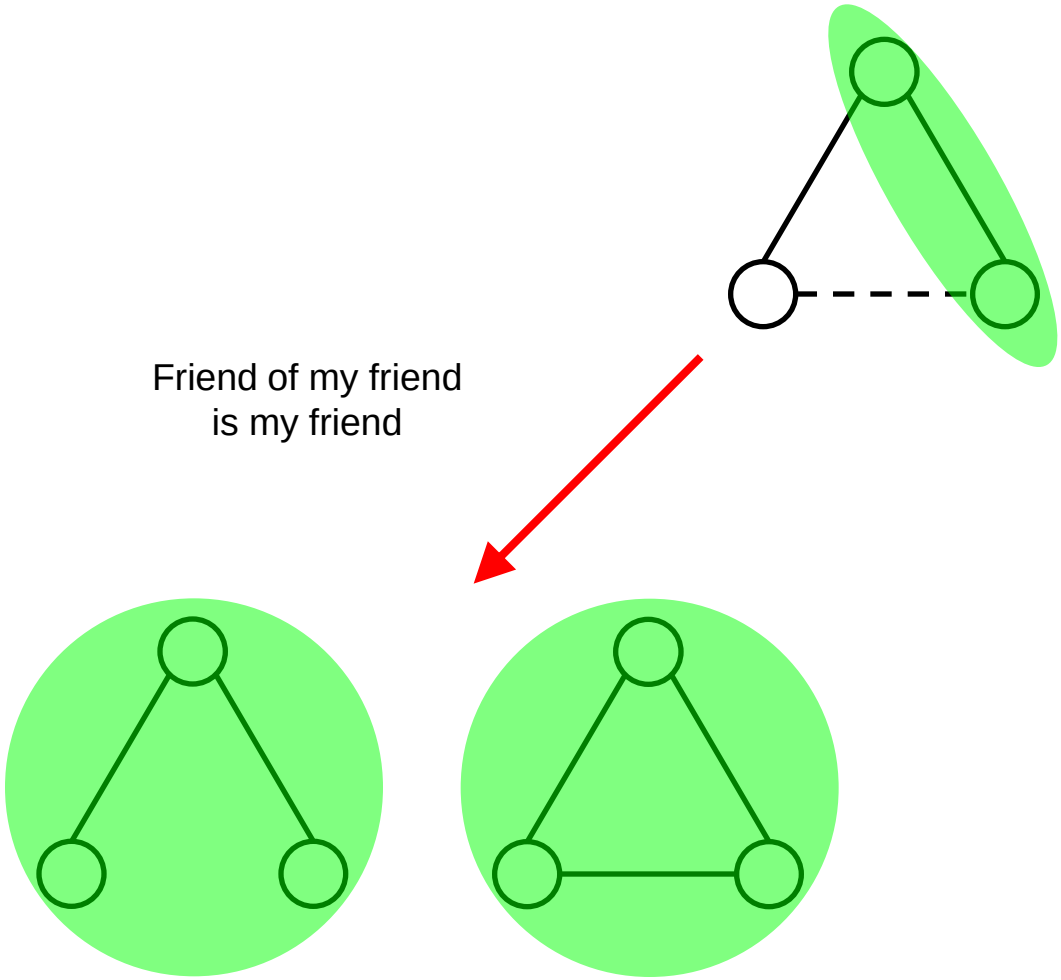


Imperfect balanced

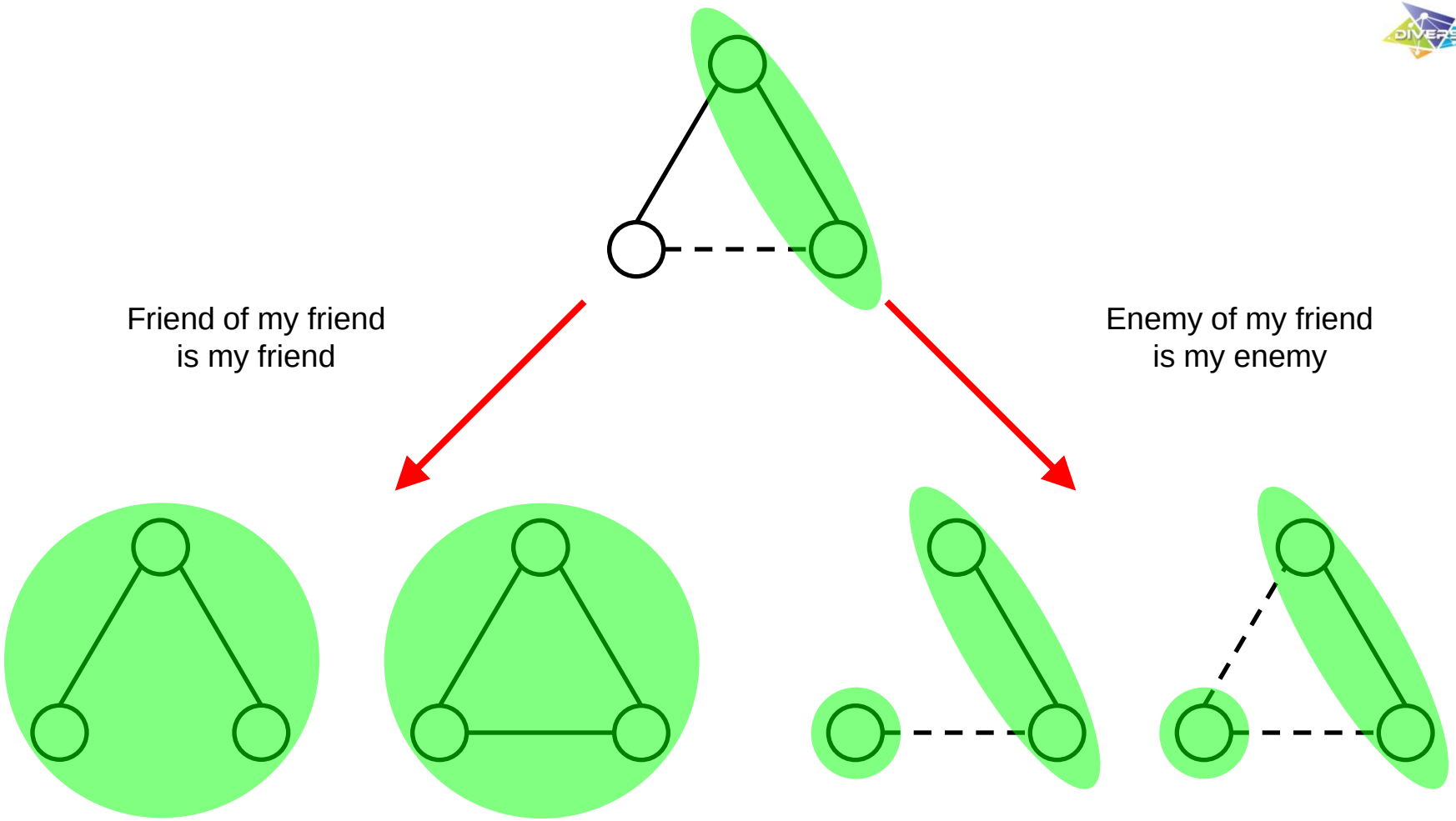
Networks can be unbalanced.



Evolution of (+ + -) triad



Evolution of (+ + -) triad



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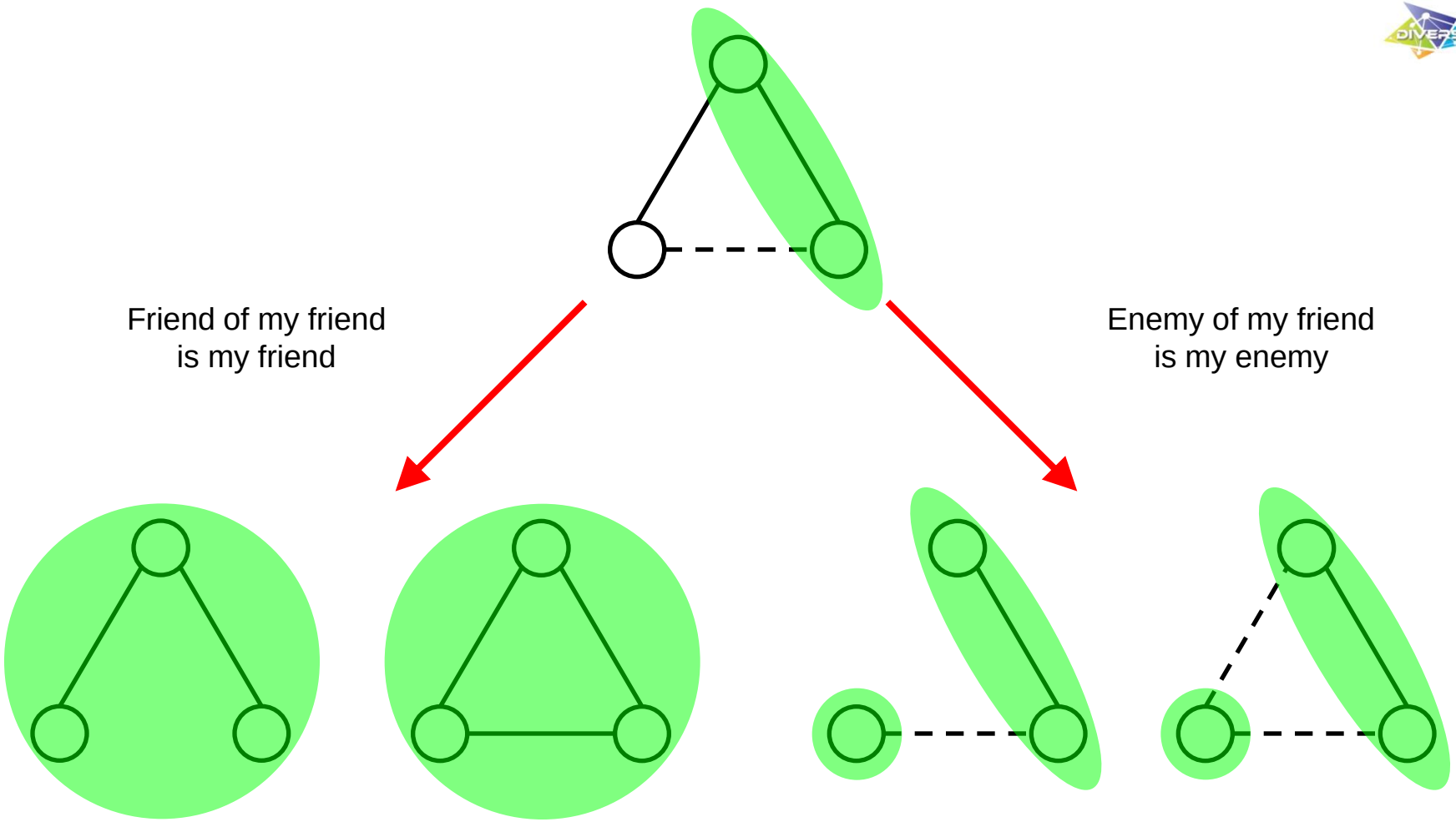

Evolution should promote structural balance

Szell et al. 2010, PNAS, *Ilany et al. 2013, Anim Beh*.

Are ecological systems in balance?

Plant-plant signed network

VOL. 172, NO. 6 THE AMERICAN NATURALIST DECEMBER 2008

The Nested Assembly of Plant Facilitation Networks Prevents Species Extinctions

Verdú & Valiente-Banuet 2008

Plant-plant signed network

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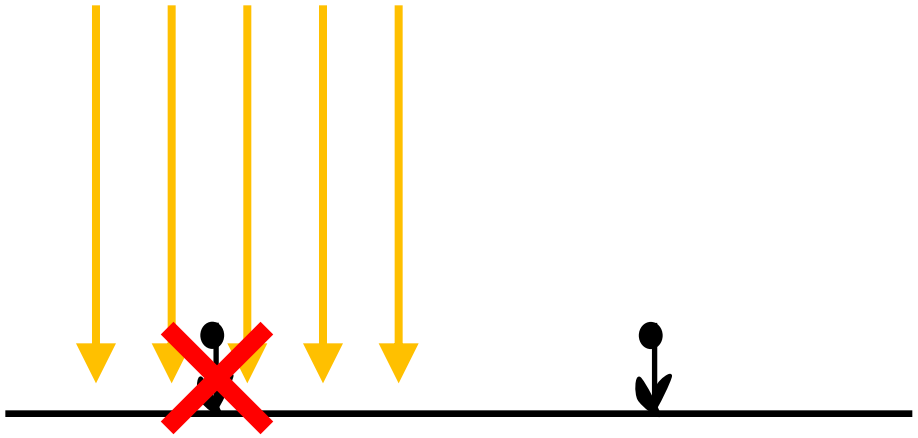

Plant-plant signed network

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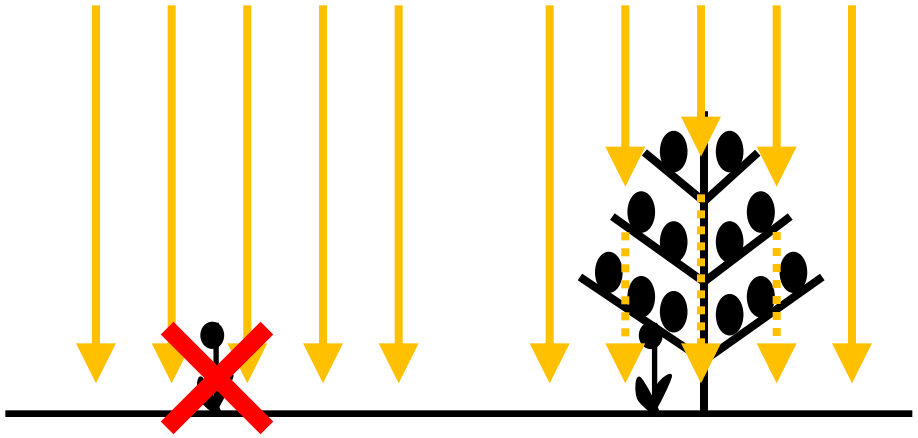
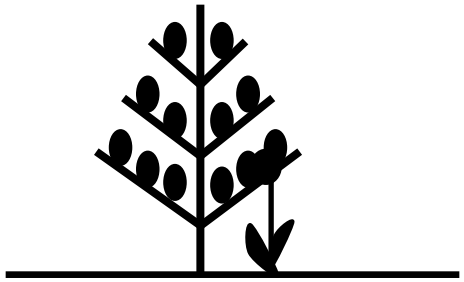


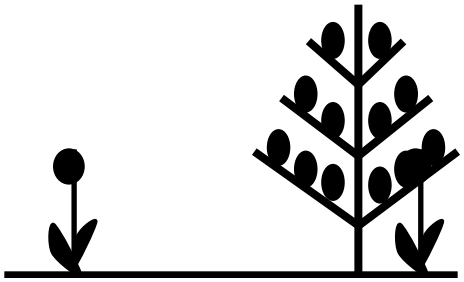
Plant-plant signed network

Positive association



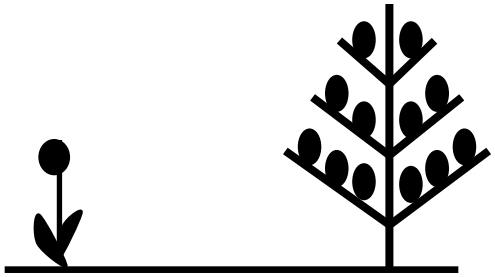
Positive interaction

Neutral association



No interaction

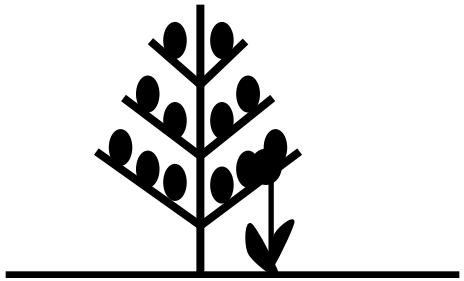
Negative association



Negative interaction

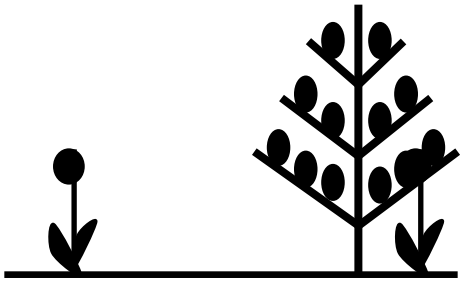
Plant-plant signed network

Positive association



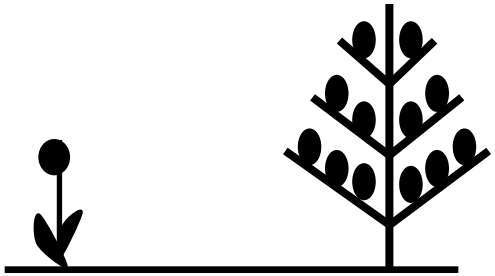
Positive interaction

Neutral association



No interaction

Negative association



Negative interaction

IT IS AN APPROXIMATION!!!

(Biotic interactions + Plants dispersion patterns + environmental heterogeneity)

Plant-plant signed networks

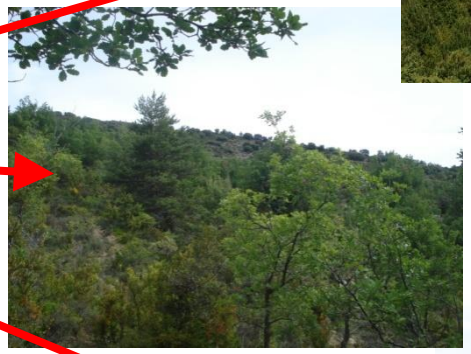
31 networks

https://maps.google.es

Plant-plant signed networks

31 networks

https://maps.google.es



S	→	21 … 125
Ratio	→	-0.37 … 0.69

Plant-plant networks structural balance

For each network:

Frustration = Unbalanced links / Total links

Number of each type of triad.

Null model:

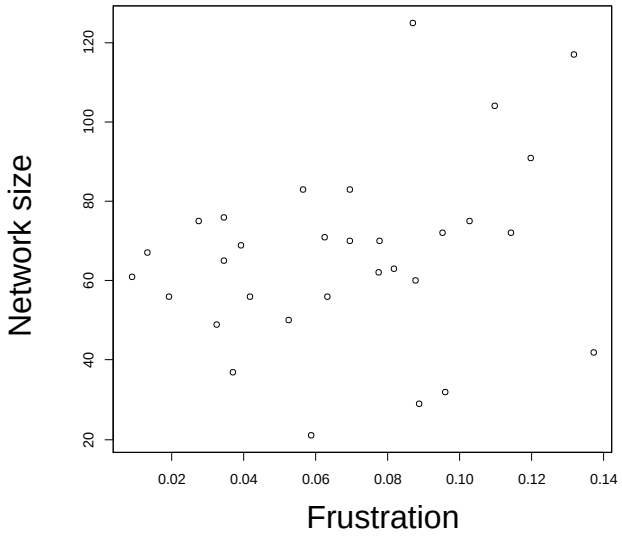
Network with the same positive and negative degree distribution.

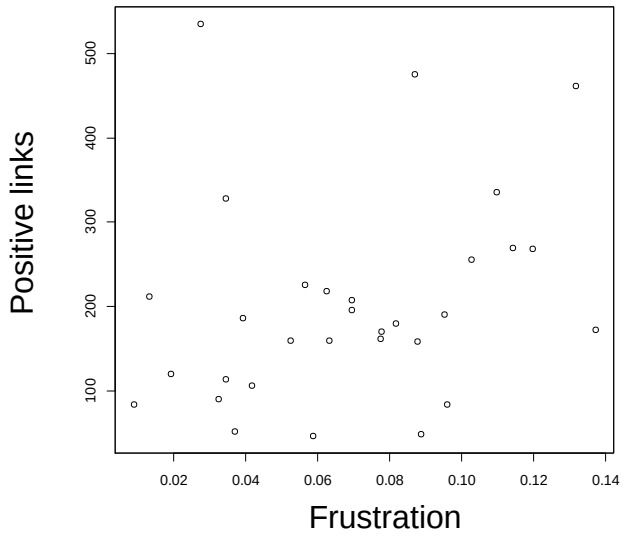
Indices:

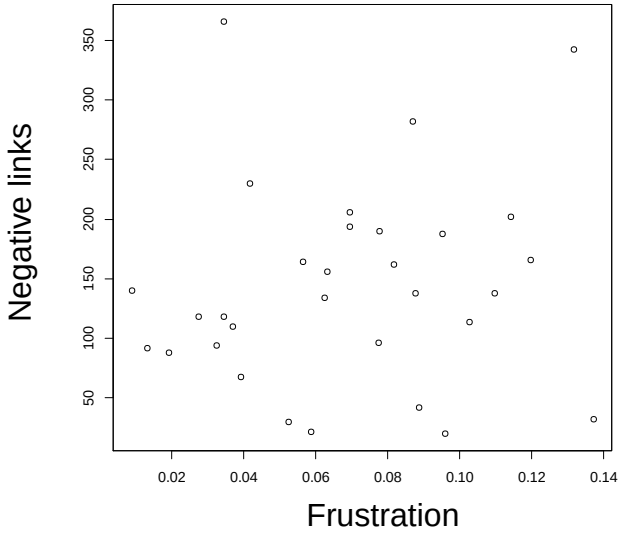
Global balance → Real frustration – Simulated frustration

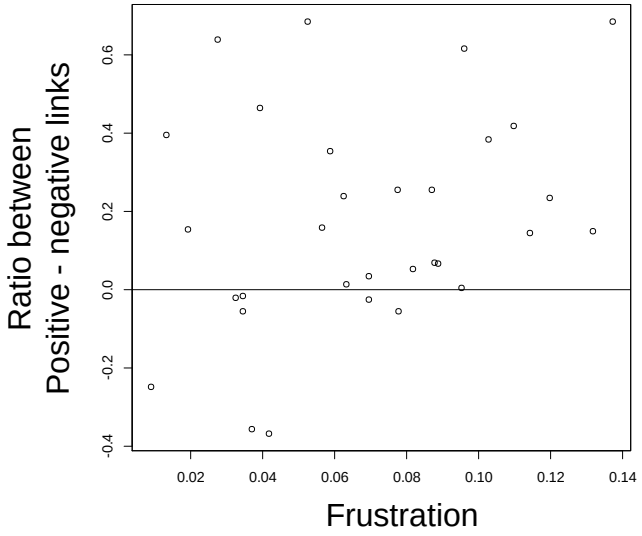
Local balance → Real number of triads – Simulated number of triads

Controlling balance



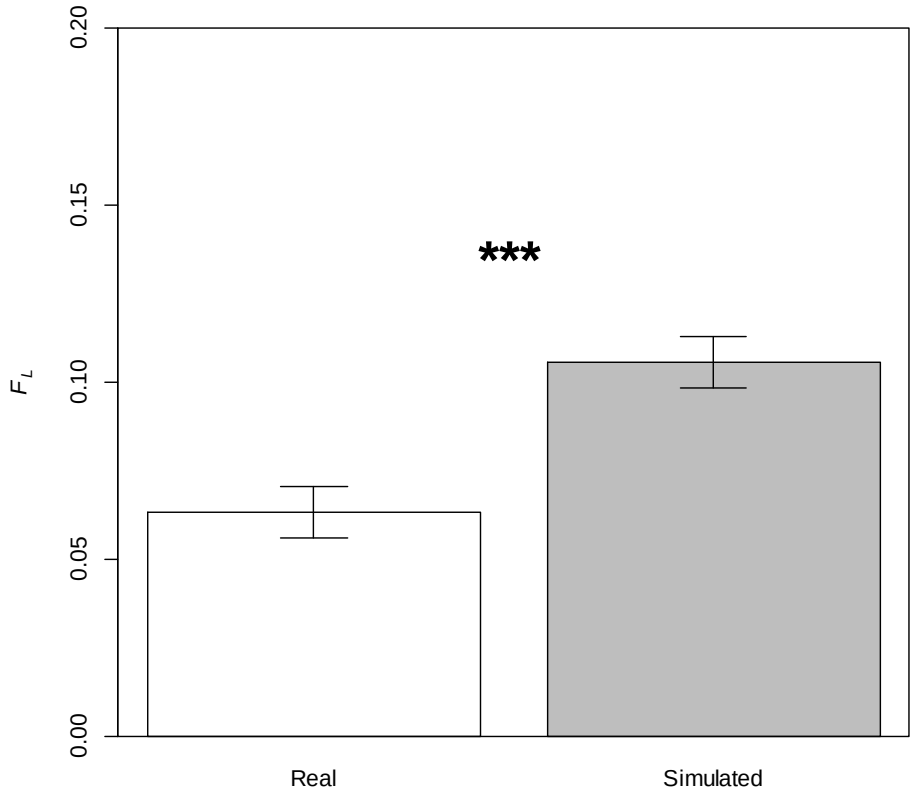






Global balance

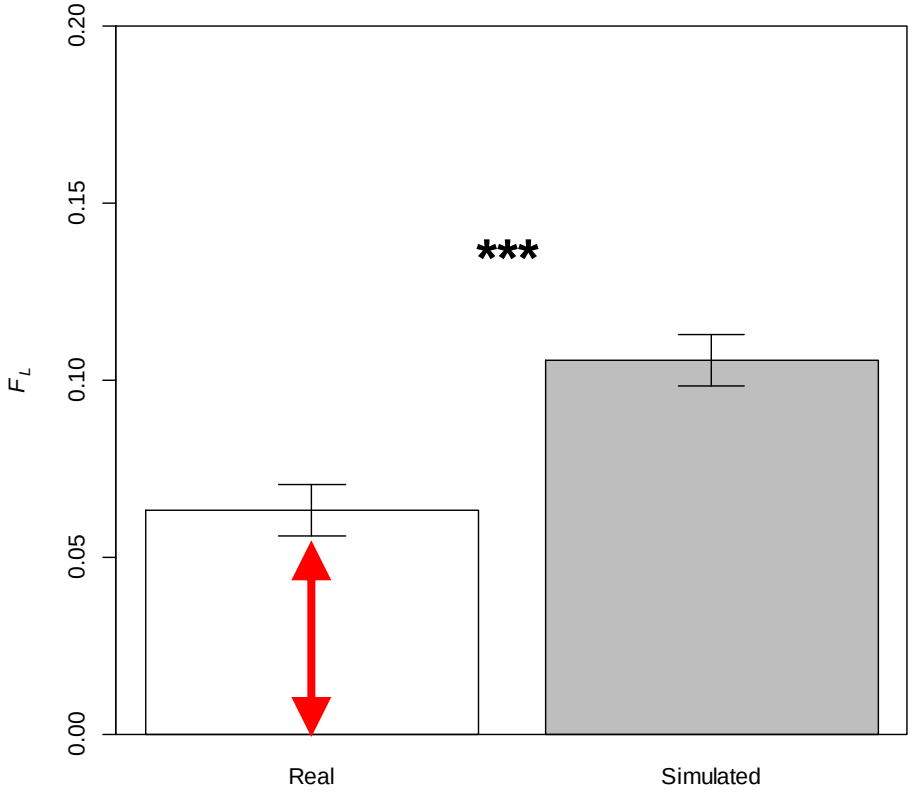
21 of 31 (68%) networks are more balanced than expected



Global balance

21 of 31 (68%) networks are more balanced than expected

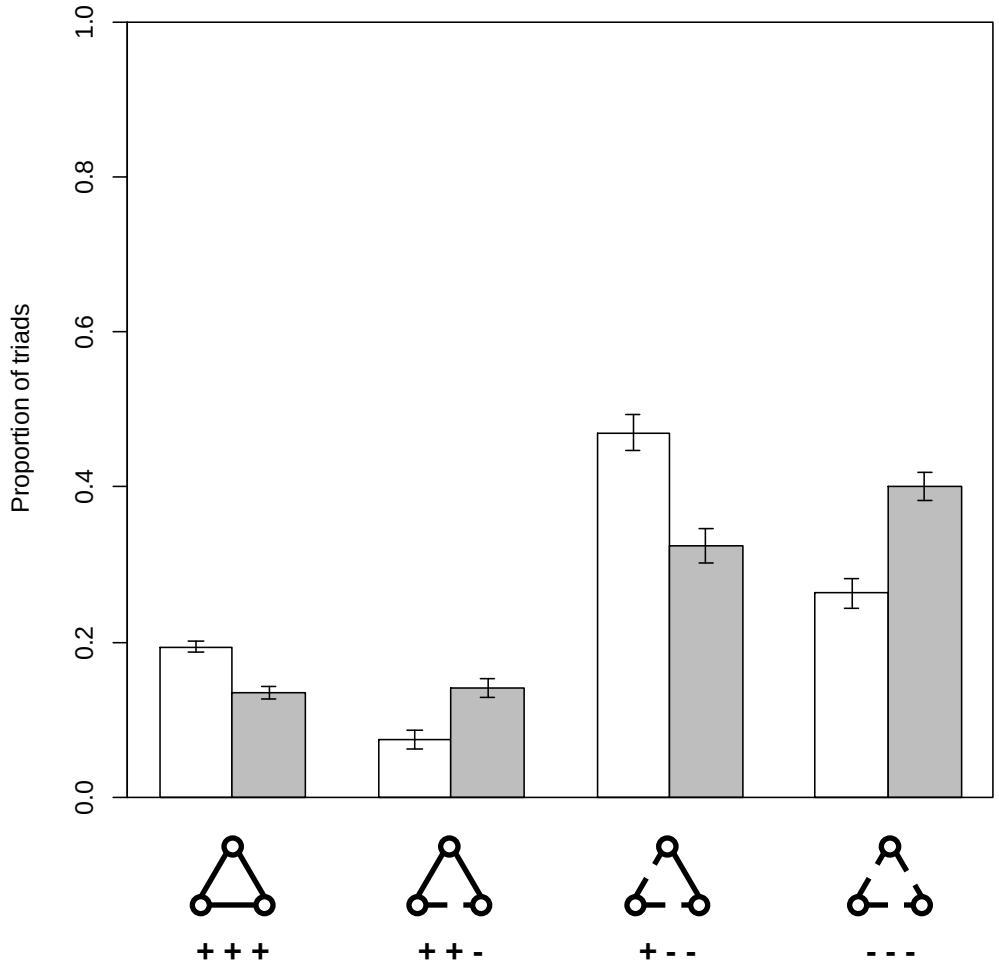
30 of 31 (97%) networks have frustration > 0



Adaptability of the system

Local balance

26 of 31 (84%) networks have different proportion of triads than expected



Local balance

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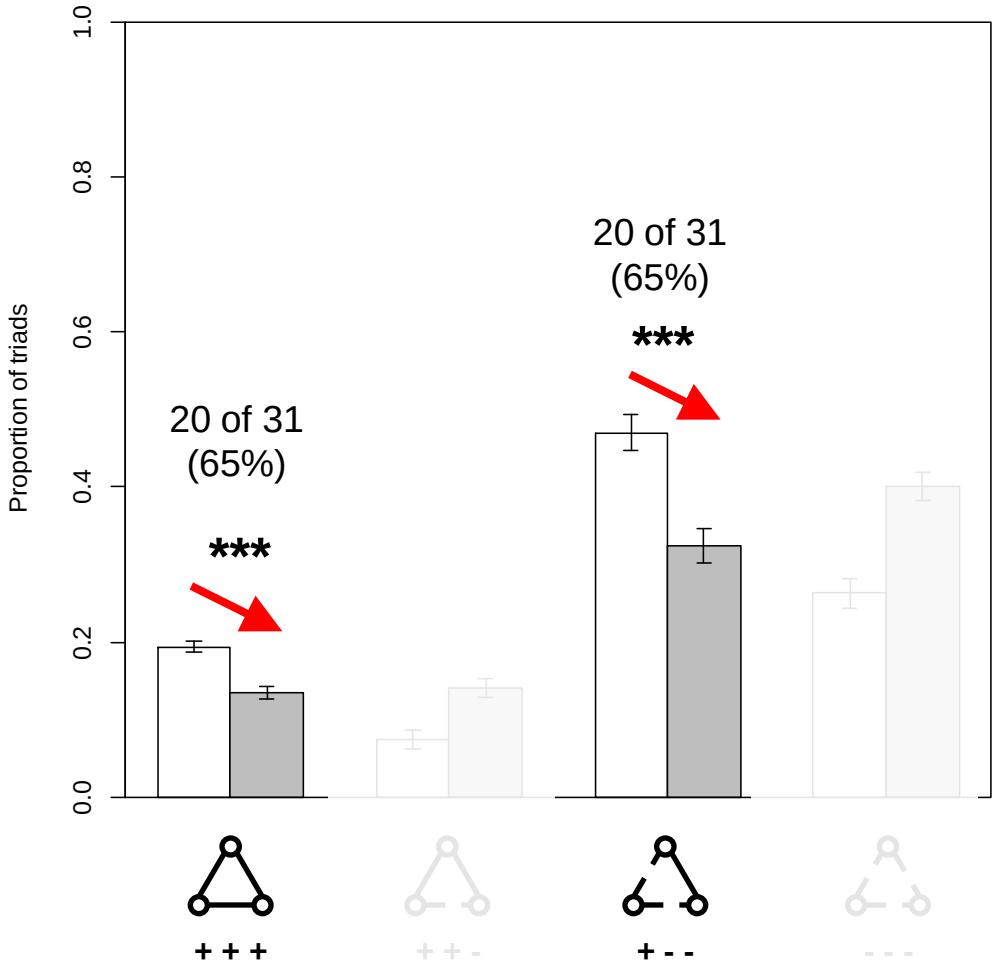

Local balance

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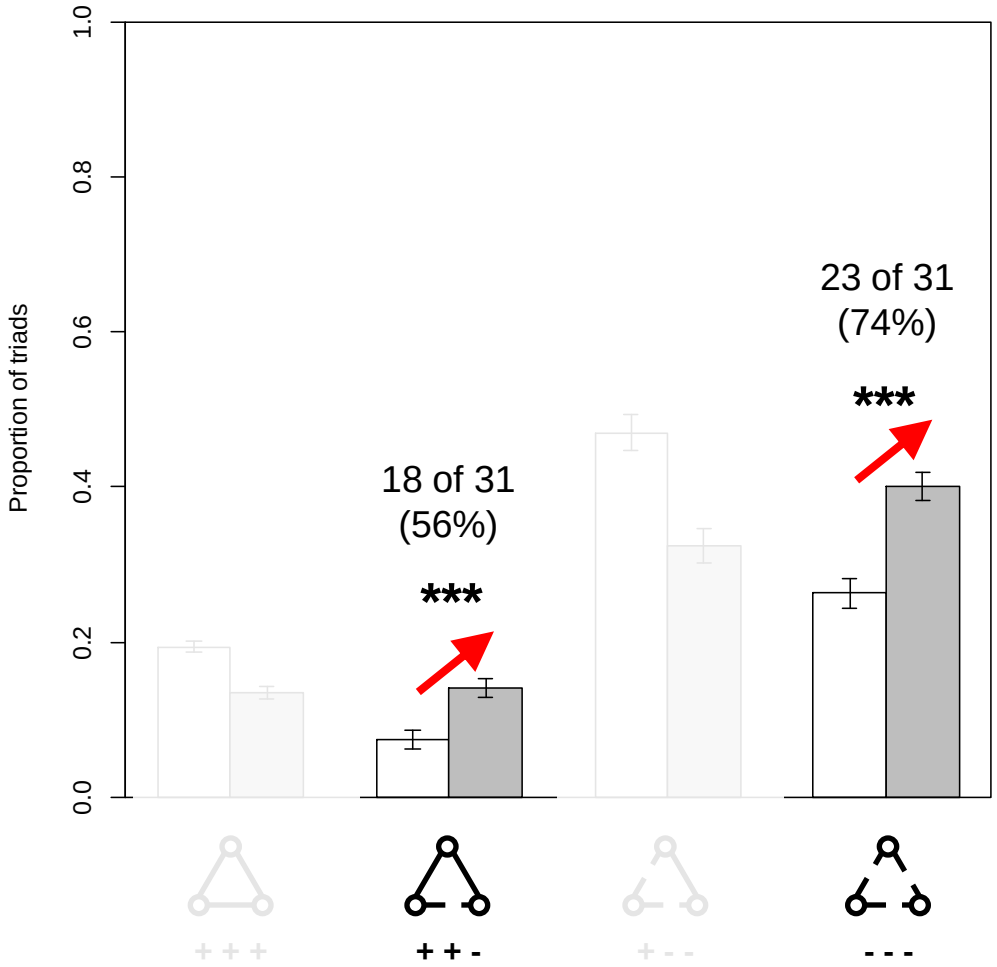

General results

No differences between locations

No networks with more frustration

No networks with less balance triads

No networks with more unbalance triads

Summary

- Ecology is starting to include different types of interactions in the same ecological networks .

- Working with these networks supposes new challenges that will require the collaboration with other disciplines.

- Structural balance is one possible property to consider when working with ecological signed networks.

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- Ecology is starting to include different types of interactions in the same ecological networks .

- Working with these networks supposes new challenges that will require the collaboration with other disciplines.

- Structural balance is one possible property to consider when working with ecological signed networks.

TONS OF WORK TO DO!!!

Collaborators

Antonio Arroyo, Guillermo Bueno, Raquel Charte, María Luisa Dehesa, Juan Escós, Ana Foronda, Ángel de Frutos, Maite Gartzia, Mari Luz Giner, Ben Komac, Yacine Kouba, Pablo Lucas, Felipe Martínez, Teresa Navarro, Pedro Sánchez.

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¡Muchas gracias!

Thank you very much!

Eskerrik asko!

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