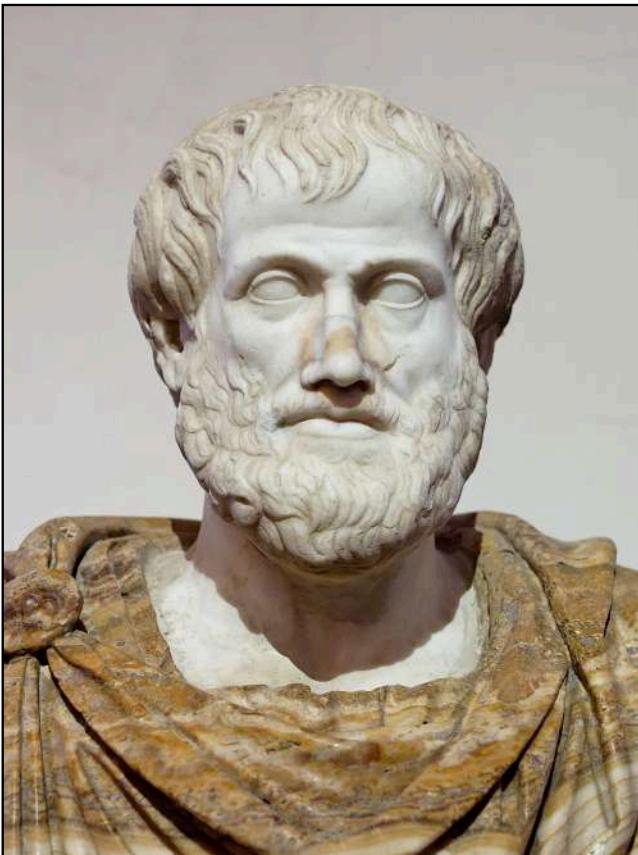




# Descrição de padrões



*None of the arts theorize about individual cases...*

*individual cases are so infinitely various that no systematic knowledge of them is possible.*

*Rhetoric, ~23 centuries ago*

# Padrões estruturais

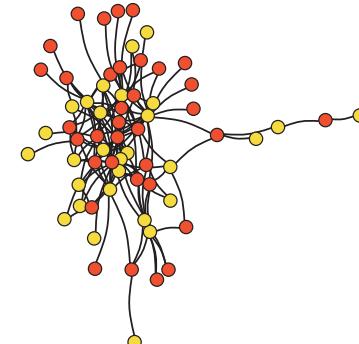
Possibilidades infinitas



JP Krajewski

31 espécies de plantas

21 espécies de vertebrados



Plants and frugivores

# Padrões estruturais

Possibilidades infinitas

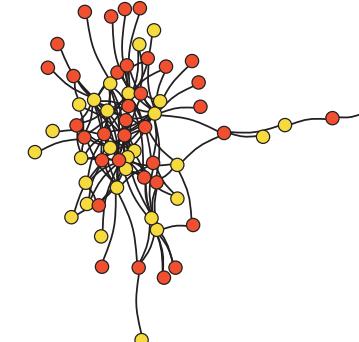


JP Krajewski

31 espécies de plantas

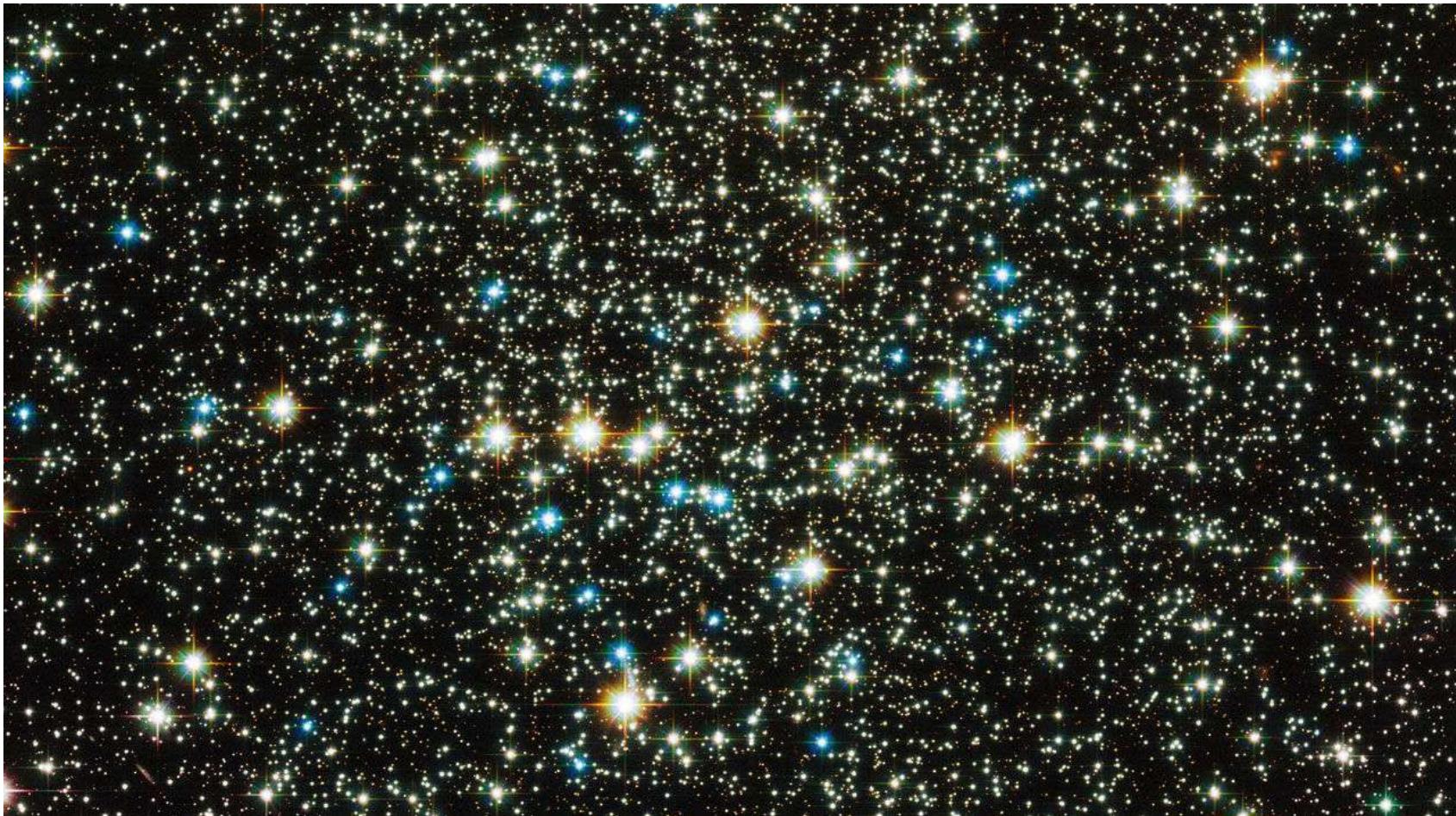
21 espécies de vertebrados

$2^{651} = 10^{196}$  possíveis interações



Plants and frugivores

$10^{196}$  interações possíveis >>>  $10^{79}$  elétrons no universo



# Aula 2: Estrutura

- A trindade: conectividade, modularidade e distância
- Assimetrias e sobreposição
- Centralidade
- Resumo

# **Três princípios do estudo de redes (I)**

Três aspectos fundamentais do estudo de redes ecológicas

**1. Estrutura está sempre associada à inferências sobre dinâmica**

# **Três princípios do estudo de redes (I)**

Três aspectos fundamentais do estudo de redes ecológicas

## **1. Estrutura está sempre associada à inferências sobre dinâmica**

- Inferências verbais e correlacionais sobre a dinâmica da rede**

# **Três princípios do estudo de redes (II)**

Três aspectos fundamentais do estudo de redes ecológicas

1. Estrutura está sempre associada à inferências sobre dinâmica

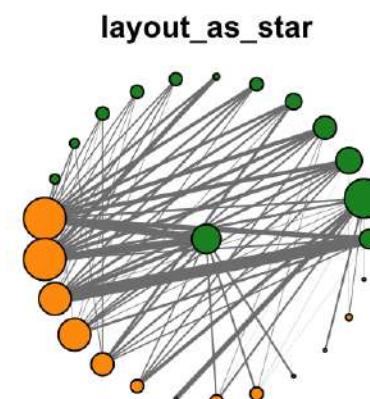
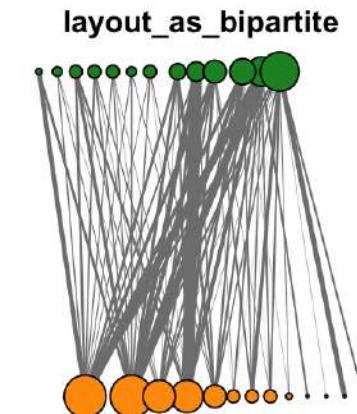
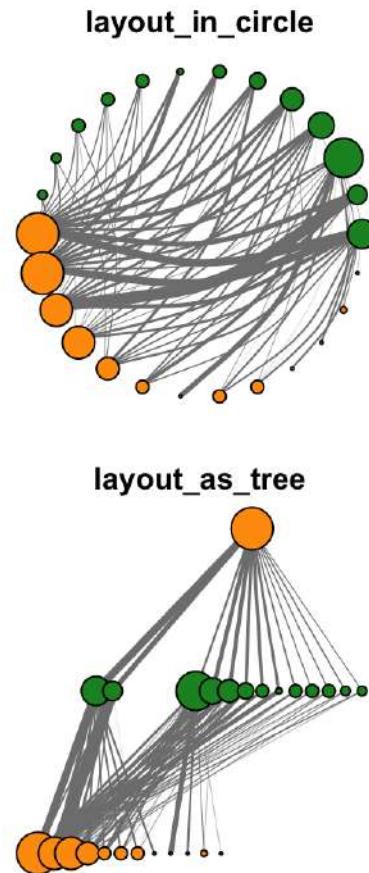
**2. Visualização leva a criatividade**

# Visualização

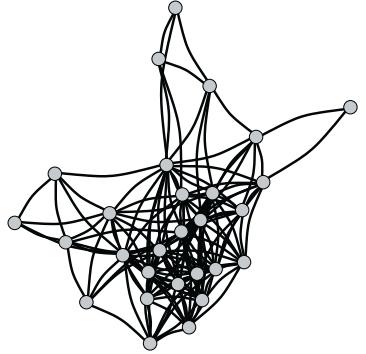
Tutorial disponível por Marília Gaiarsa (na nossa pasta)



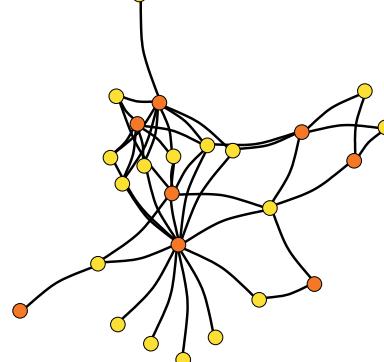
Marília Gaiarsa



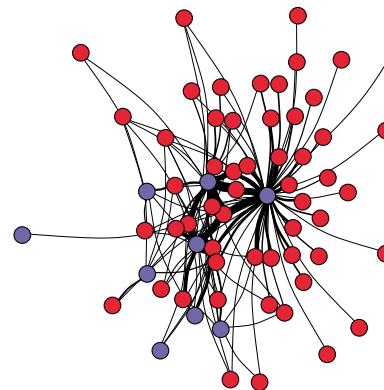
# Exemplo: Tipos de grafos



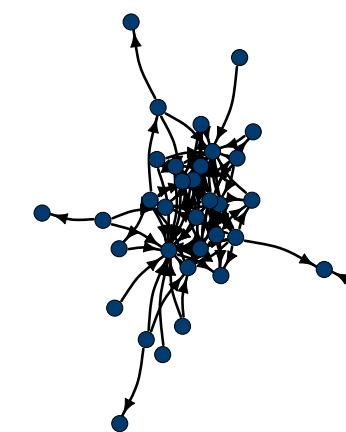
Grafo simples



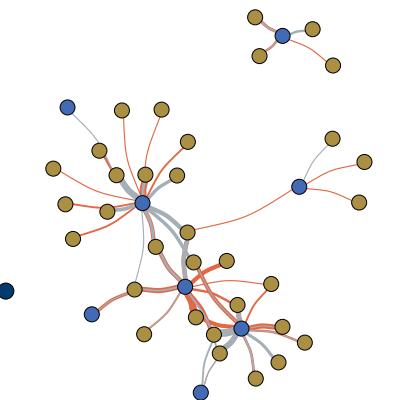
Grafo bipartido



Grafo com peso



Grafo direcionado



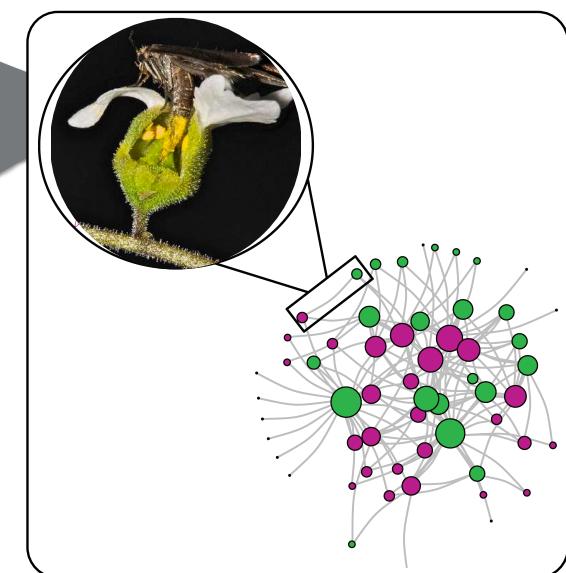
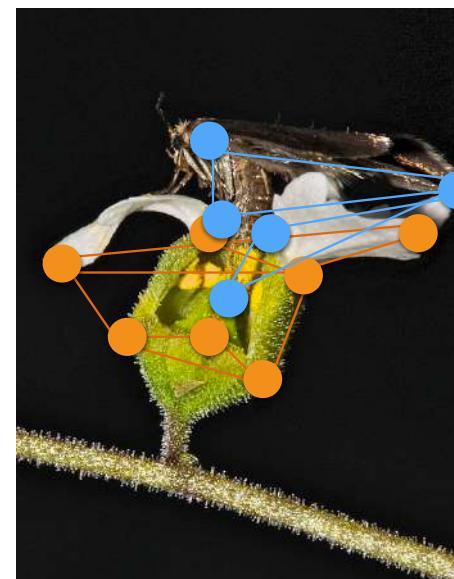
Grafo multicamadas

# Combinando redes de diferentes tipos

## Redes multi-camadas



Ana P. A. Assis



Assis et al. 2020

# **Três princípios do estudo de redes (III)**

Três aspectos fundamentais do estudo de redes ecológicas

1. Estrutura está sempre associada à inferências sobre dinâmica

2. Visualização leva a criatividade

**3. Há sempre uma métrica para o que quisermos medir (mas se não existir, inventamos!)**

# **Alguns princípios**

## **IV. Descritores individuais, locais e globais**

- A maior parte das métricas de redes
  - Descritor individual ou local (na vizinhança de um ponto)
  - Descritor global (na escala da rede)
- Exceção: algumas métricas baseadas em álgebra linear

# Aula 2: Estrutura

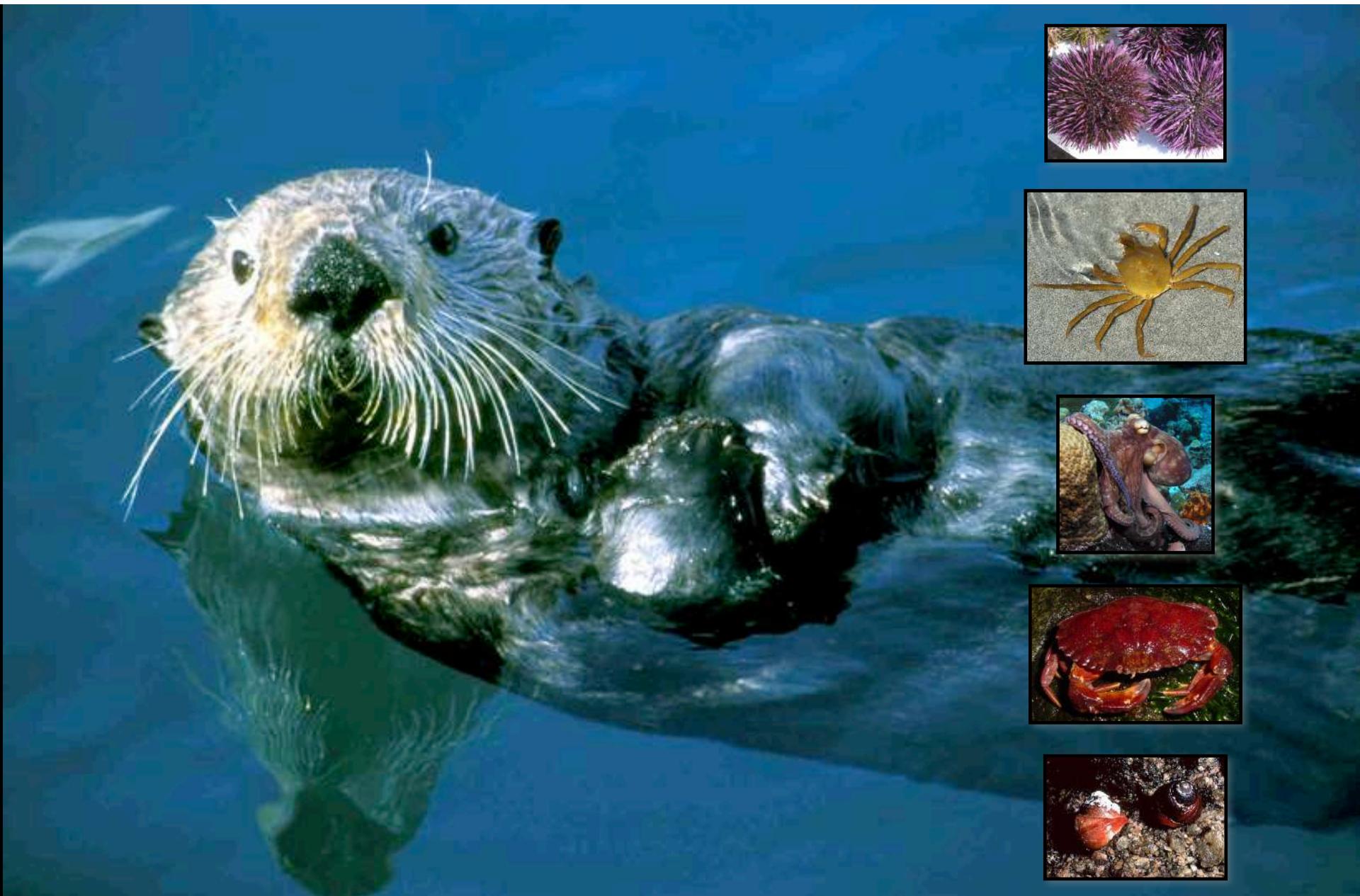
- A trindade: conectividade, modularidade e distância
  - Assimetrias e sobreposição
  - Centralidade
  - Resumo

# A trindade

**Os três conceitos mais importantes sobre a estrutura de redes**

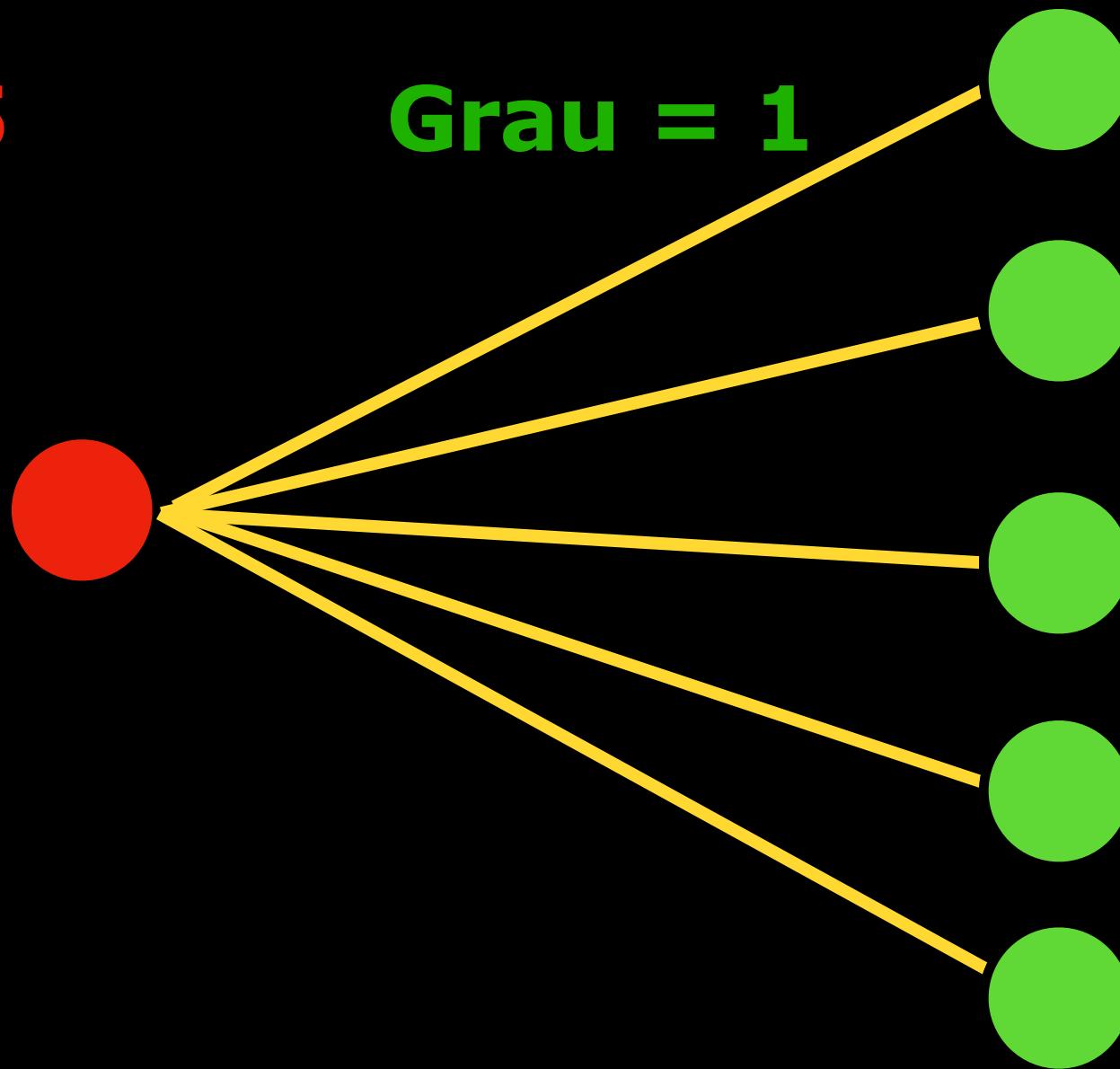
- **Conectividade**
- Modularidade
- Distância

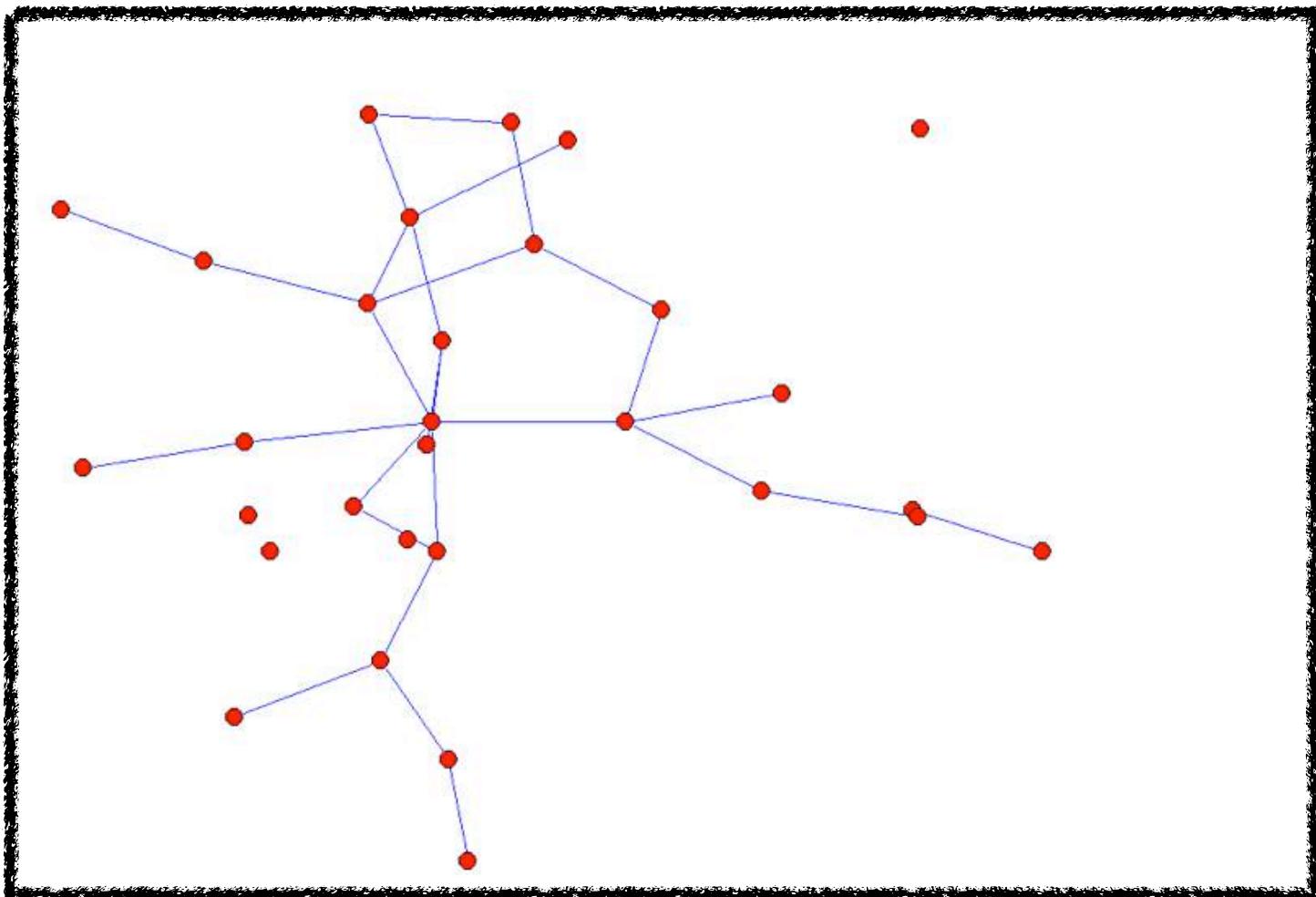


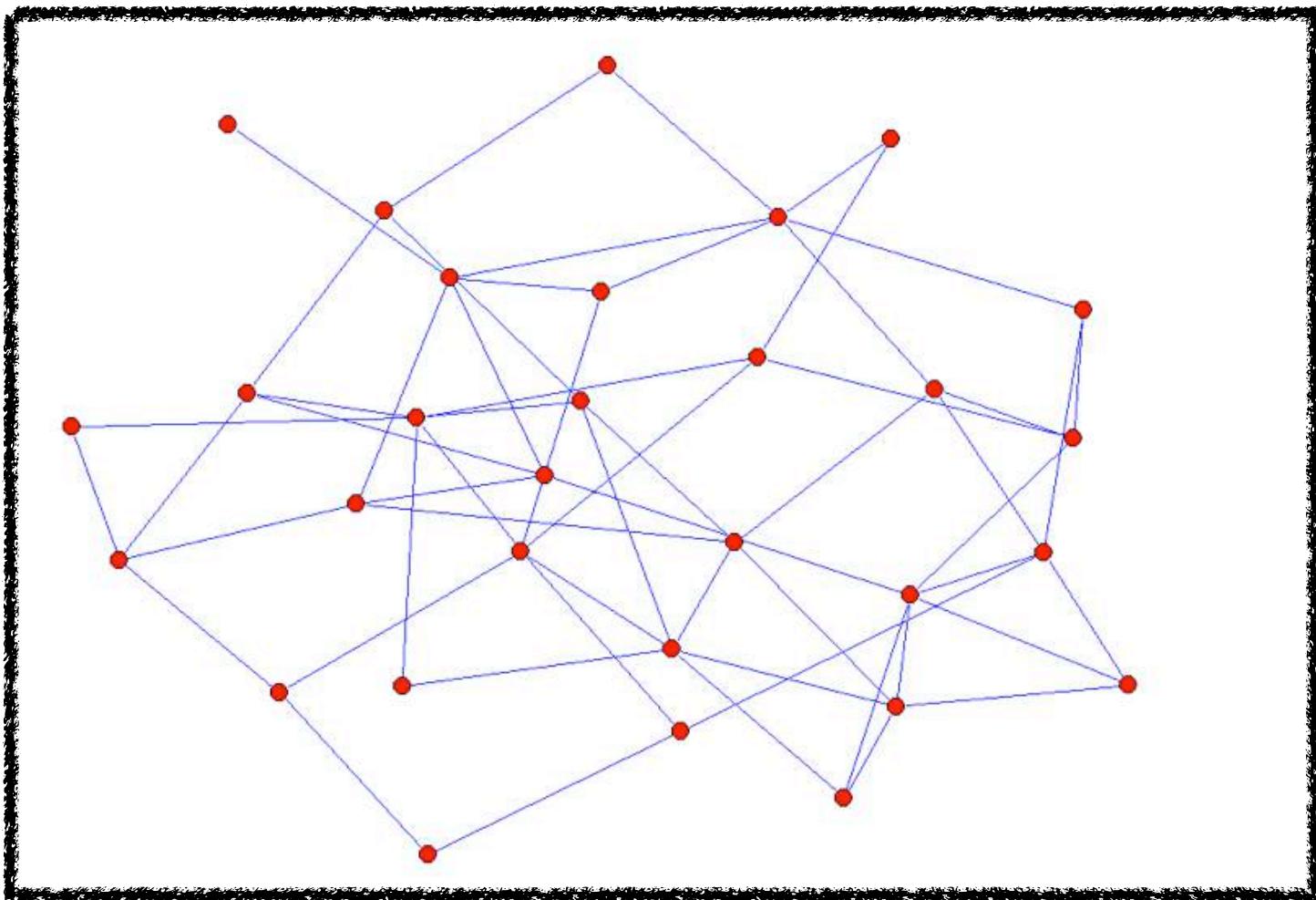


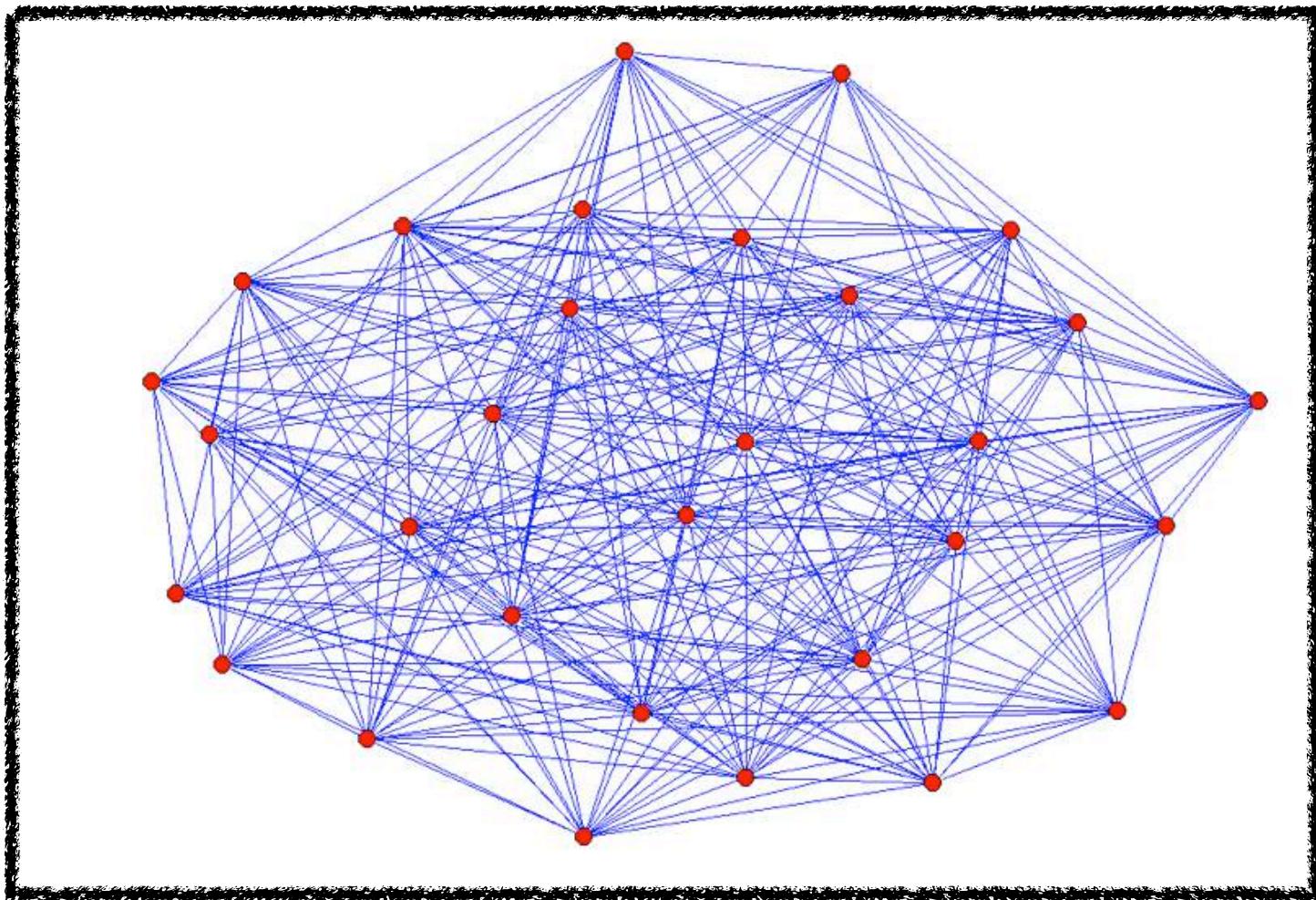
**Grau = 5**

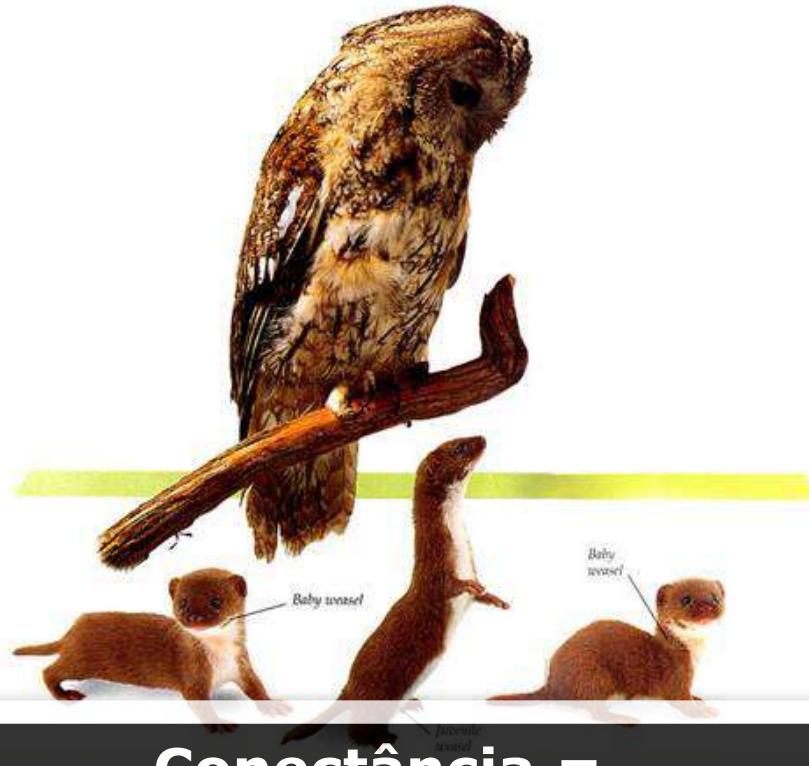
**Grau = 1**



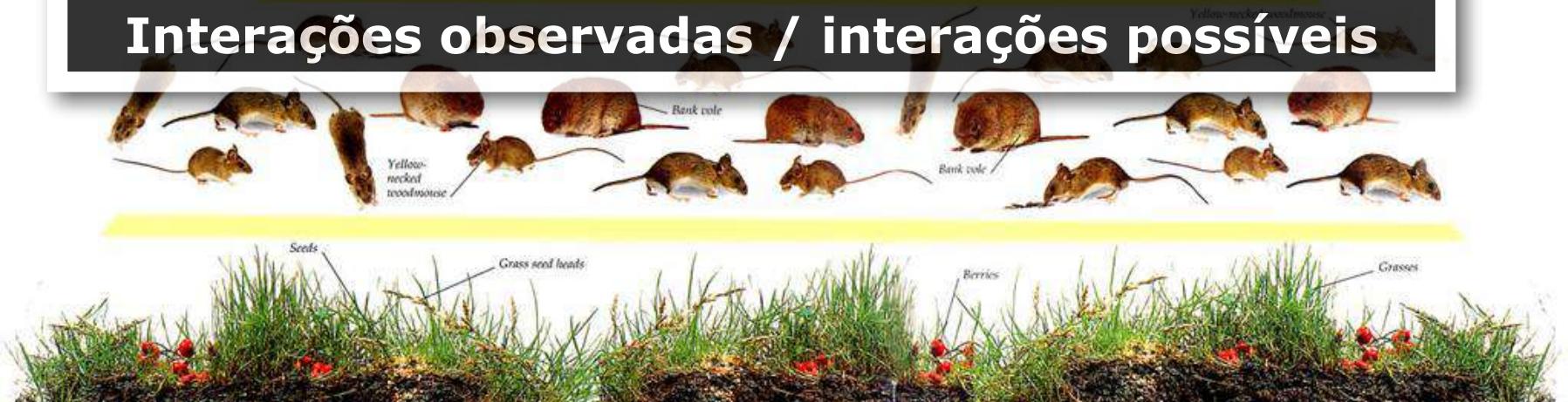








**Conectância =  
Interações observadas / interações possíveis**



# Conectividade

- Ponto (espécie):

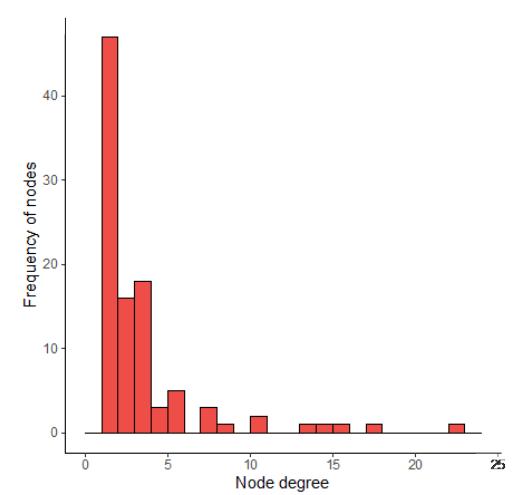
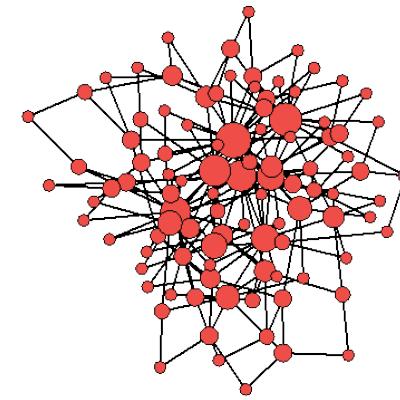
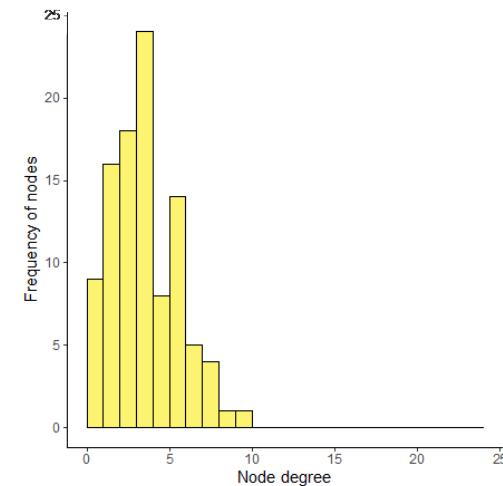
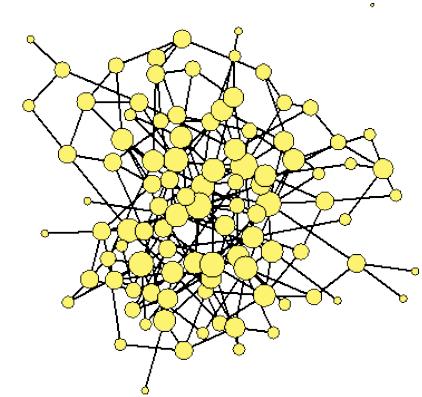
✓ Grau

- Rede

✓ Conectância

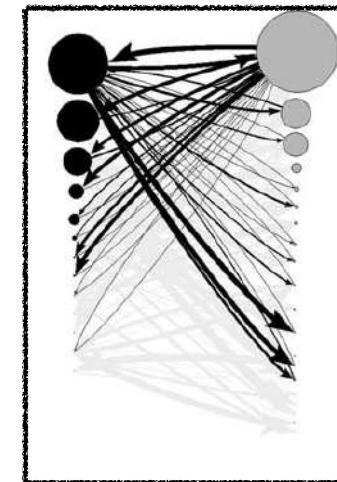
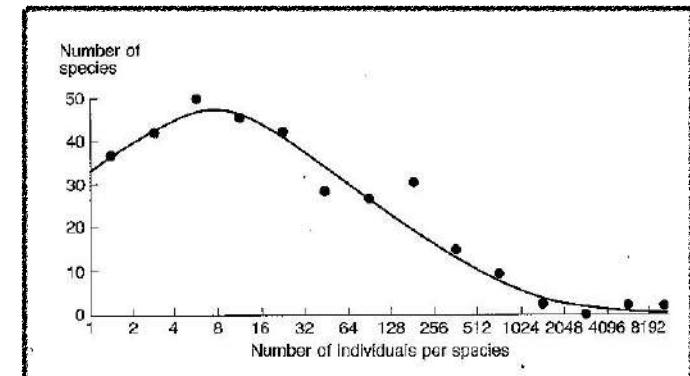
# Conectividade

- Ponto (espécie):
  - ✓ Grau
- Rede
  - ✓ Conectância
  - ✓ Grau médio
  - ✓ Distribuição do grau



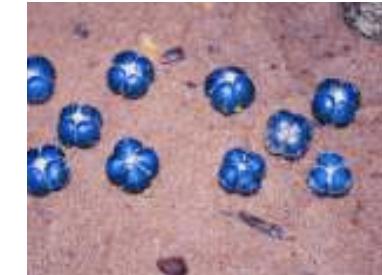
# Abundância e a conectividade

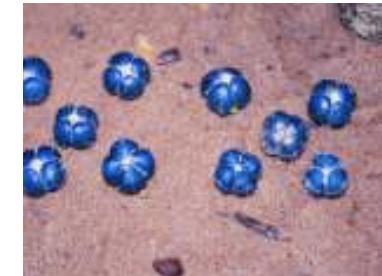
- Lei de ação de massas no nível do indivíduo



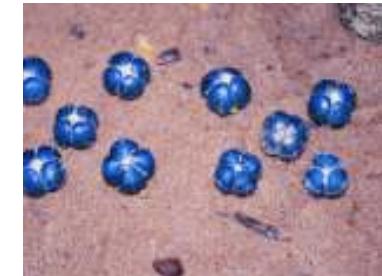
Vázquez et al. 2005





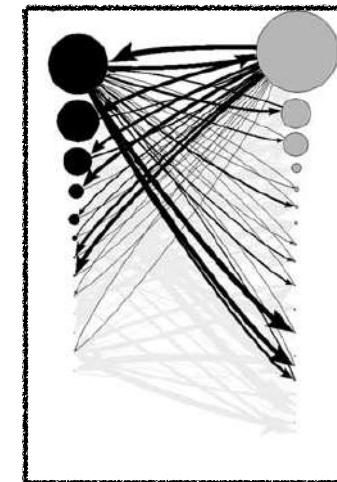
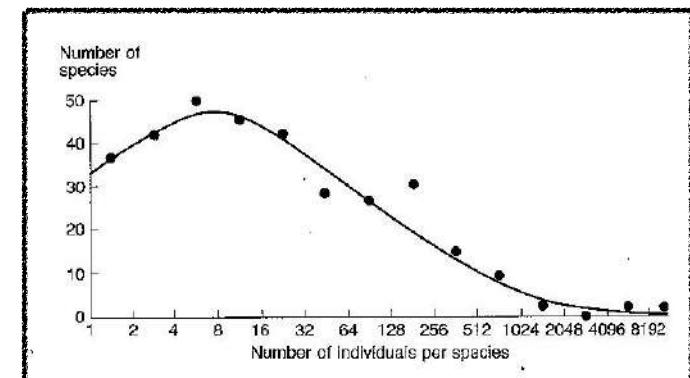






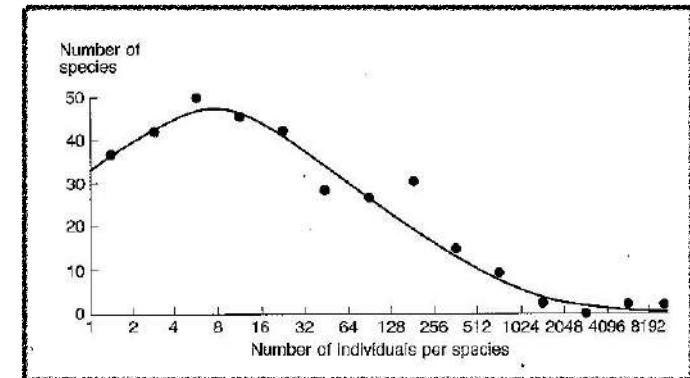
# Abundância e a conectividade

- Lei de ação de massas no nível do indivíduo

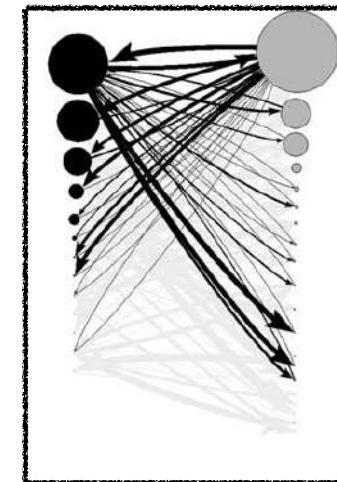


# Abundância e a conectividade

- Lei de ação de massas no nível do indivíduo



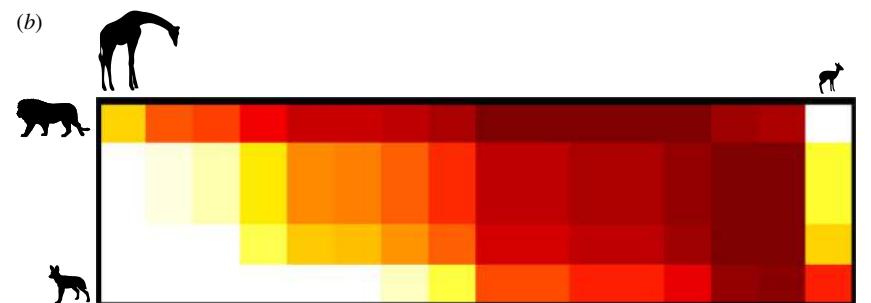
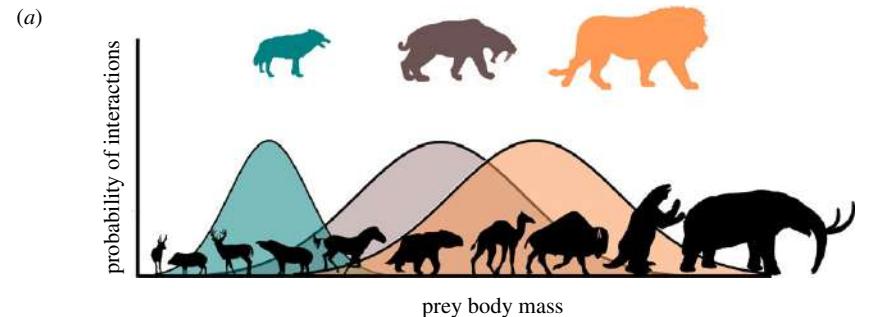
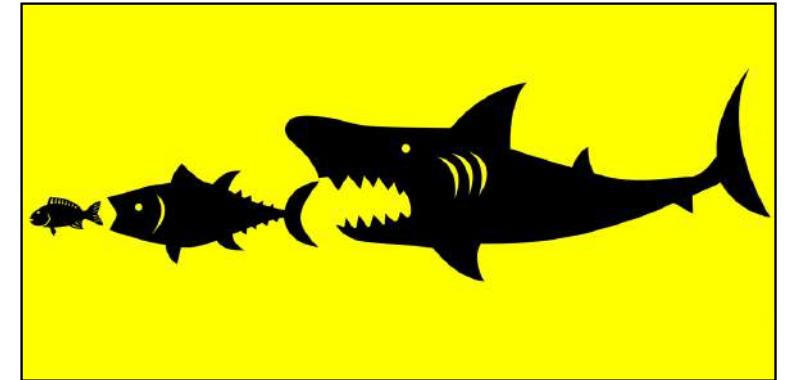
**Exceção fundamental**



# Tamanho corporal



Mathias Pires

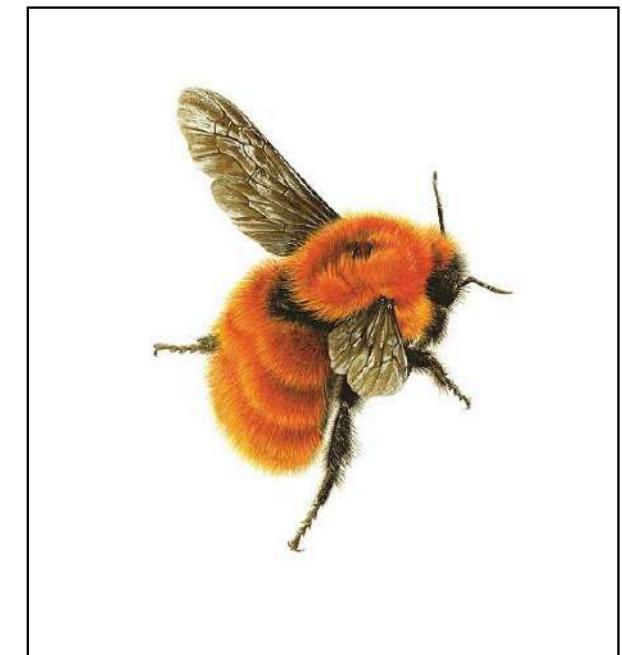
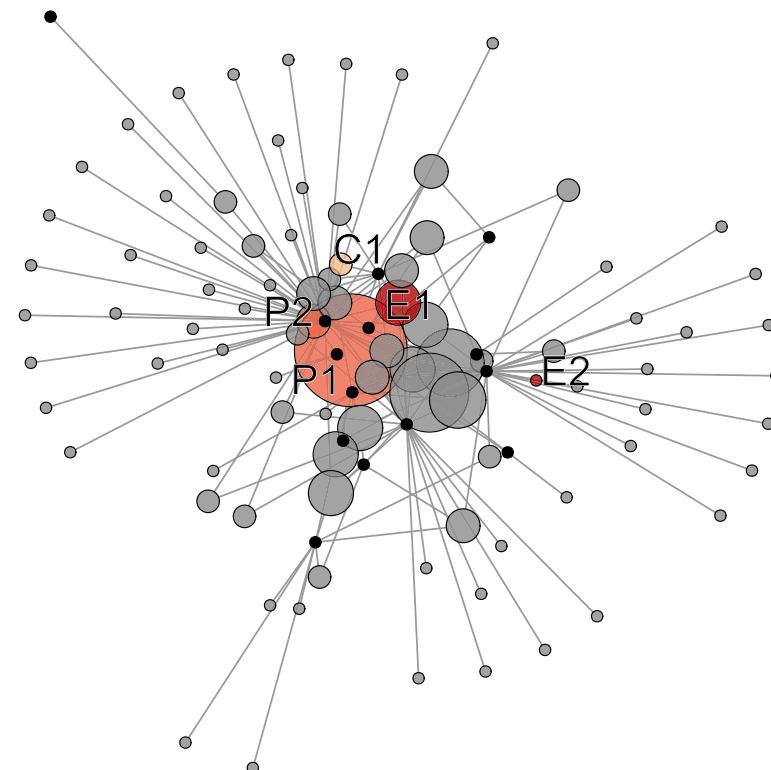


Pires et al. 2015

# História natural

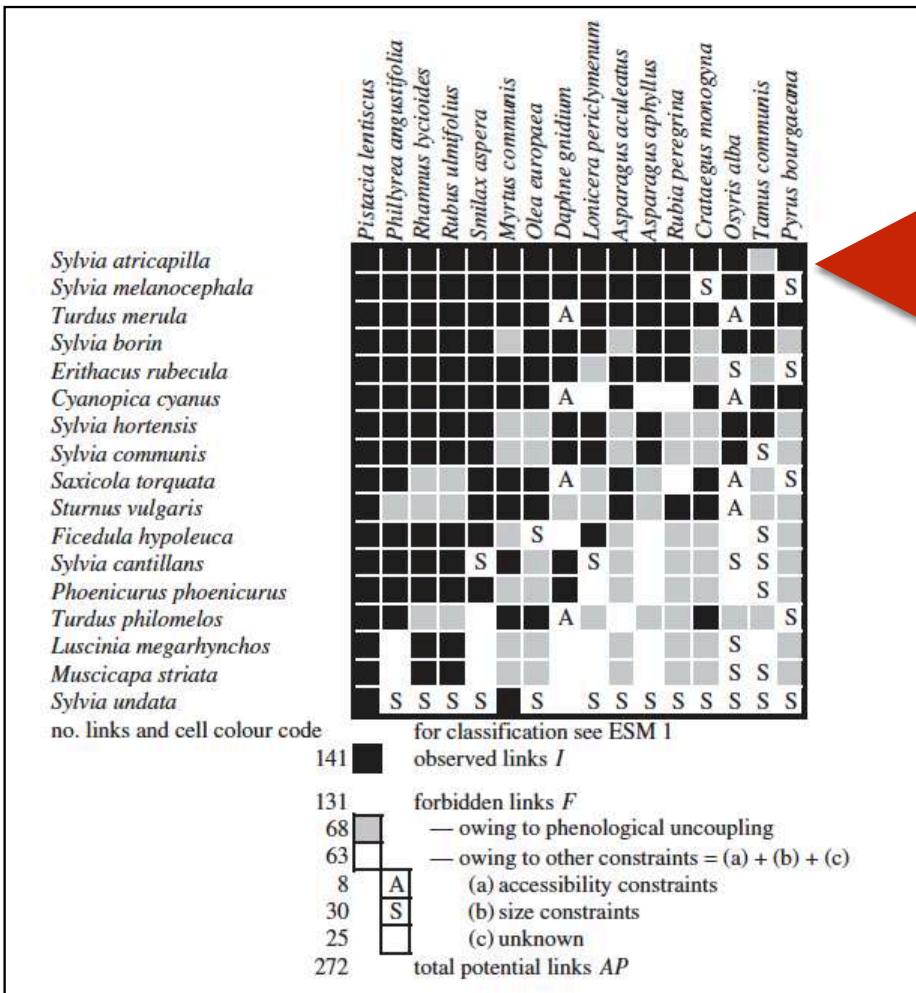


**Kate Maia**



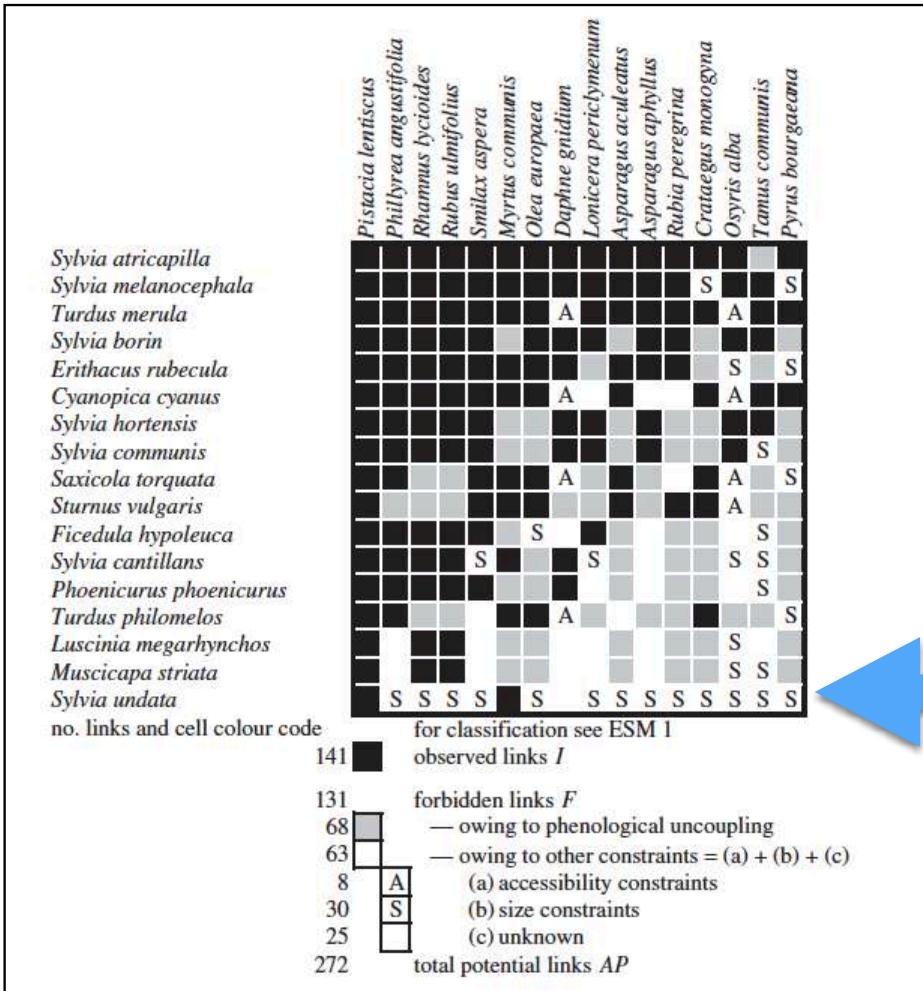
Maia et al. 2020

# As ligações proibidas



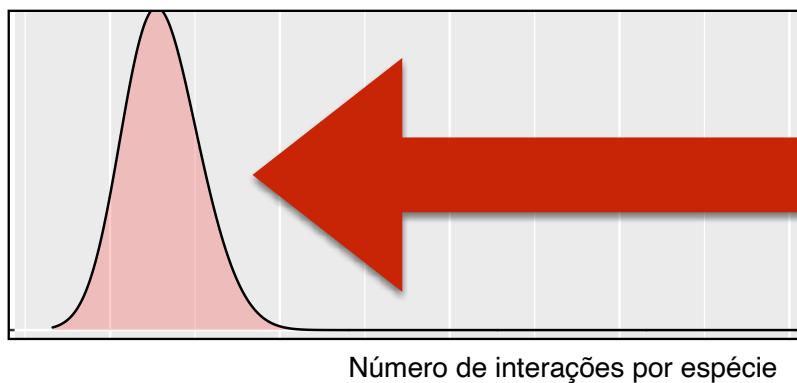
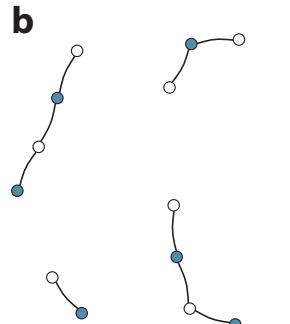
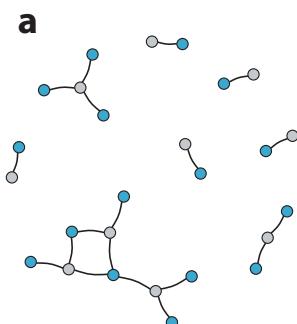
Olesen et al. 2011

# As ligações proibidas



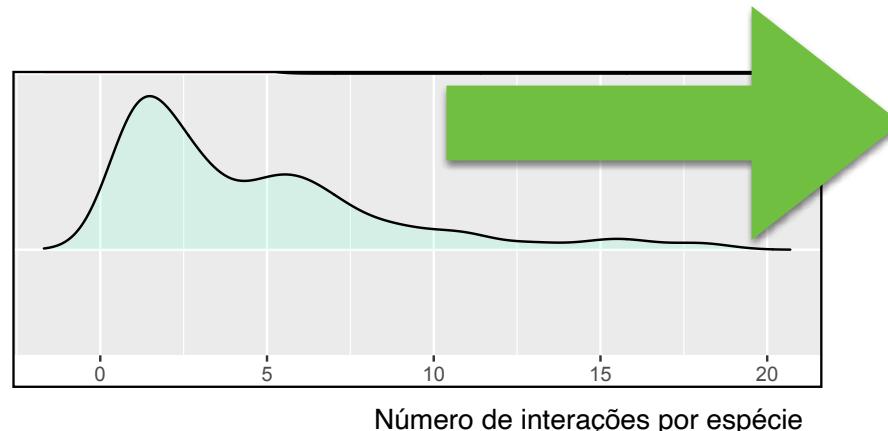
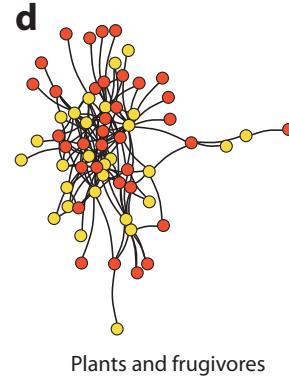
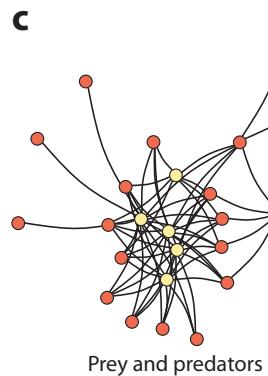
Olesen et al. 2011

# Seleção natural favorecendo especialização



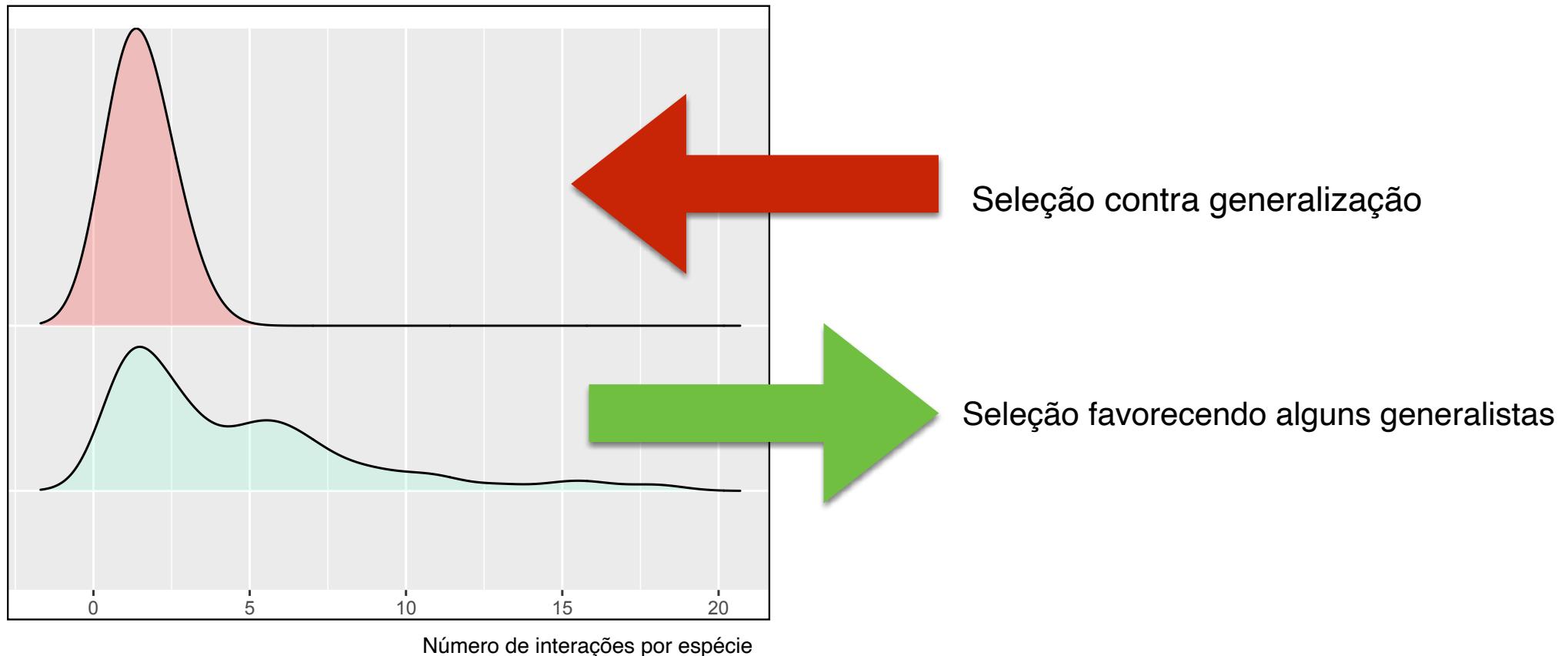
Seleção contra generalização  
nas interações íntimas

# Seleção natural favorecendo especialização

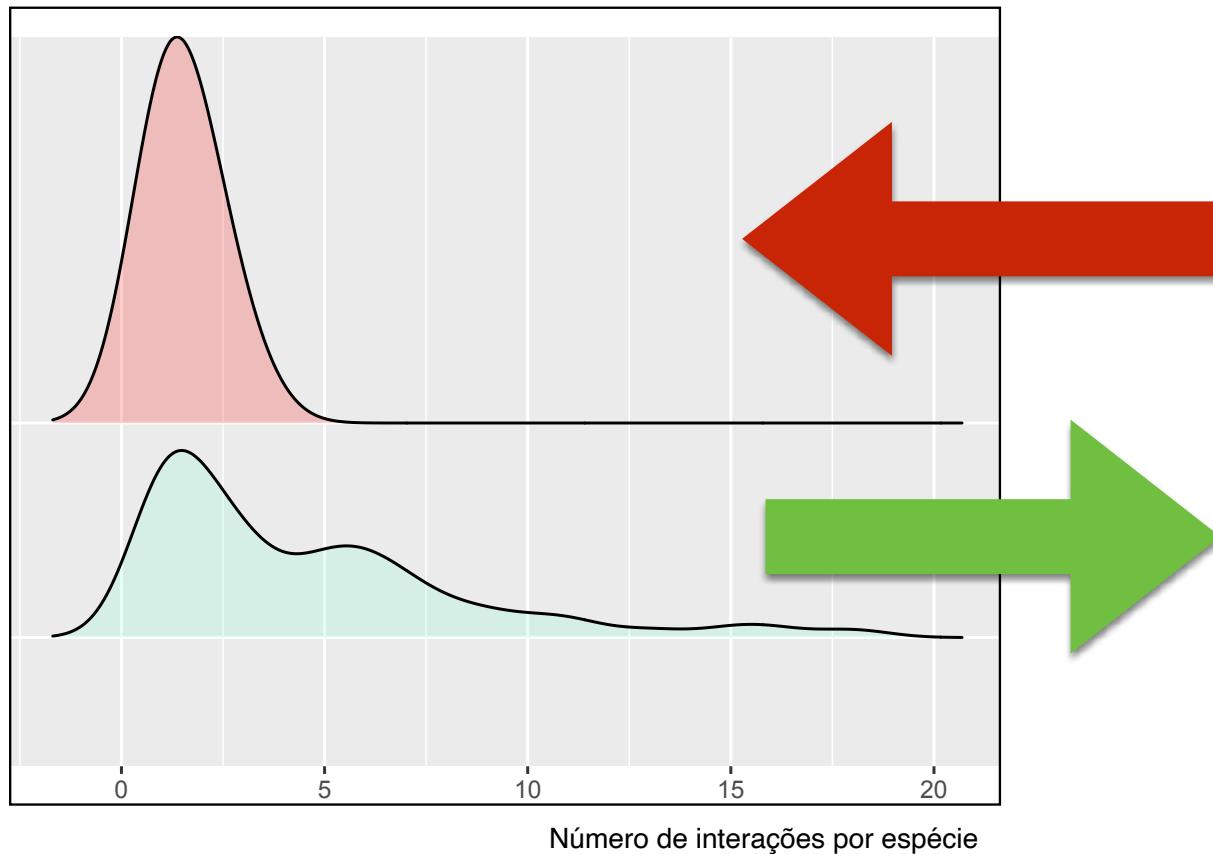


Seleção favorecendo modos de vida super-conectados

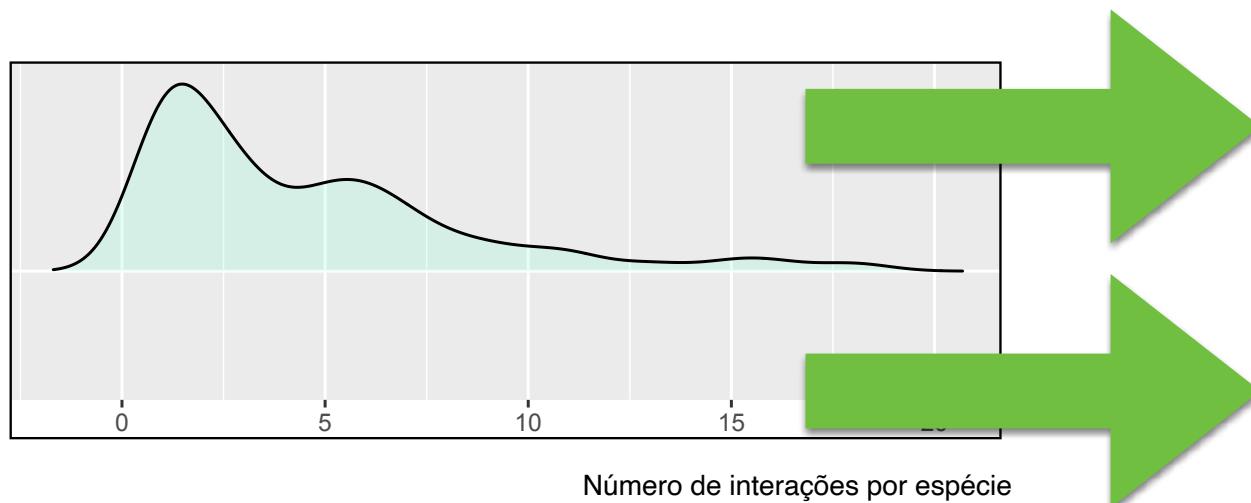
# Seleção natural & especialização



# Seleção natural & especialização



# Quem disse que a especialização é em binômios latinos?



# Super-generalistas: especialistas em redes



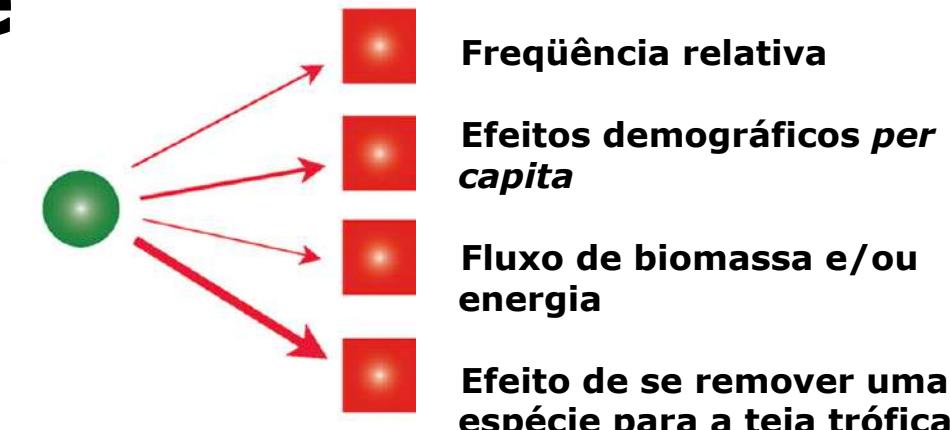
Jordano et al. 2003. Ecology Letters, Thompson 2005

# Conectividade

- Ponto (espécie):

✓ Grau

✓ Força de interações

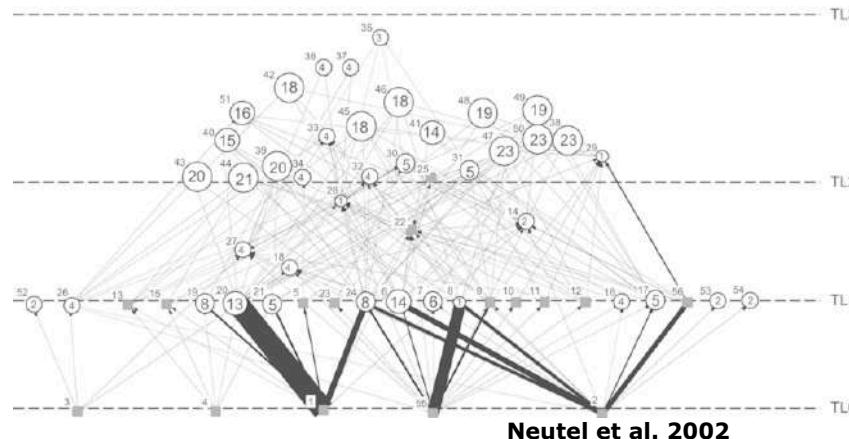


- Rede

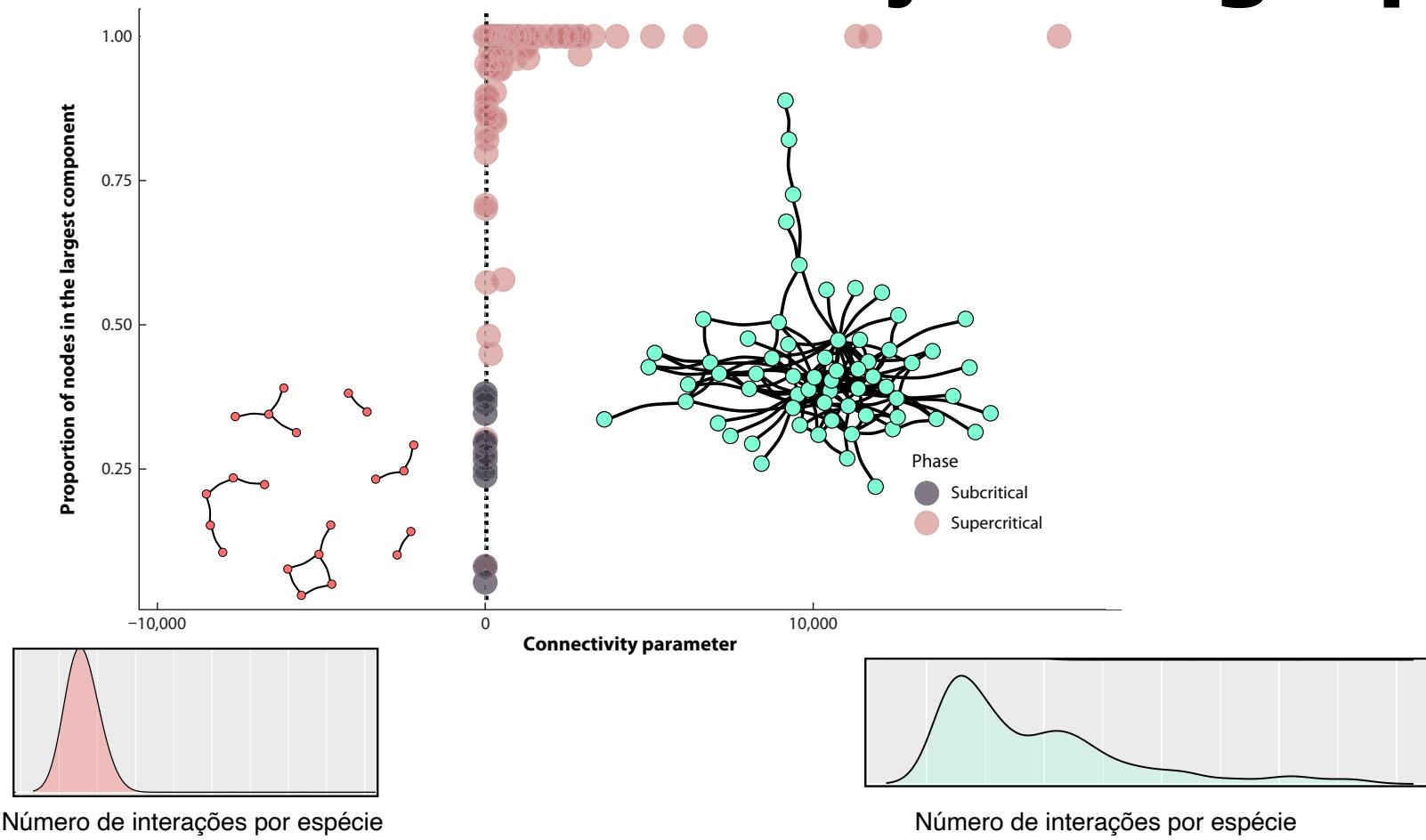
✓ Grau médio

✓ Conectância

✓ Distribuição do grau



# Conectividade e formação de grupos



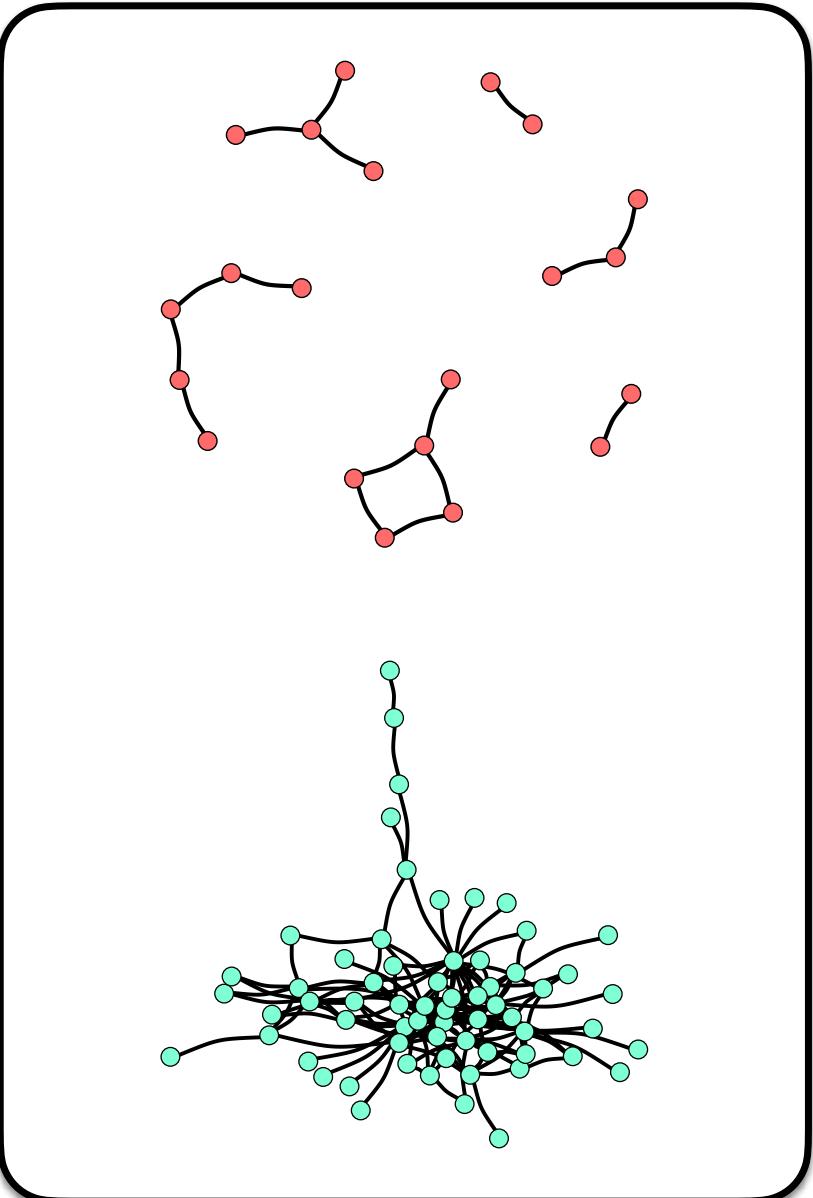
Guimarães 2020. AREES

# A trindade

Os três conceitos mais importantes sobre a estrutura de redes

- Conectividade
- **Modularidade**
- Distância



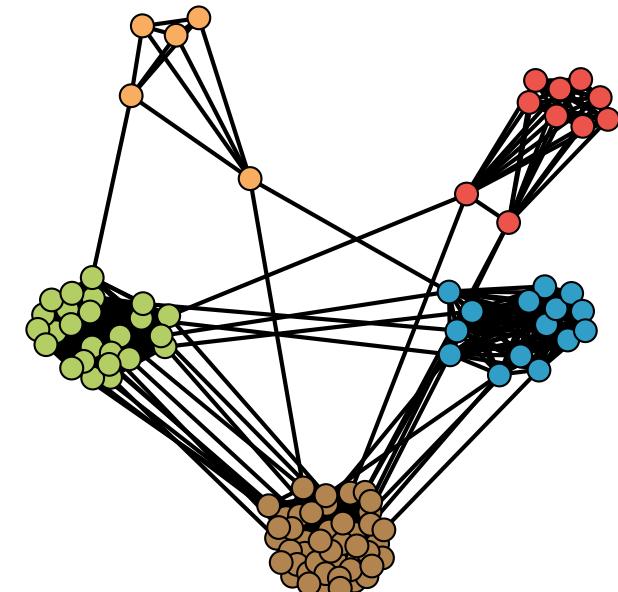


**Redes desconectadas  
(componentes múltiplos)**

**Redes conectadas  
(a componente gigante)**

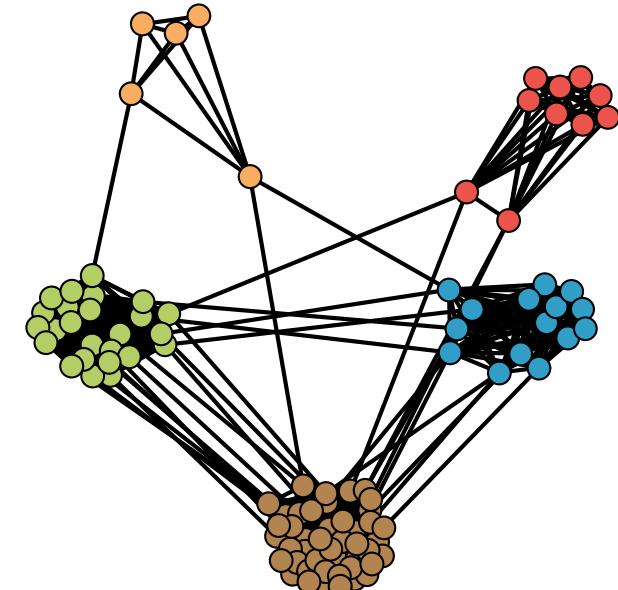
# Módulos/Comunidades/Compartimentos

- Regiões densas em conexões (módulos)
- Regiões rarefeitas em conexões (entre os módulos)



# Módulos/Comunidades/Compartimentos

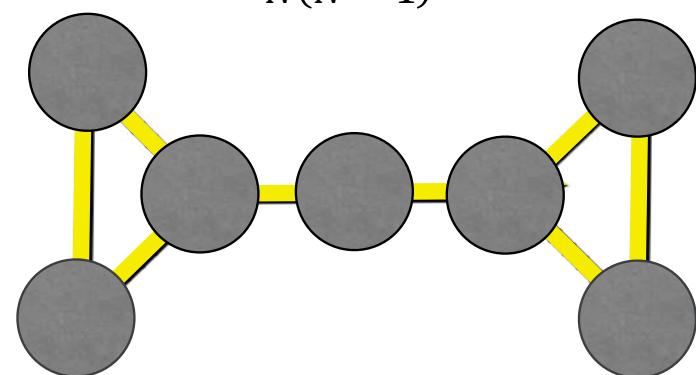
- Regiões densas em conexões (módulos)
- Regiões rarefeitas em conexões (entre os módulos)
- **Adensamentos sem identificar módulos**



# Coeficiente de agregação

- Uma conectância ao redor do ponto
- O quanto meus amigos são amigos entre si?

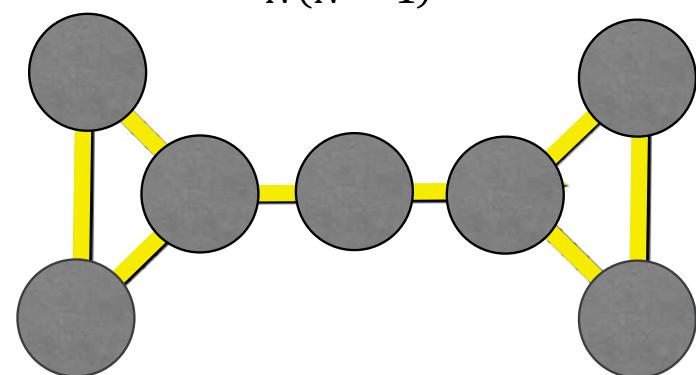
$$C = \frac{2E}{N(N - 1)} = 2 \times 8 / 42 = 0,38$$



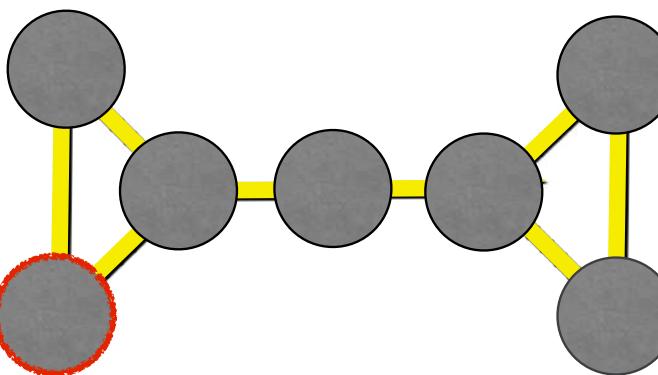
# Coeficiente de agregação

- Uma conectância ao redor do ponto
- O quanto meus amigos são amigos entre si?

$$C = \frac{2E}{N(N - 1)} = 2 \times 8 / 42 = 0,38$$



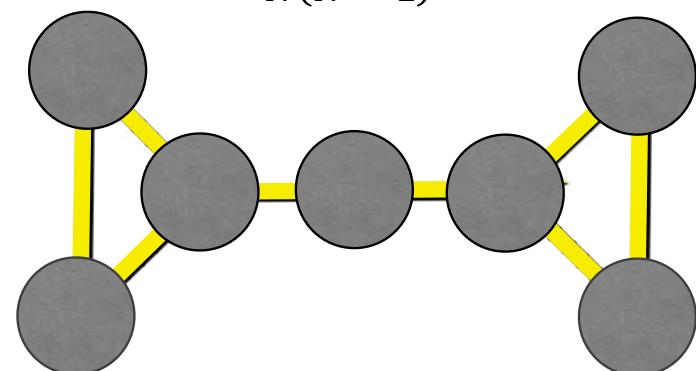
$$C_i = \frac{2E_i}{k_i(k_i - 1)}$$



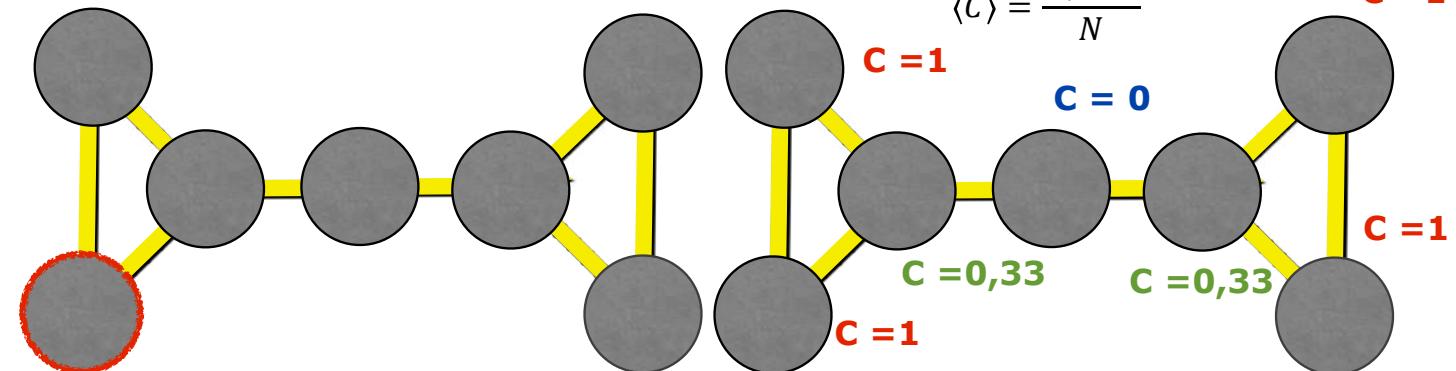
# Coeficiente de agregação

- Uma conectância ao redor do ponto
- O quanto meus amigos são amigos entre si?

$$C = \frac{2E}{N(N - 1)} = 2 \times 8 / 42 = 0,38$$

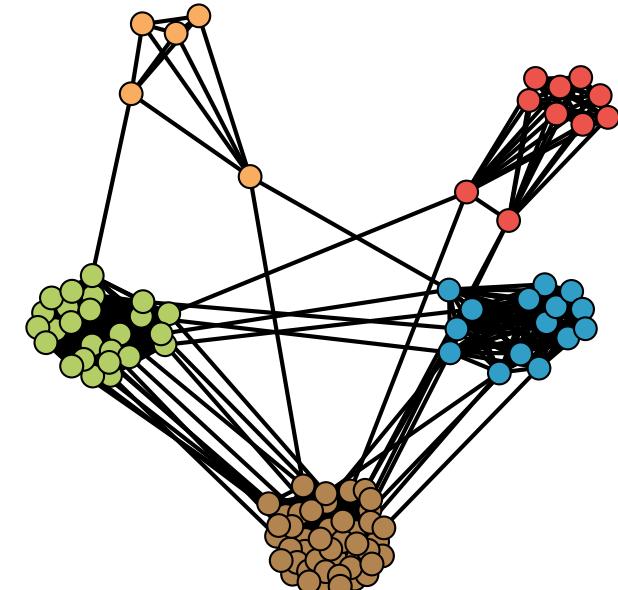


$$C_i = \frac{2E_i}{k_i(k_i - 1)}$$

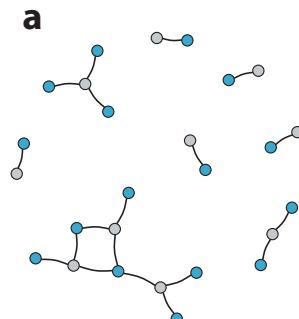


# Módulos/Comunidades/Compartimentos

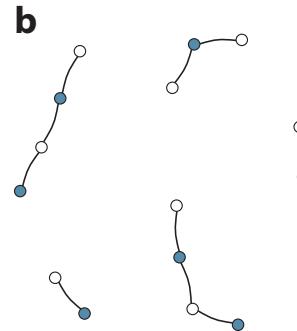
- Regiões densas em conexões (módulos)
- Regiões rarefeitas em conexões (entre os módulos)
- Adensamentos sem identificar módulos
- **Identificando módulos na rede**
  - **Métodos analíticos**



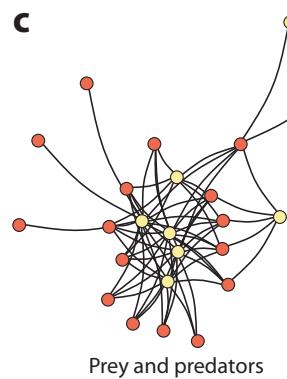
# Módulos identificados analiticamente



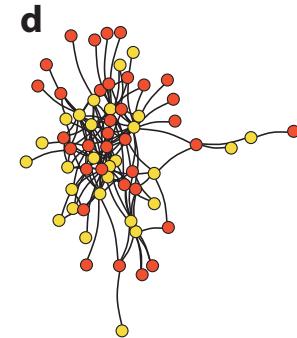
Plants and galling insects



Myrmecophytes and ants



Prey and predators



Plants and frugivores

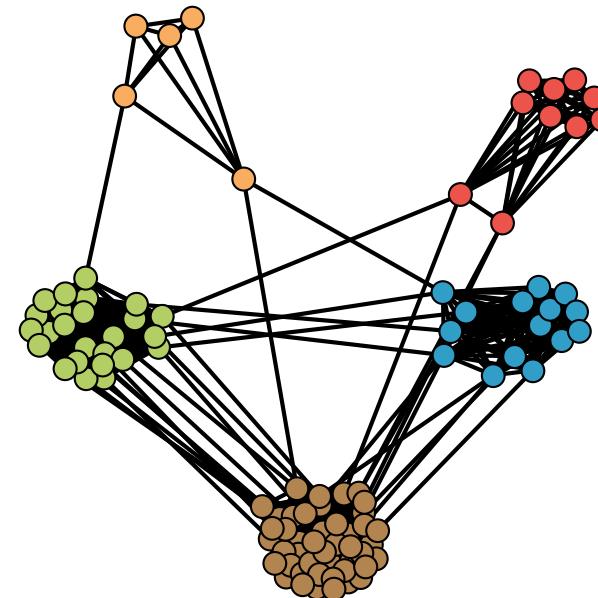


Foto: Motta Jr

Fontaine et al. 2011. Ecology letters, Pires & Guimarães 2013. Interface

# Módulos identificados computacionalmente

- Número de possíveis módulos
- Quantos pontos estão em cada módulo?
- Qual ponto está em qual módulo?
- Qual arranjo:
  - Concentração maior de conexões dentro dos módulos
  - Concentração menor de conexões entre módulos



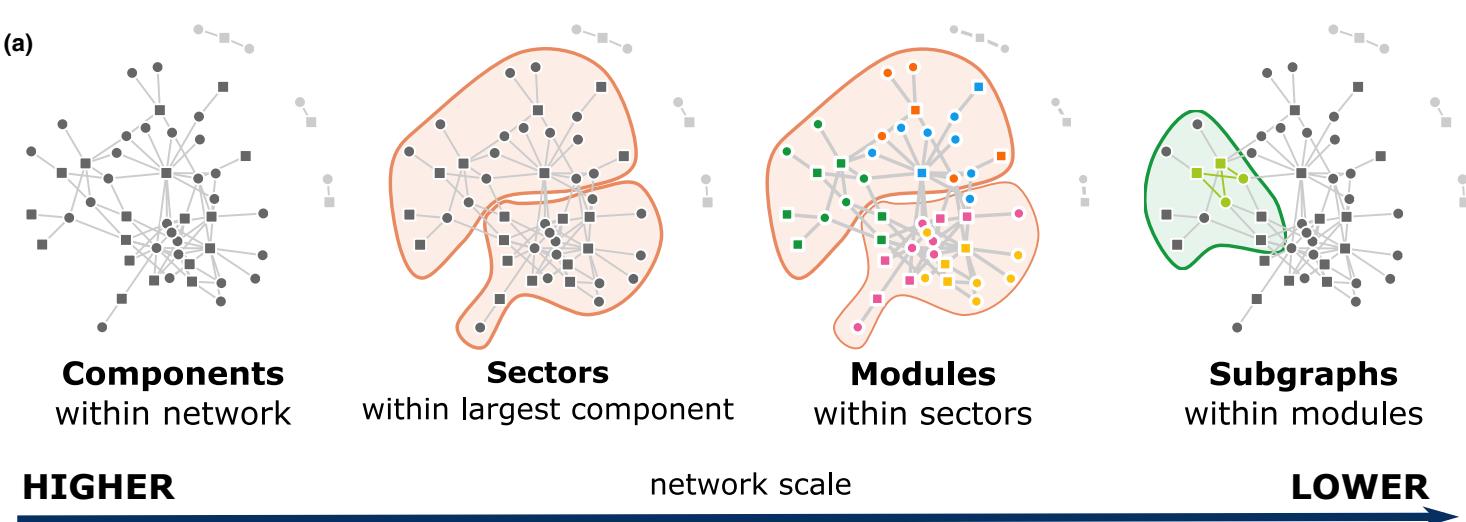
**Flavia Marquitti**

Marquitti et al. 2014

# Organização hierárquica



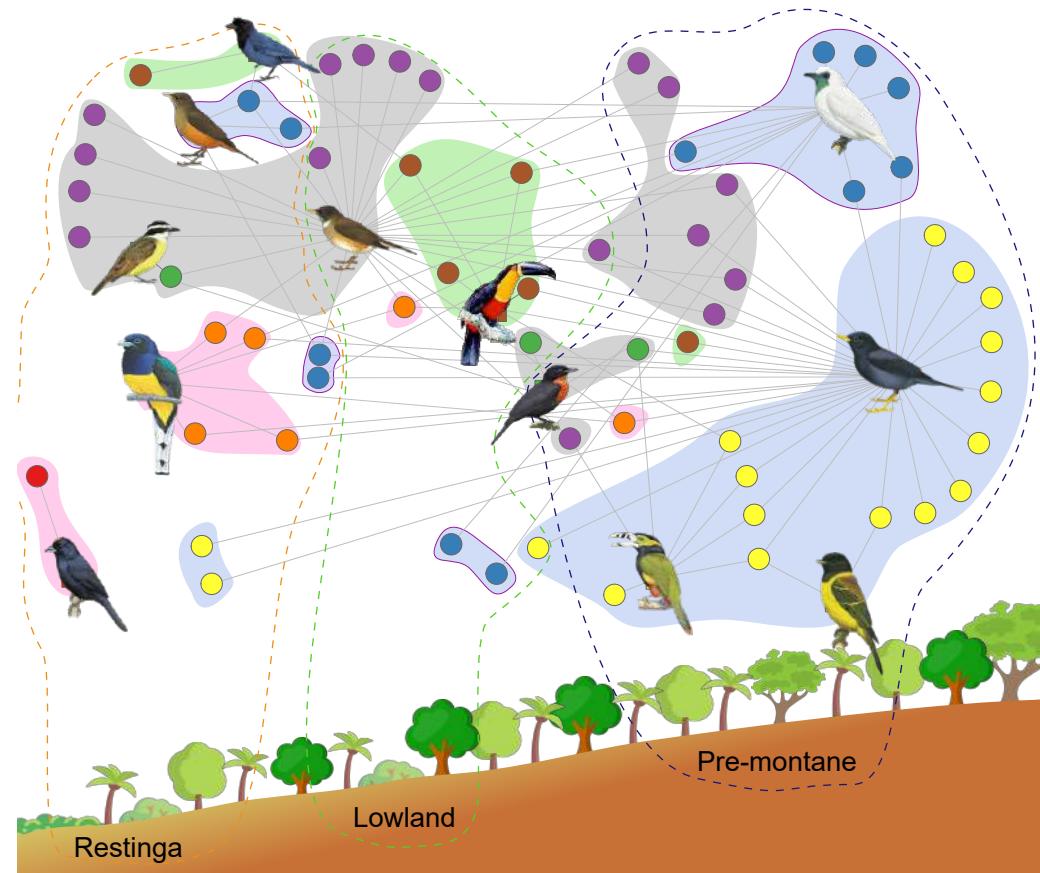
Kate Maia



# Módulos estruturados no espaço



Pâmela Friedemann



Friedemann et al. 2023. Oikos



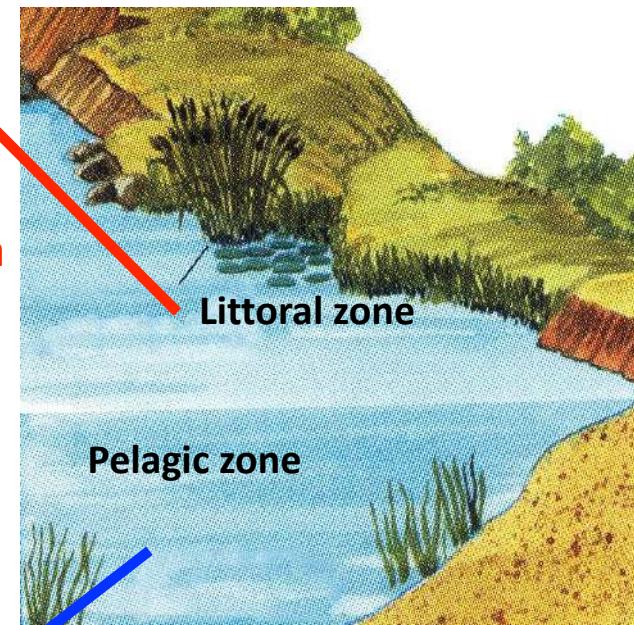
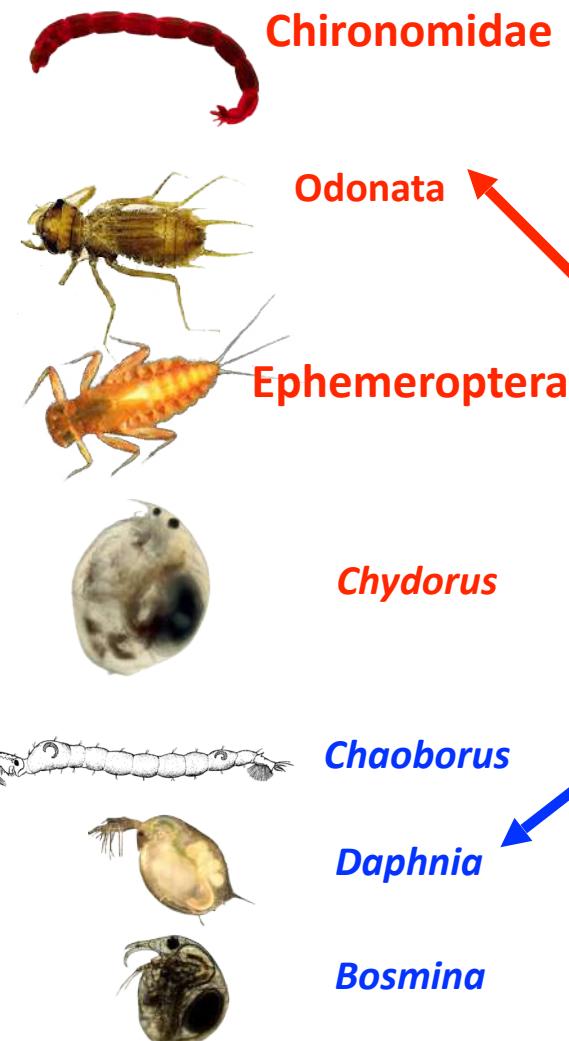
# Módulos estruturados no espaço



*Gasterosteus aculeatus*



Márcio Araújo

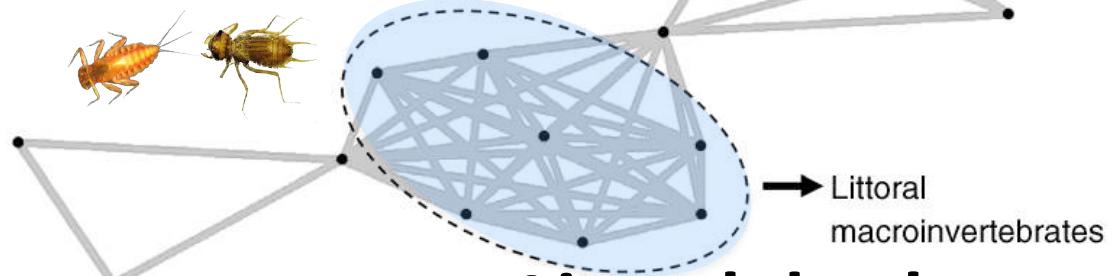
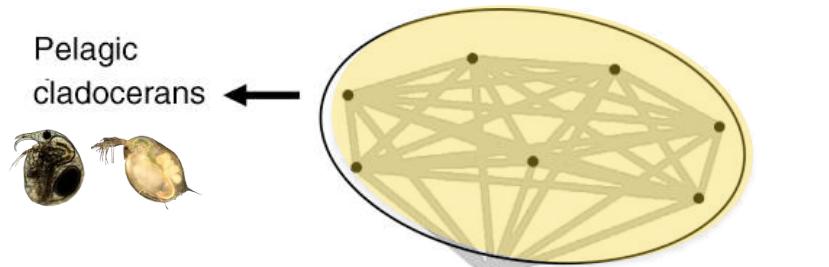


# Módulos estruturados no espaço



*Gasterosteus aculeatus*

## Zona pelágica dos lagos



## Litoral dos lagos

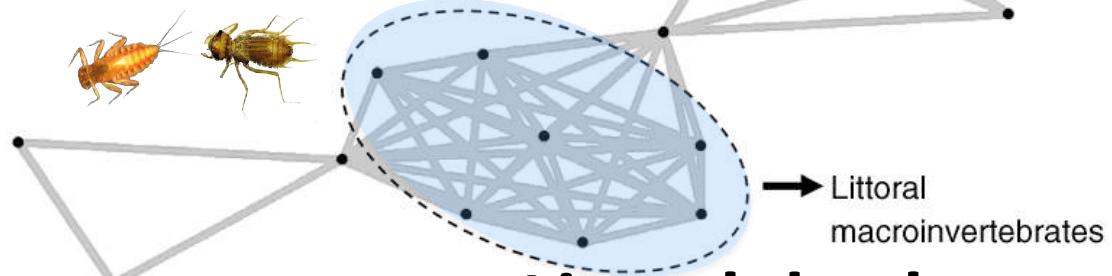
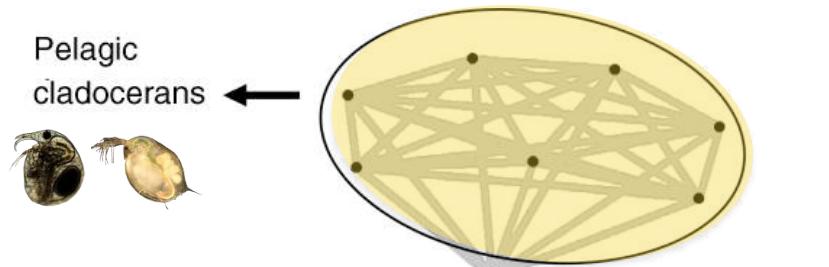
Araújo et al 2008. Ecology

# Módulos estruturados no espaço



*Gasterosteus aculeatus*

## Zona pelágica dos lagos



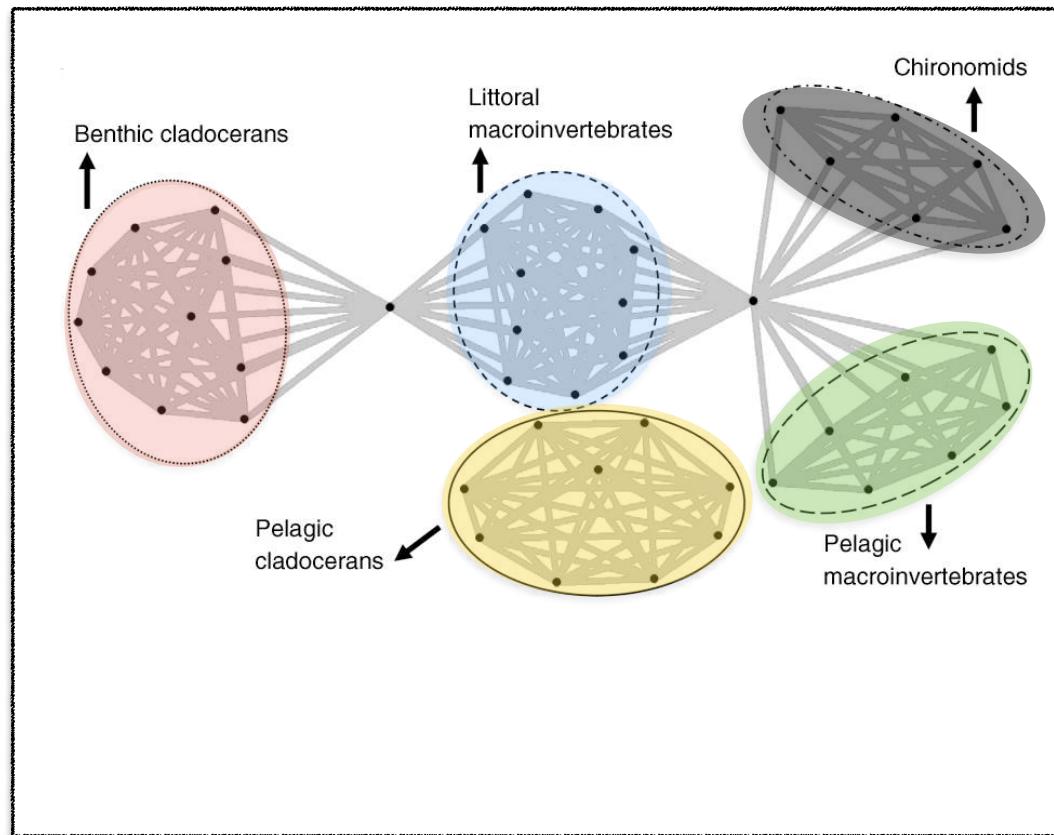
## Litoral dos lagos

Araújo et al 2008. Ecology

# E por competição ....



*Gasterosteus aculeatus*

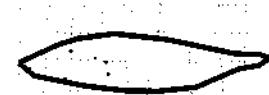
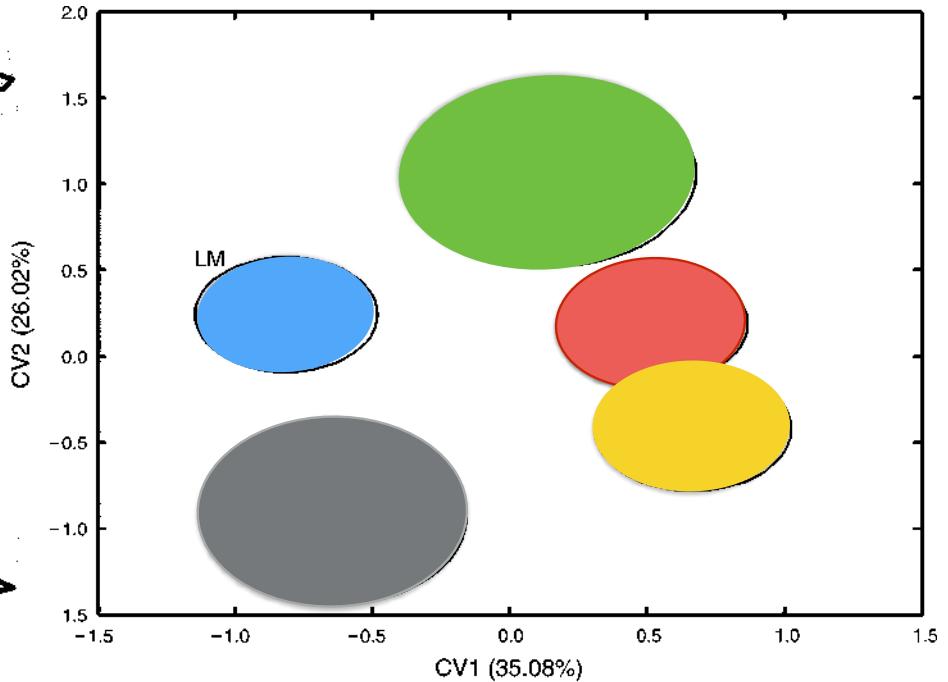
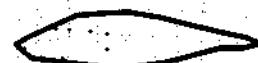


Araújo et al 2008. Ecology

# E por características ....



*Gasterosteus aculeatus*



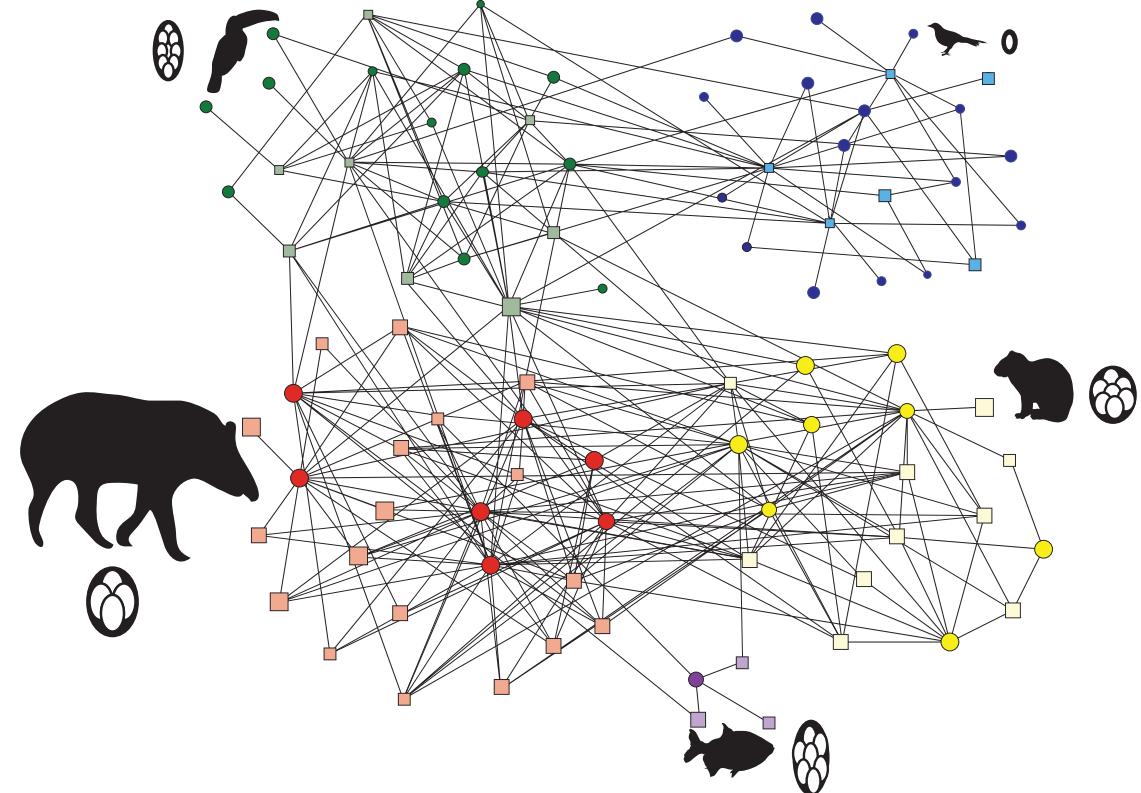
Araújo et al 2008. Ecology

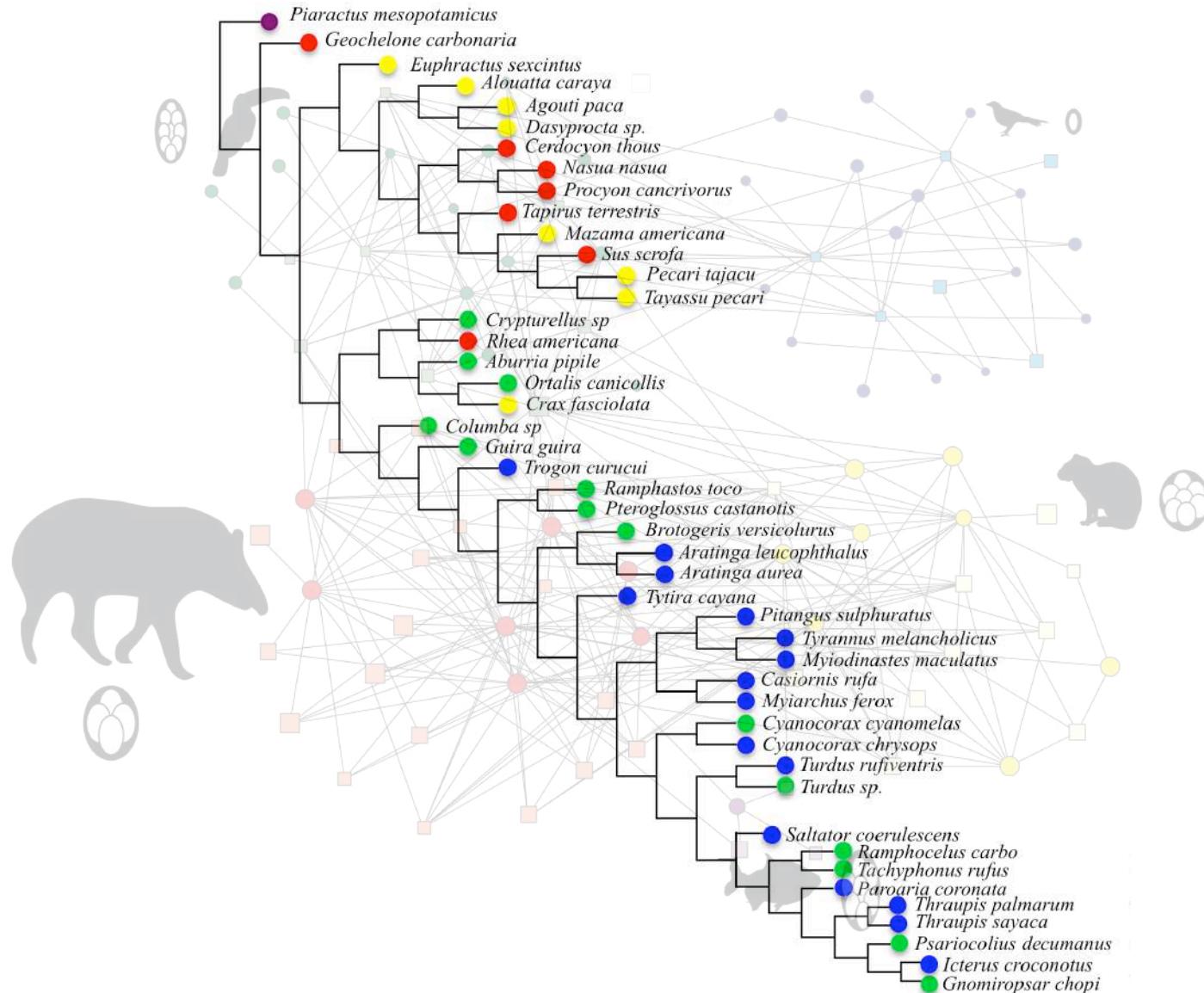
# Modularidade

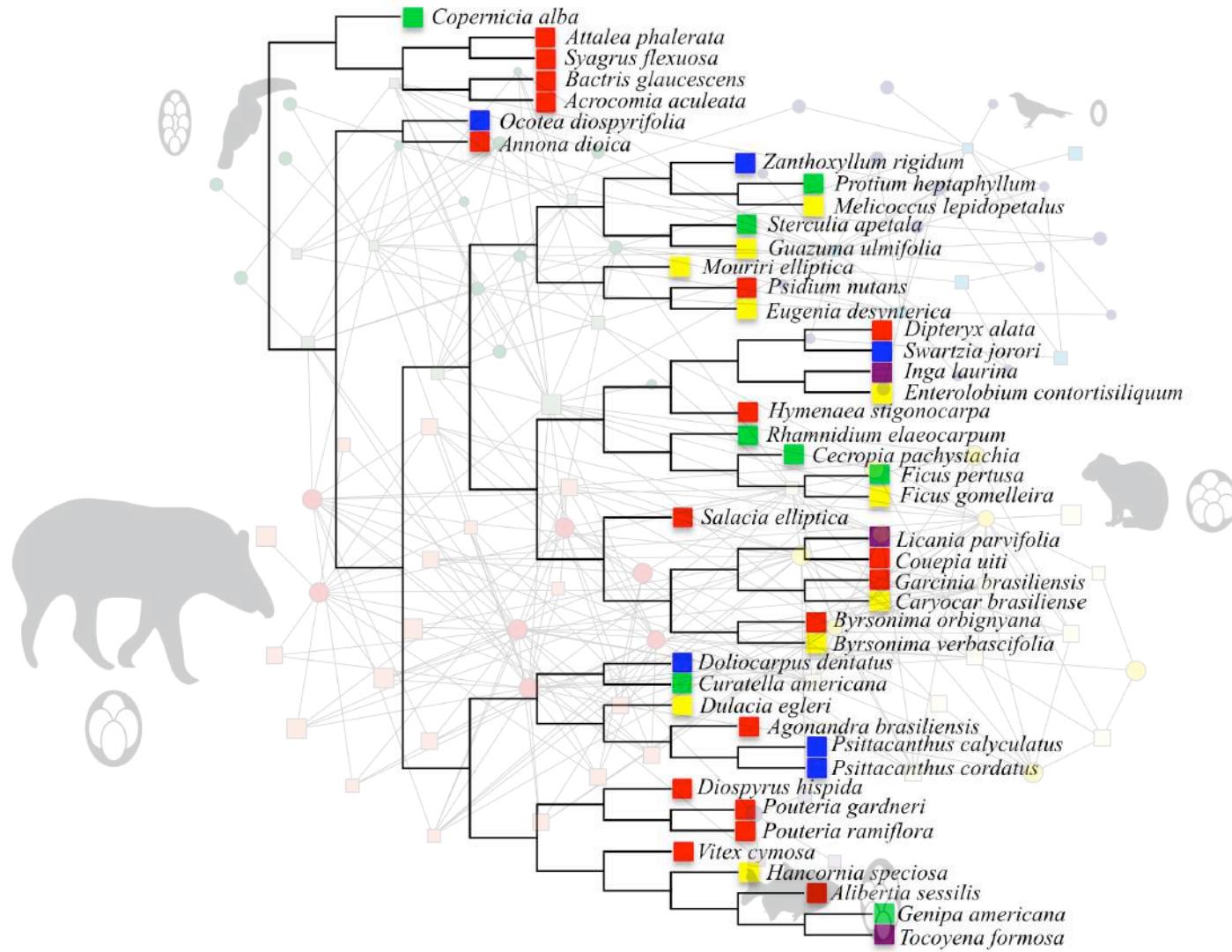
## Traços & história evolutiva



Camila Donatti







# A trindade

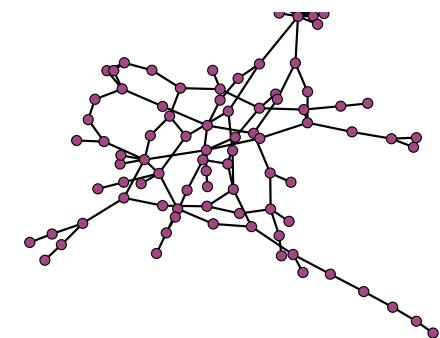
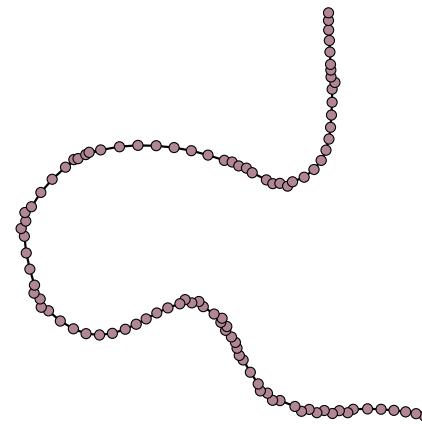
**Os três conceitos mais importantes sobre a estrutura de redes**

- Conectividade
- Modularidade
- **Distância**



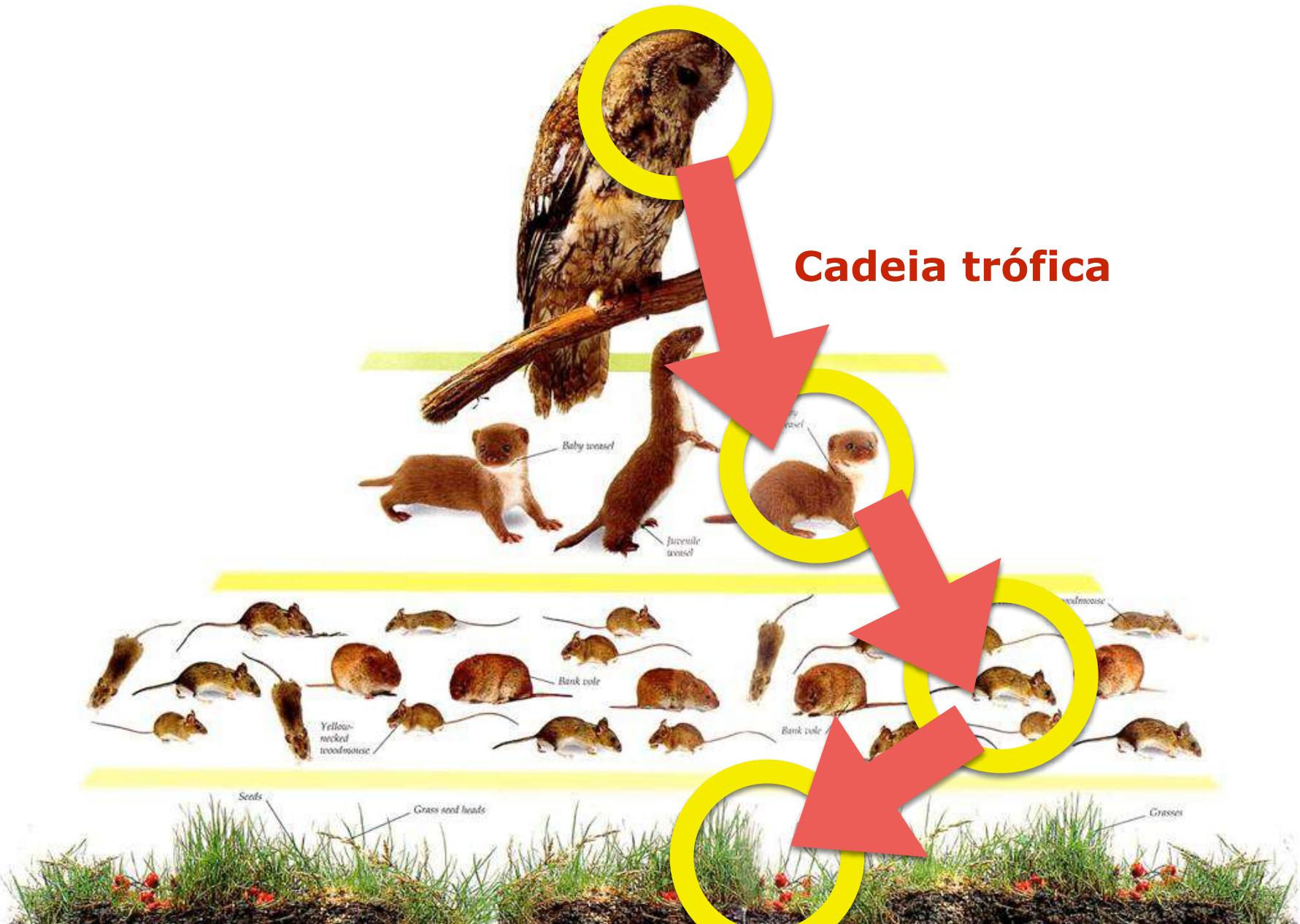
# Distância

- Ponto (espécie):
  - ✓ Distância média por ponto
- Rede
  - ✓ Comprimento médio do caminho
  - ✓ Diâmetro

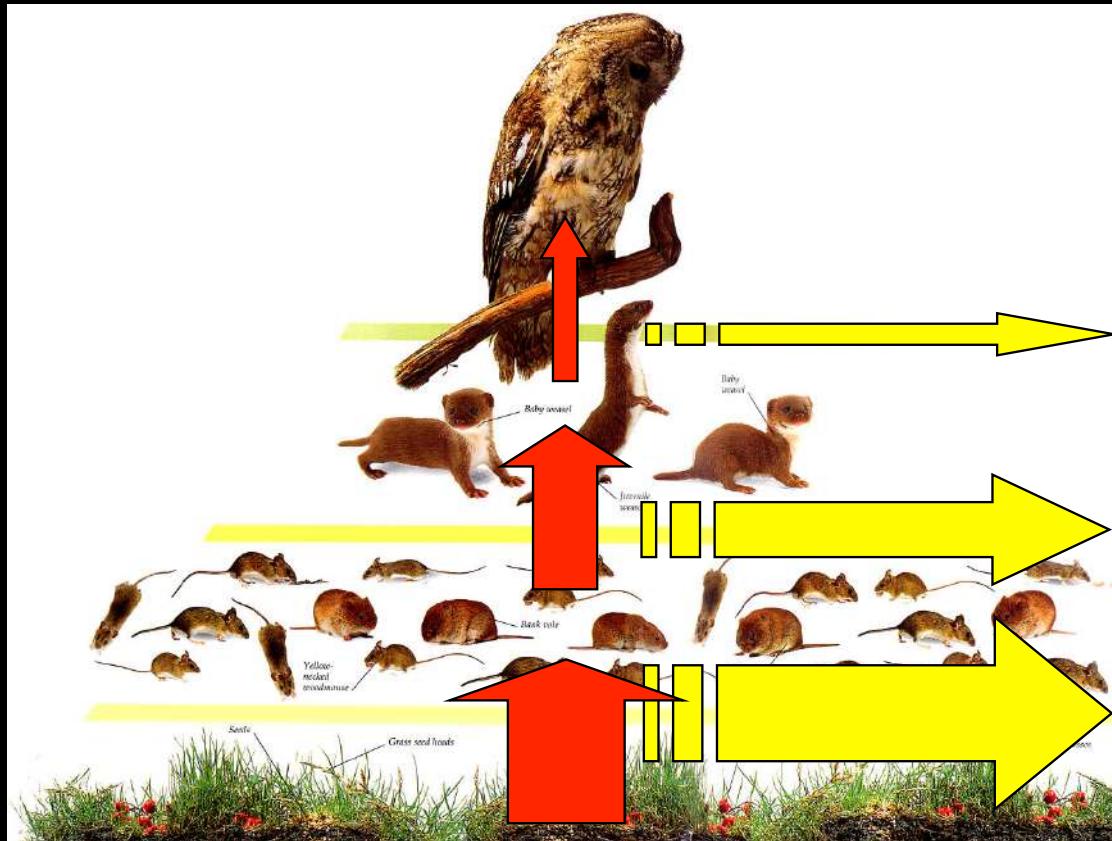


**Supplemental Figure 11.** Two theoretical graphs that have the same number of nodes (100 nodes) and the same number of links (114). On the left is a graph in which the distances between pairs of nodes in links are very large (average smallest path length,  $\ell = 29.55$ ). On the right is a network in which short pathways connect pairs of nodes ( $\ell = 5.97$ ).

## Cadeia trófica



## Não há energia disponível para muitos níveis tróficos

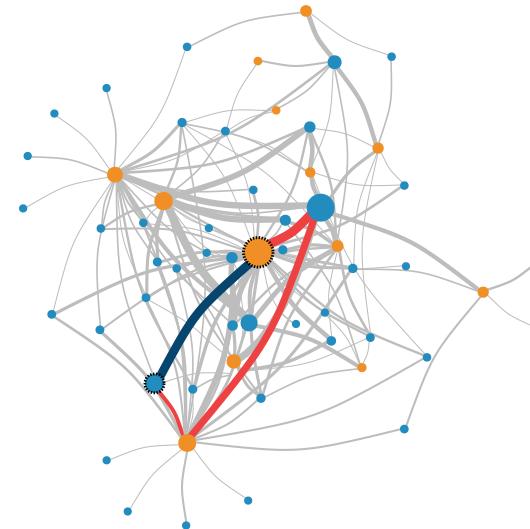
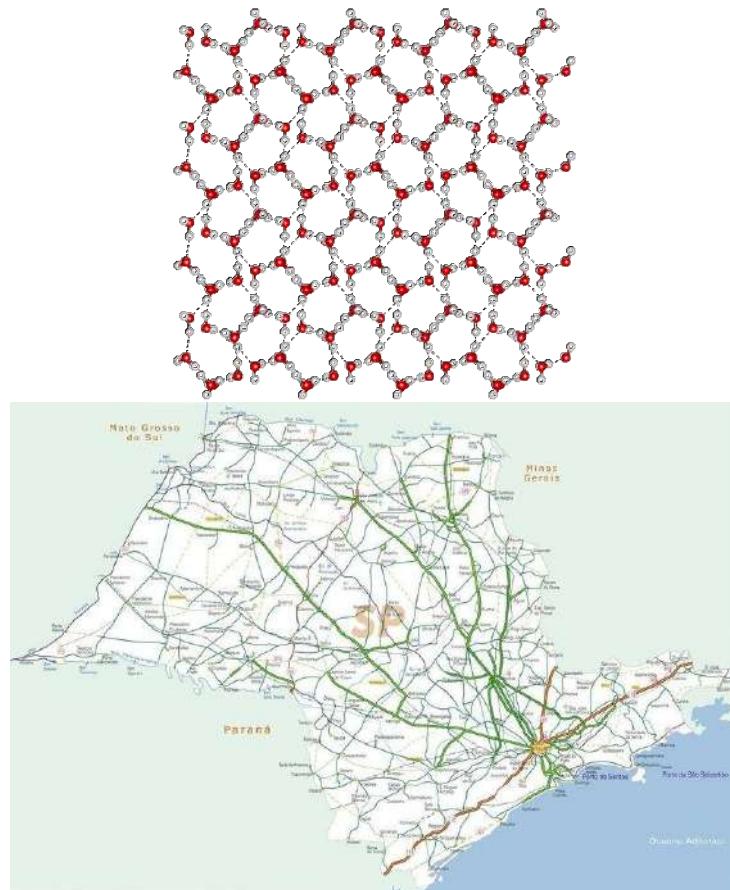


Dissipação de energia

Lindeman 1942

# O efeito mundo pequeno

Caminhos curtos ligam pontos em redes ecológicas



SmallWorlds

# Parque Nacional da Tijuca – Rio de Janeiro, Brazil



# **Uma floresta que estava vazia**



**1970s**



**2009**



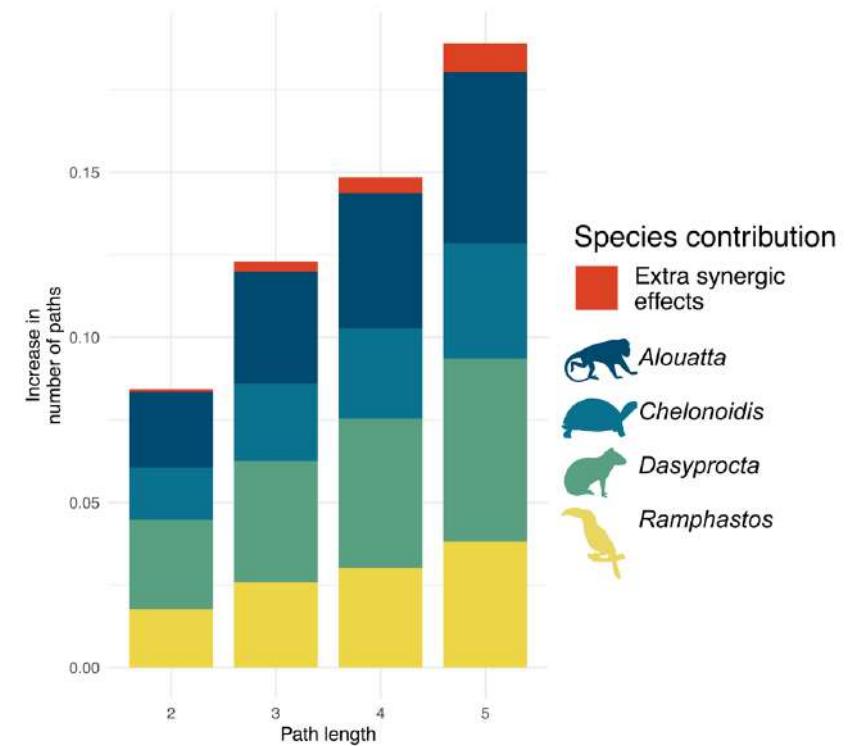
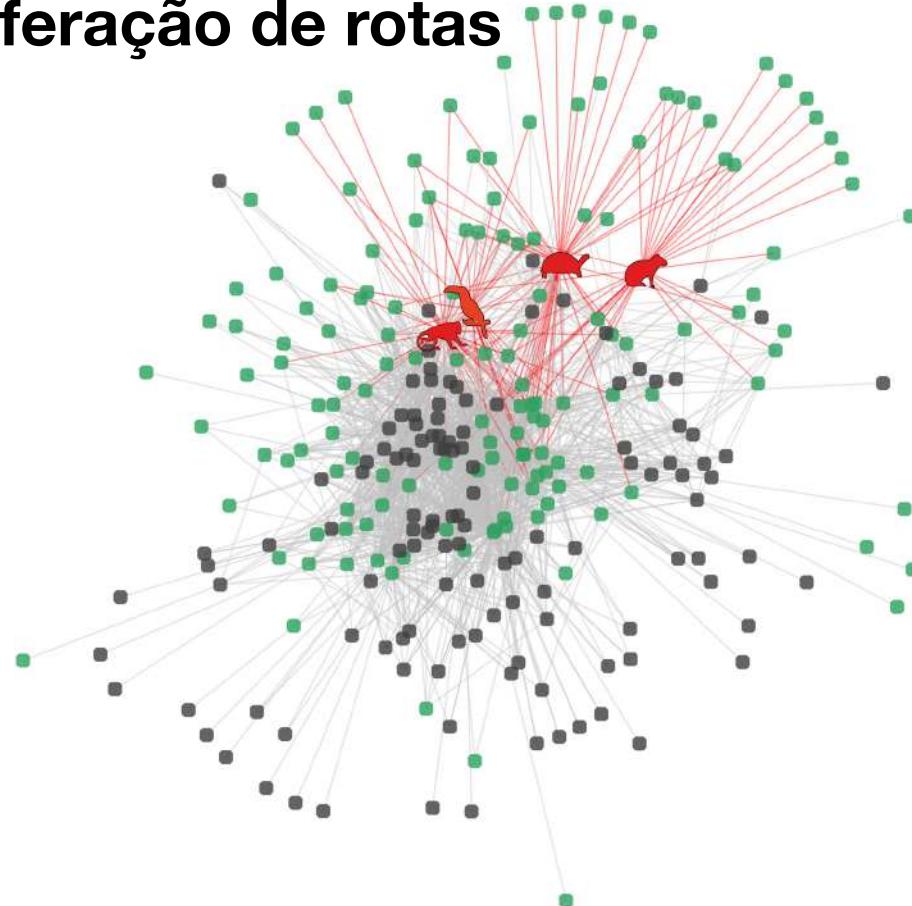
**2015**



**2018**

# Caminhos indiretos

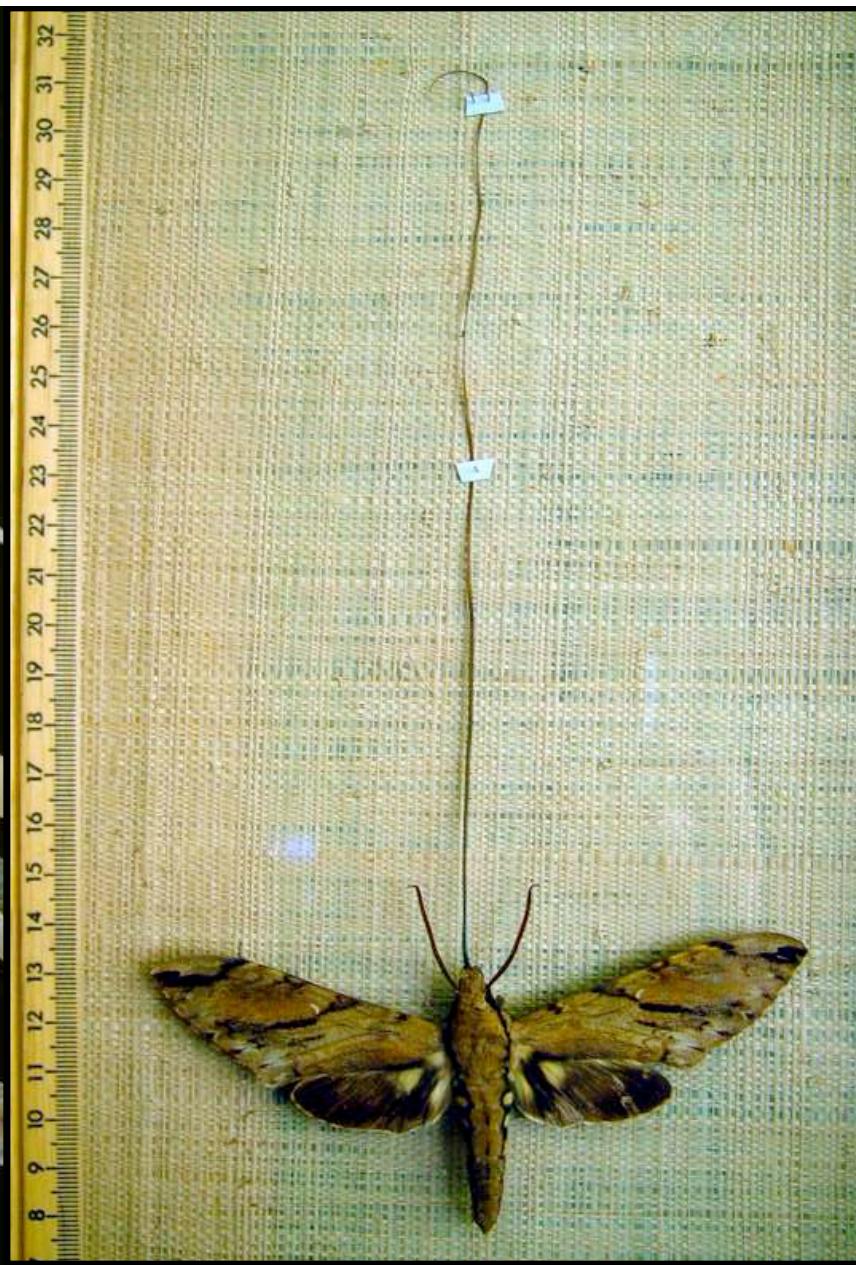
A proliferação de rotas



Mittelman et al. 2022. Oikos

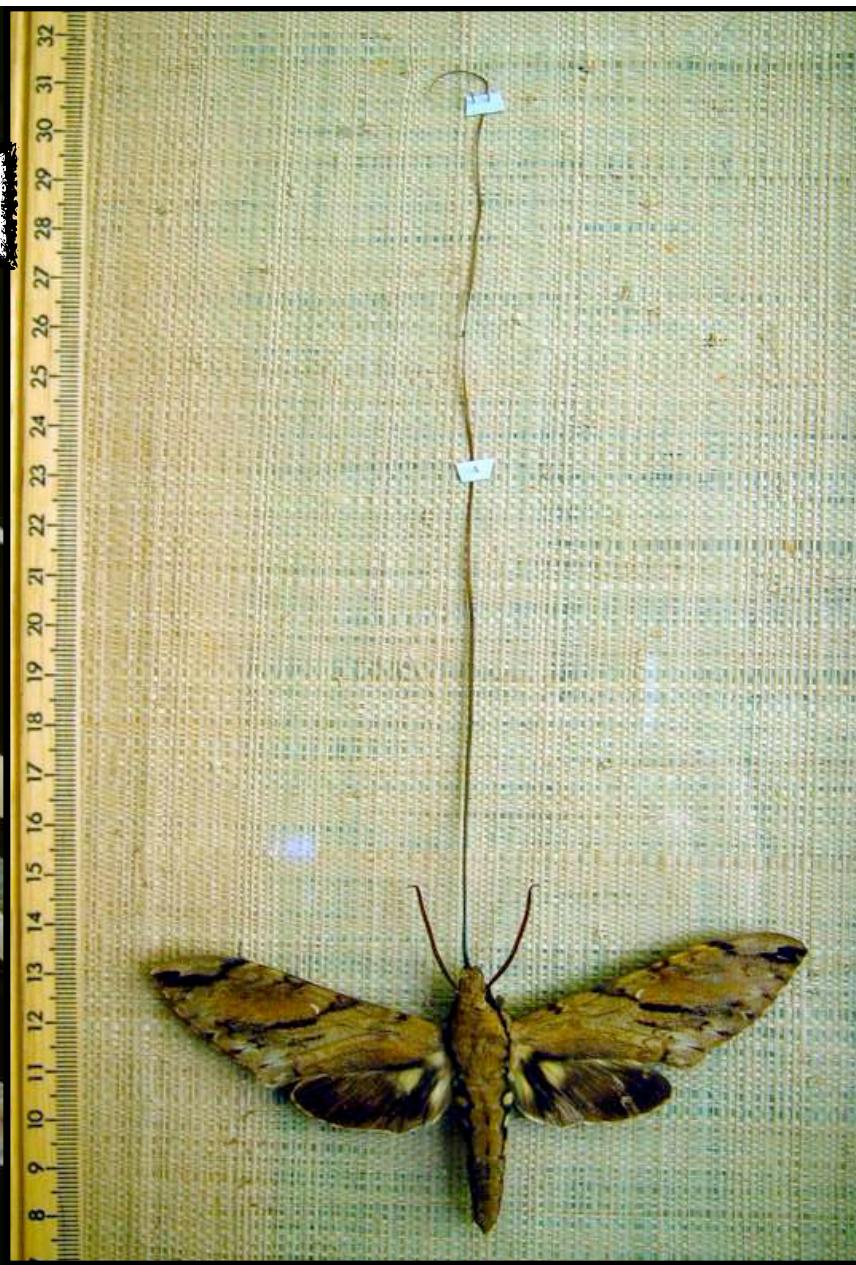
# Aula 2: Estrutura

- A trindade: conectividade, modularidade e distância
- **Assimetrias e sobreposição**
- Centralidade
- Resumo



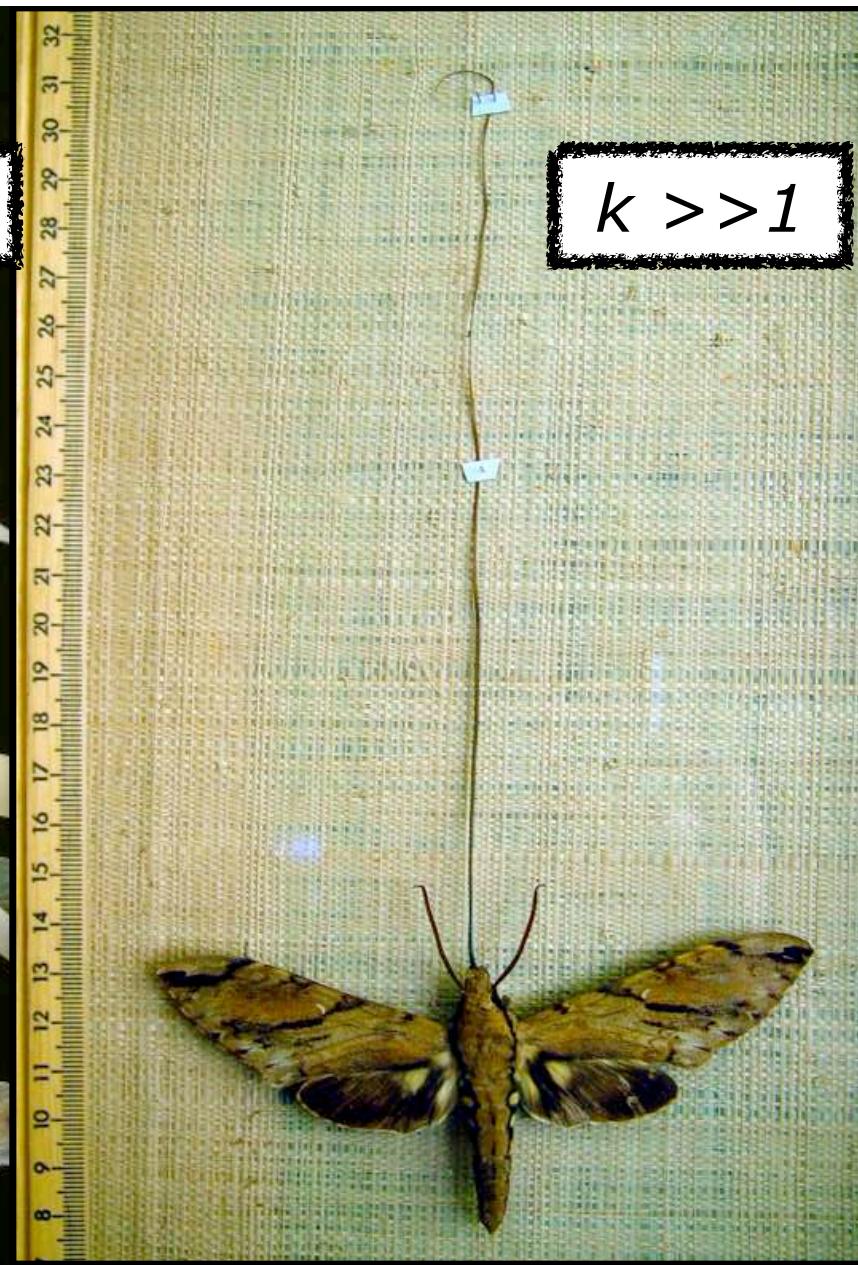


$k = 1$

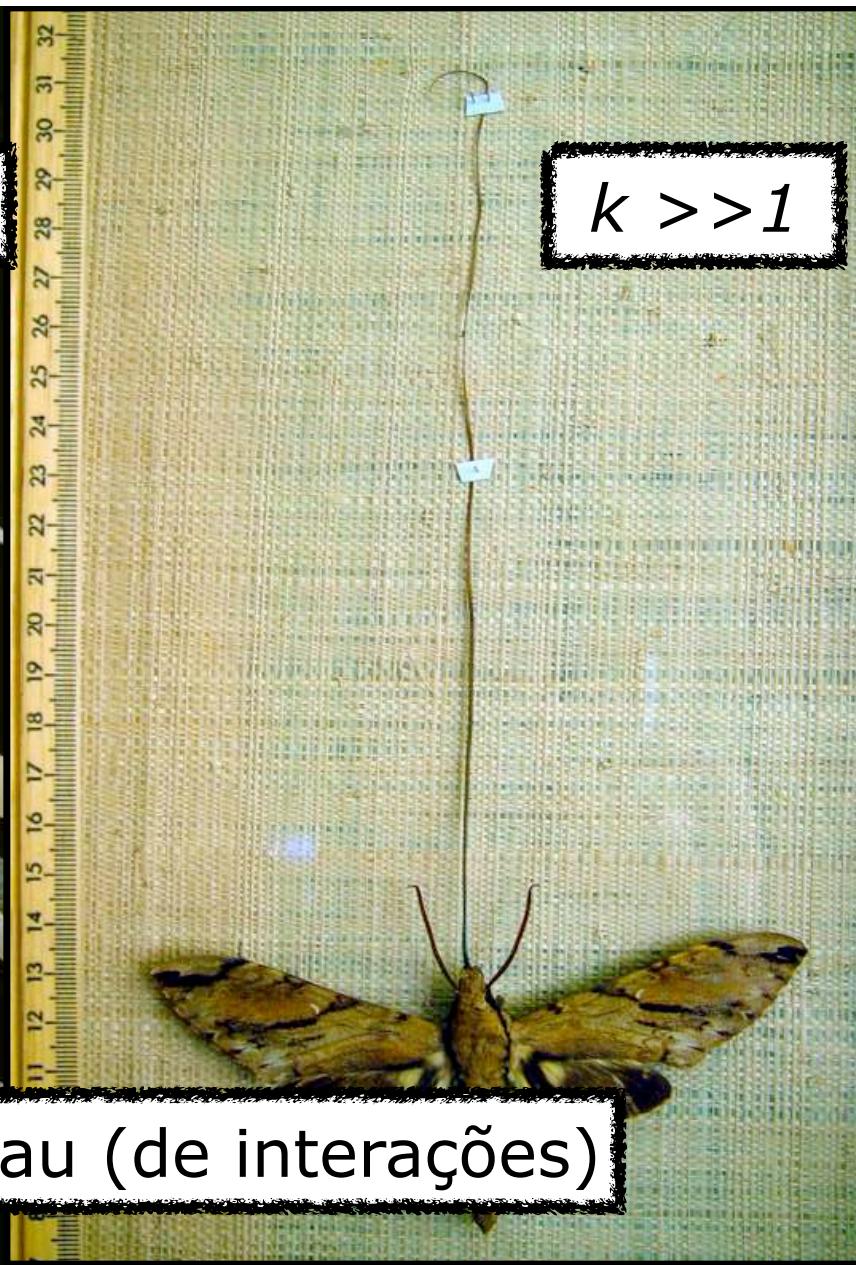




$k = 1$



$k >> 1$

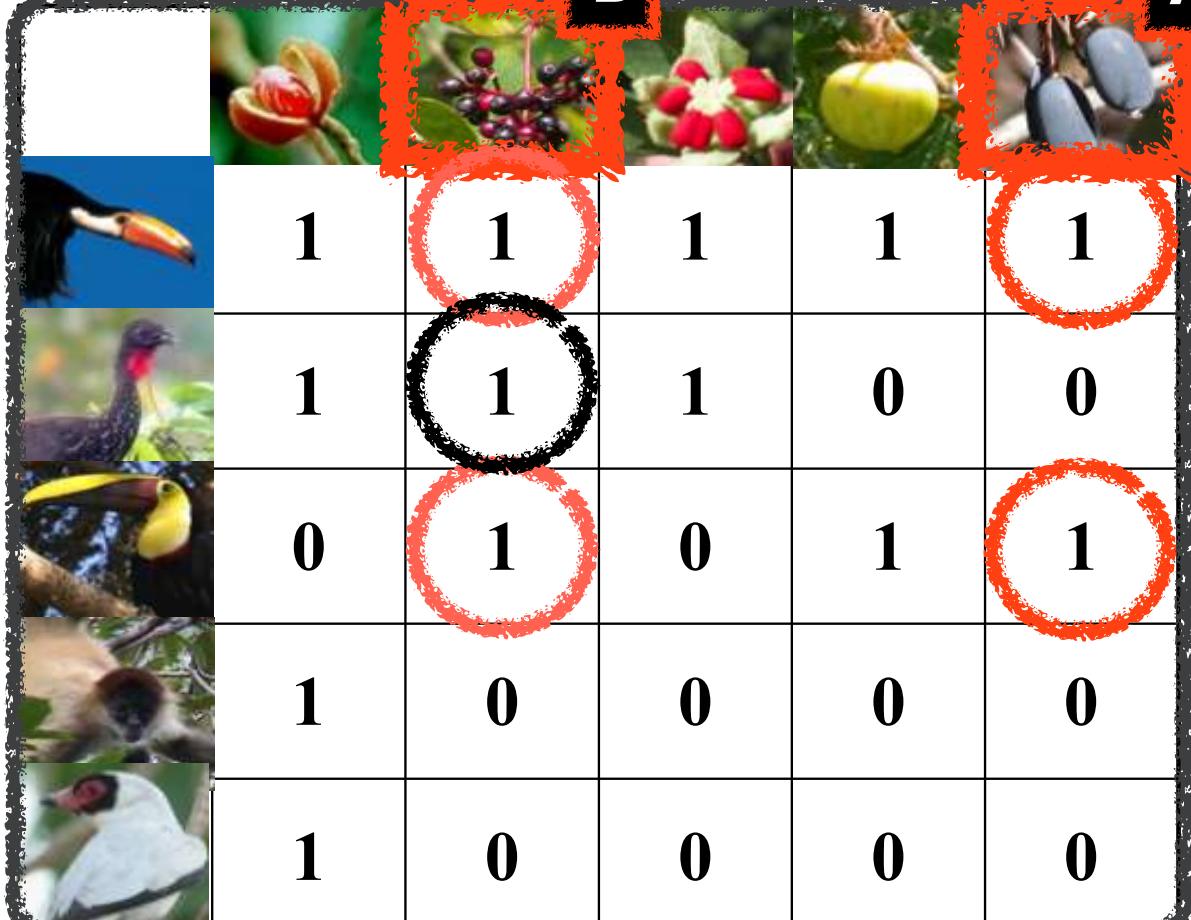


Assimetria do grau (de interações)

# Sobreposição

- Pares de espécie
- ✓ Índice de Jaccard
- Rede
- ✓ Índice de Jaccard médio
- ✓ Assortatividade
- ✓ Modularidade (já falamos)

		B	C	D	A
B	1	1	1	1	1
C	1	1	1	0	0
D	0	1	0	1	1
A	1	0	0	0	0
	1	0	0	0	0



# Aninhamento: combinando assimetria e sobreposição

- NODF: Índice de Jaccard assimétrico



Mario Almeida-Neto



Meu pai :)

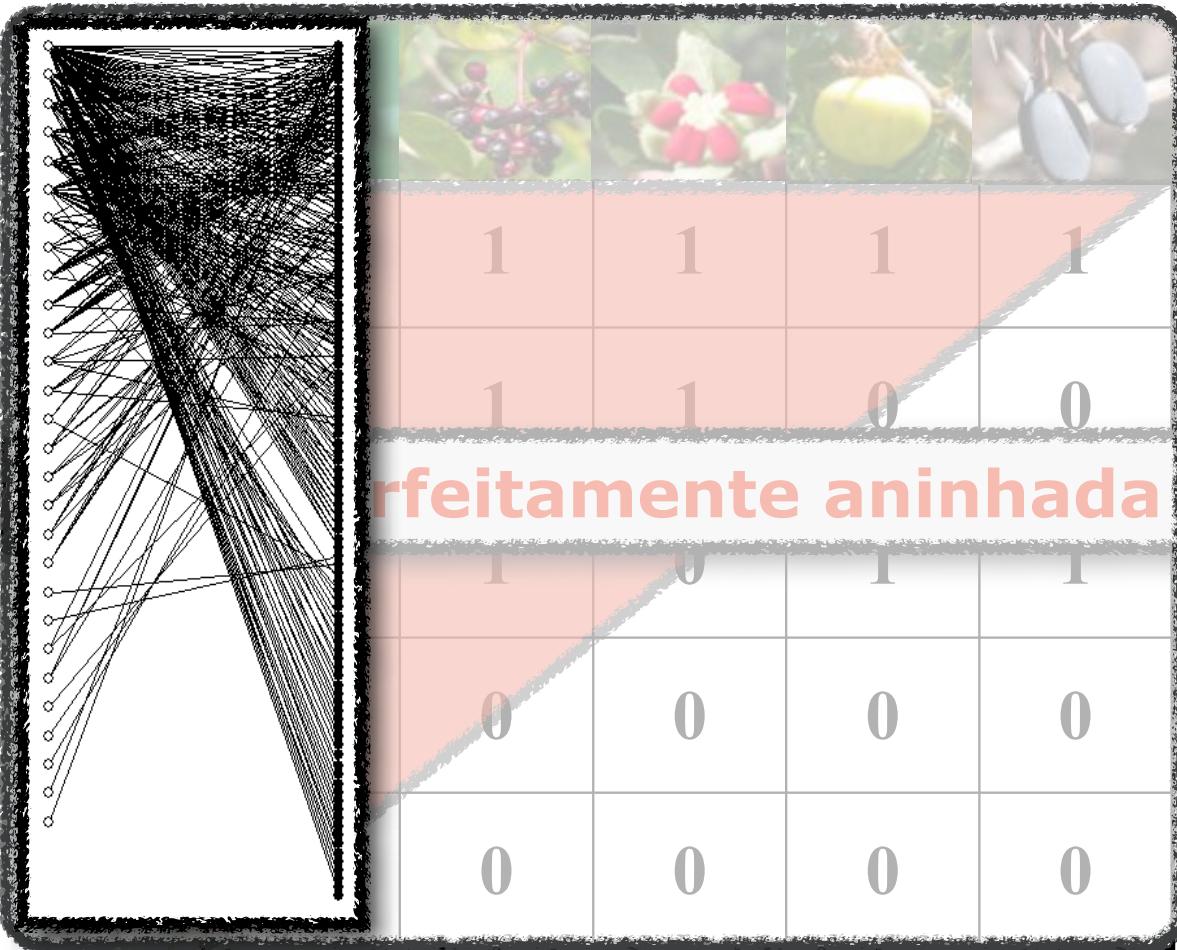
		B	C	D	A
B	1	1	1	1	1
C	1	1	1	0	0
D	0	1	0	1	1
A	1	0	0	0	0
	1	0	0	0	0

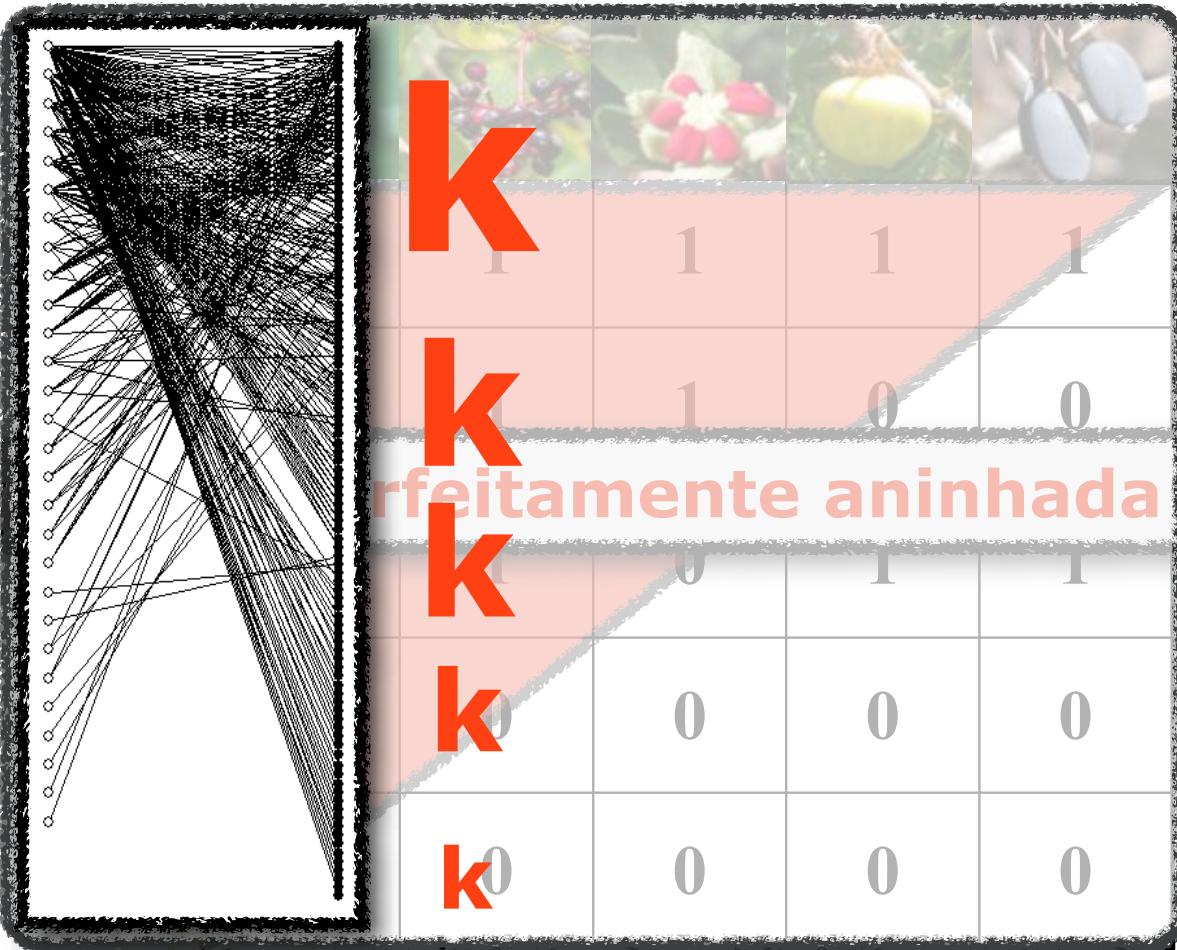
The table illustrates the asymmetric Jaccard index (NODF) between six images. The columns are labeled B, C, D, and A, while the rows are labeled with the same symbols. The values represent the presence (1) or absence (0) of shared features. Red circles highlight the diagonal elements (B-B, C-C, D-D, A-A), which are all 1, indicating perfect overlap. The off-diagonal elements show varying degrees of overlap: B-C=1, B-D=1, B-A=1; C-B=1, C-D=1, C-A=0; D-B=0, D-C=1, D-A=0; A-B=1, A-C=0, A-D=0.

	1	1	1	1	1
	1	1	1	0	0
	0	1	0	1	1
	1	0	0	0	0
	1	0	0	0	0

	1	1	1	1	1
	1	1	1	0	0
	0	1	0	1	1
	1	0	0	0	0
	1	0	0	0	0

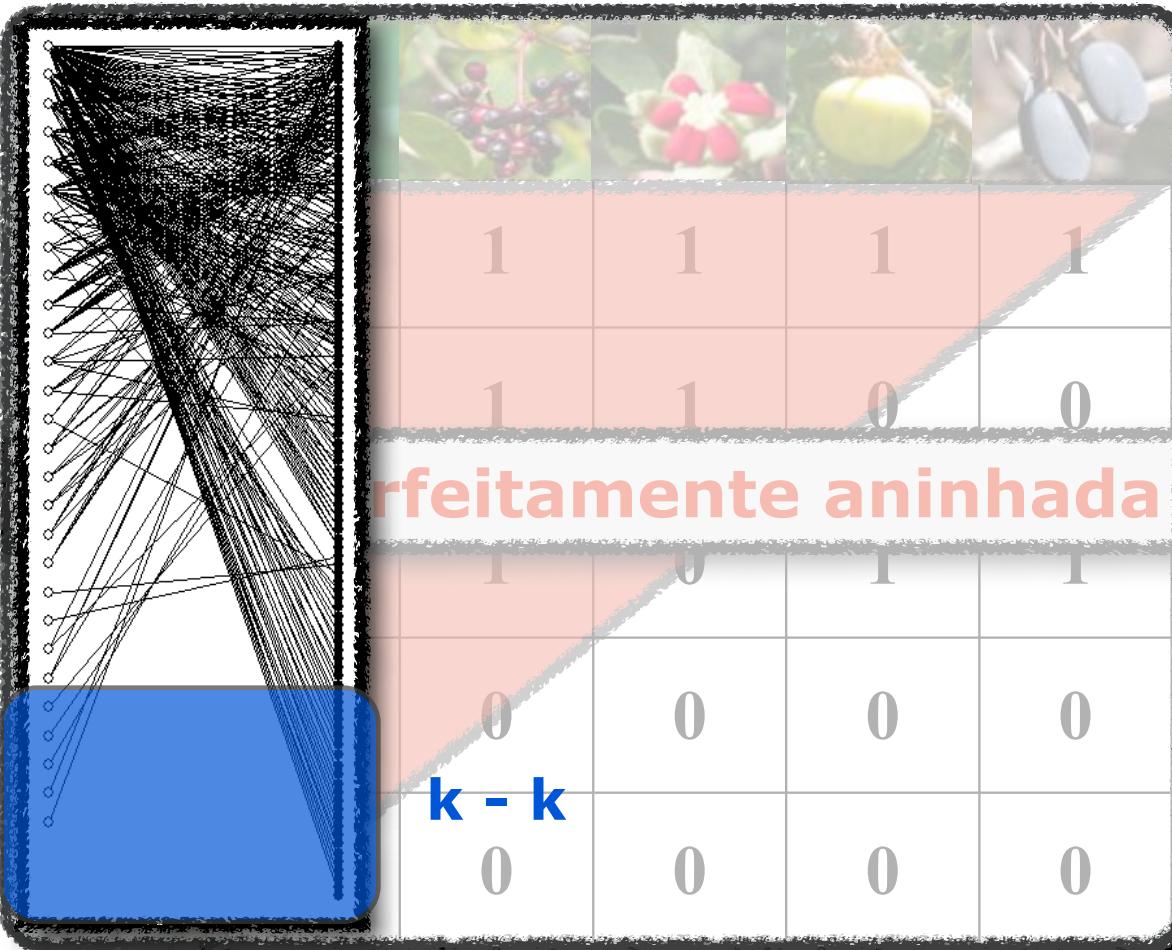
**Matriz perfeitamente aninhada**

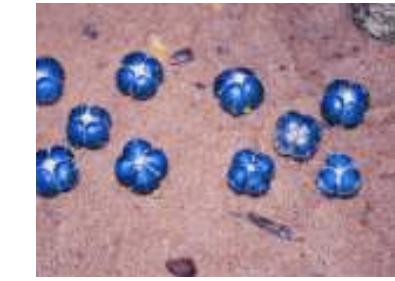


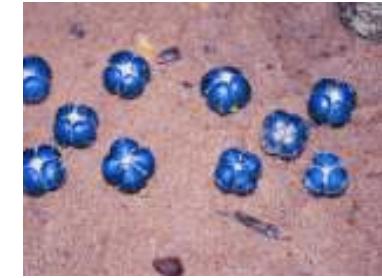


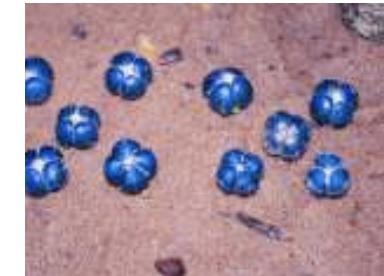




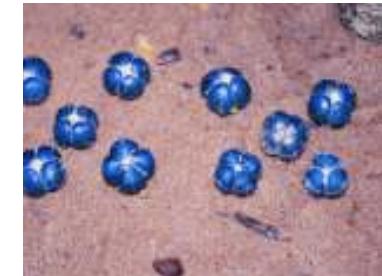


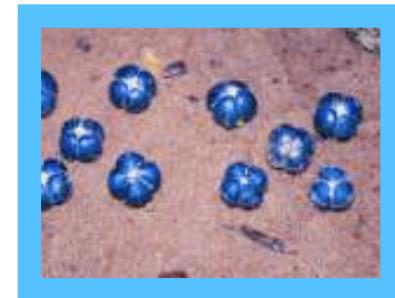














# Atributos dos mutualismos

## 1. Dependência física



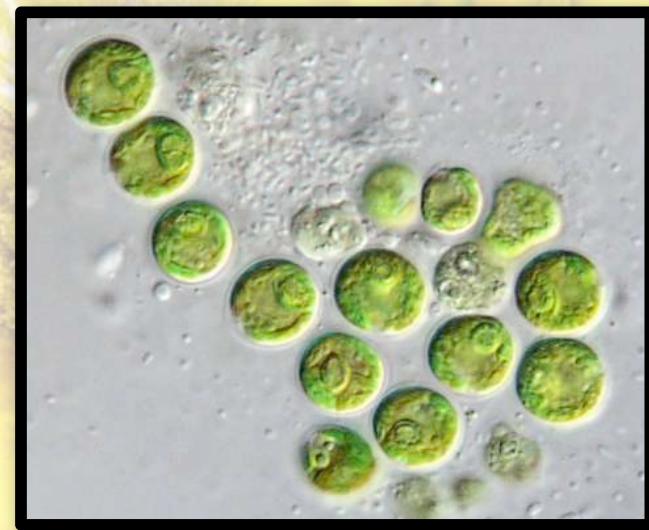
## Atributos dos mutualismos

### 2. Dependência trófica



## Atributos dos mutualismos

### 3. Integração fisiológica / dependência física



## Intimidade de interação



**Não - simbióticas**

**Simbióticas**

## Intimidade de interação

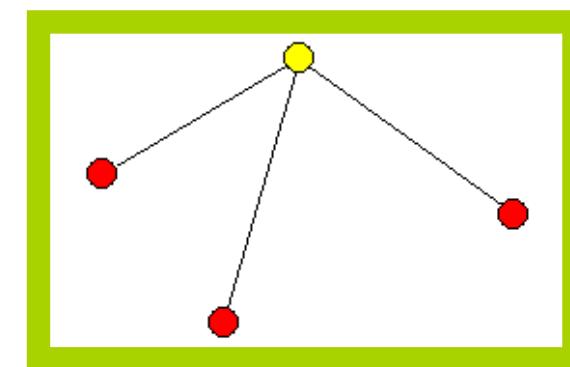
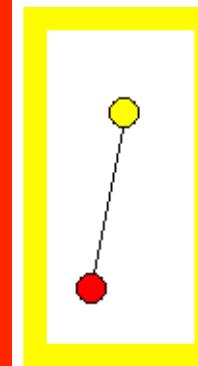
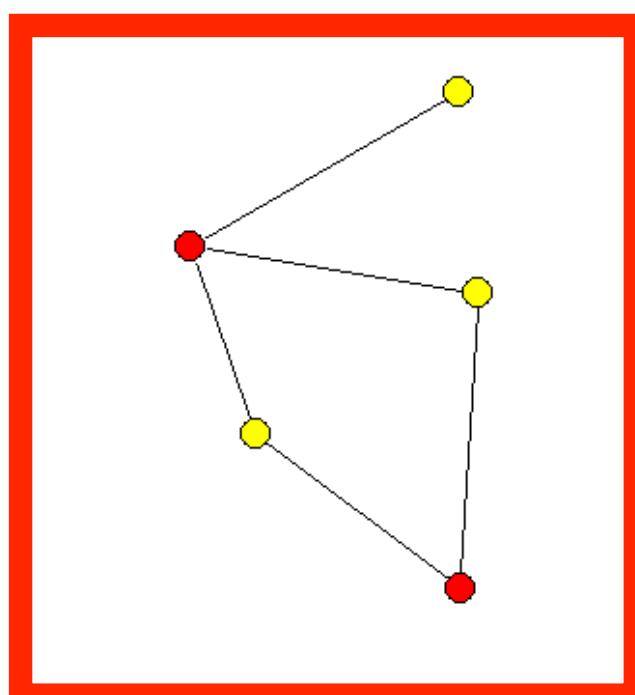
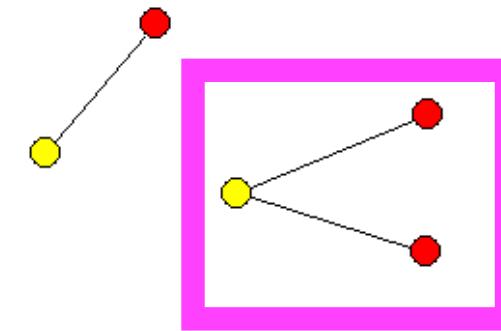
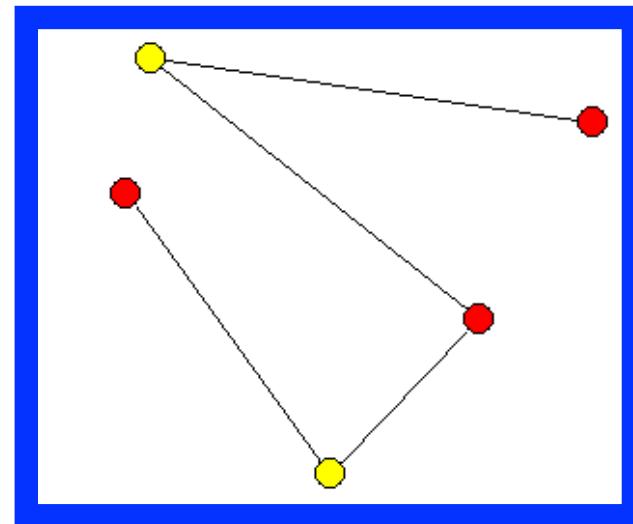


**Não - simbióticas**



**Simbióticas**





**Similar aos antagonismos**

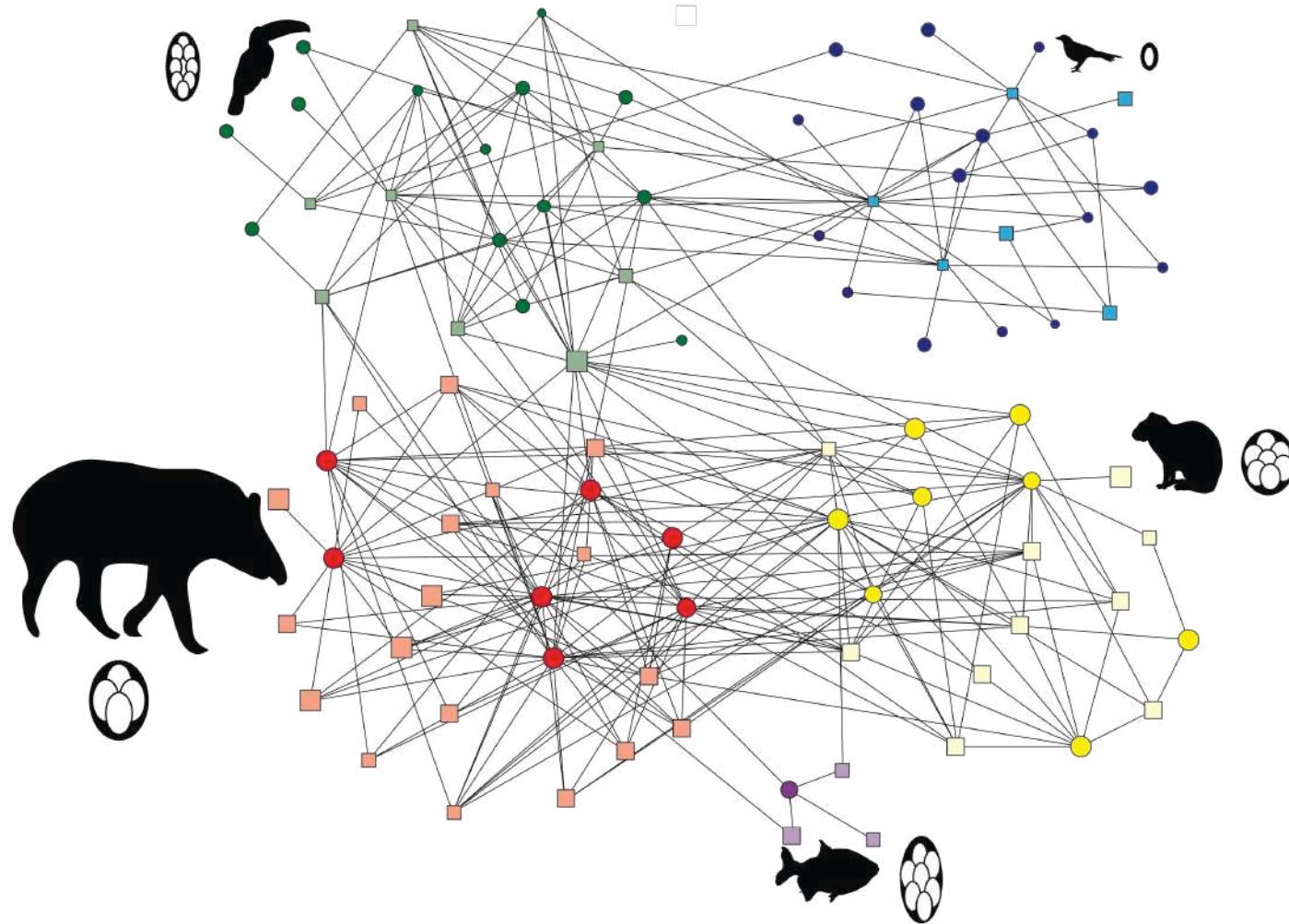


## Intimidade de interação

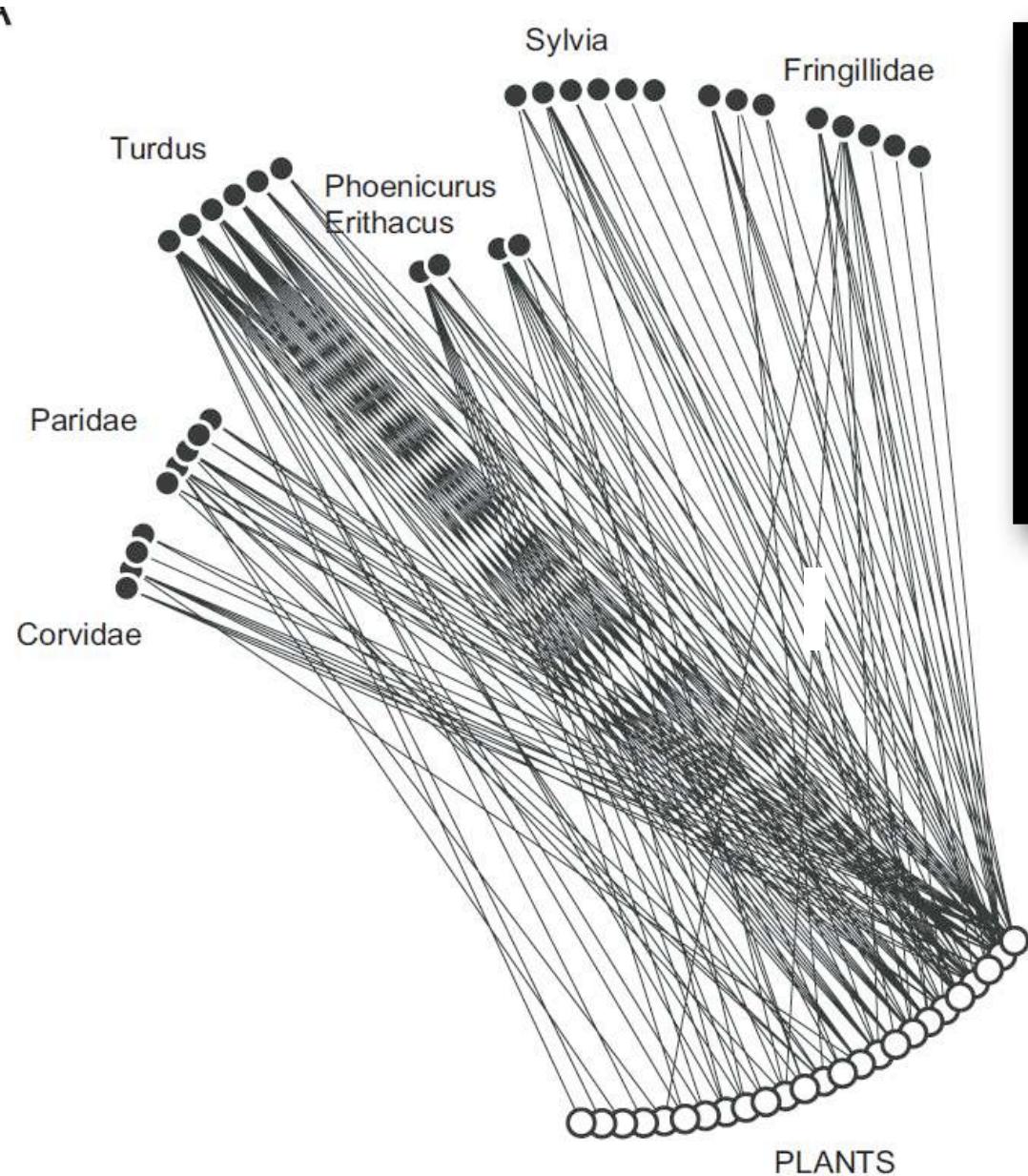


**Não - simbióticas**

**Simbióticas**

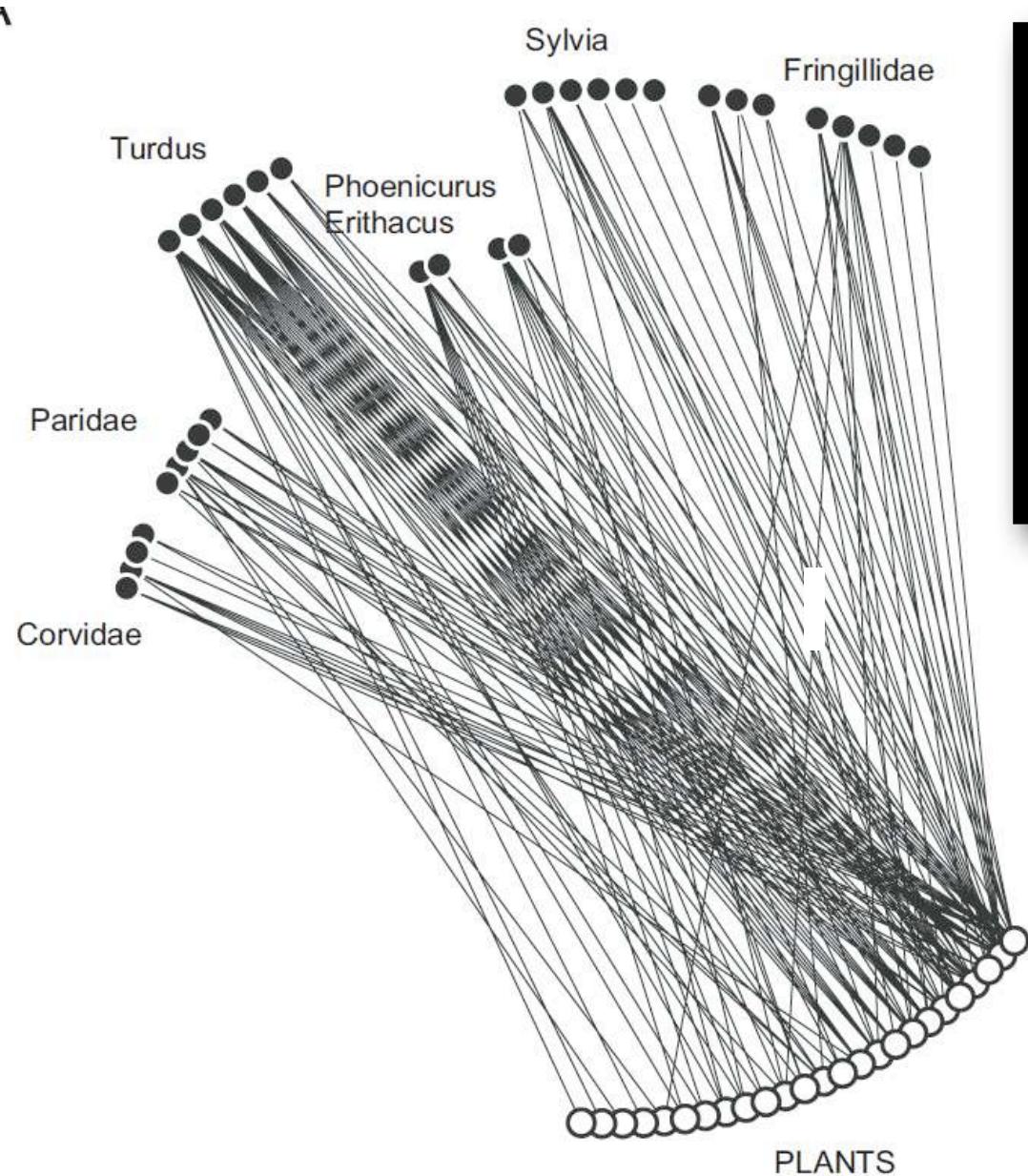


Donatti et al. 2011. *Ecology Letters*



## Características

- Baixa modularidade



## Características

- Baixa modularidade
- Aninhamento



JP Krajewski



# Aula 2: Estrutura

- A trindade: conectividade, modularidade e distância
- Assimetrias e sobreposição
- **Centralidade**
- Resumo

# Centralidade

- Ponto (espécie) - Centralidade:

✓ Grau (conectividade)

✓ Proximidade (distância curta)

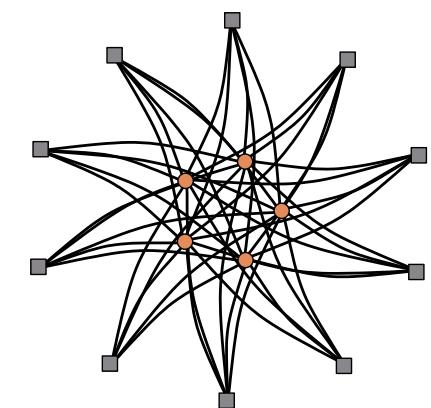
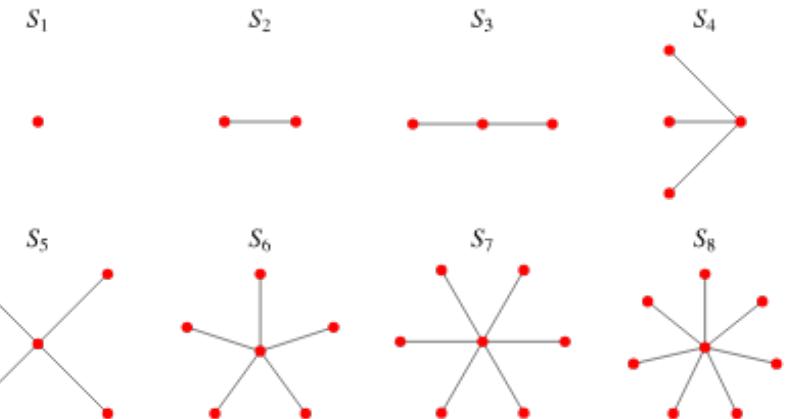
✓ Intermédio (no meio das distâncias curtas)

✓ Hubs da rede, Hubs de módulos e conectores de módulos (Modularidade)

- Rede - Centralização

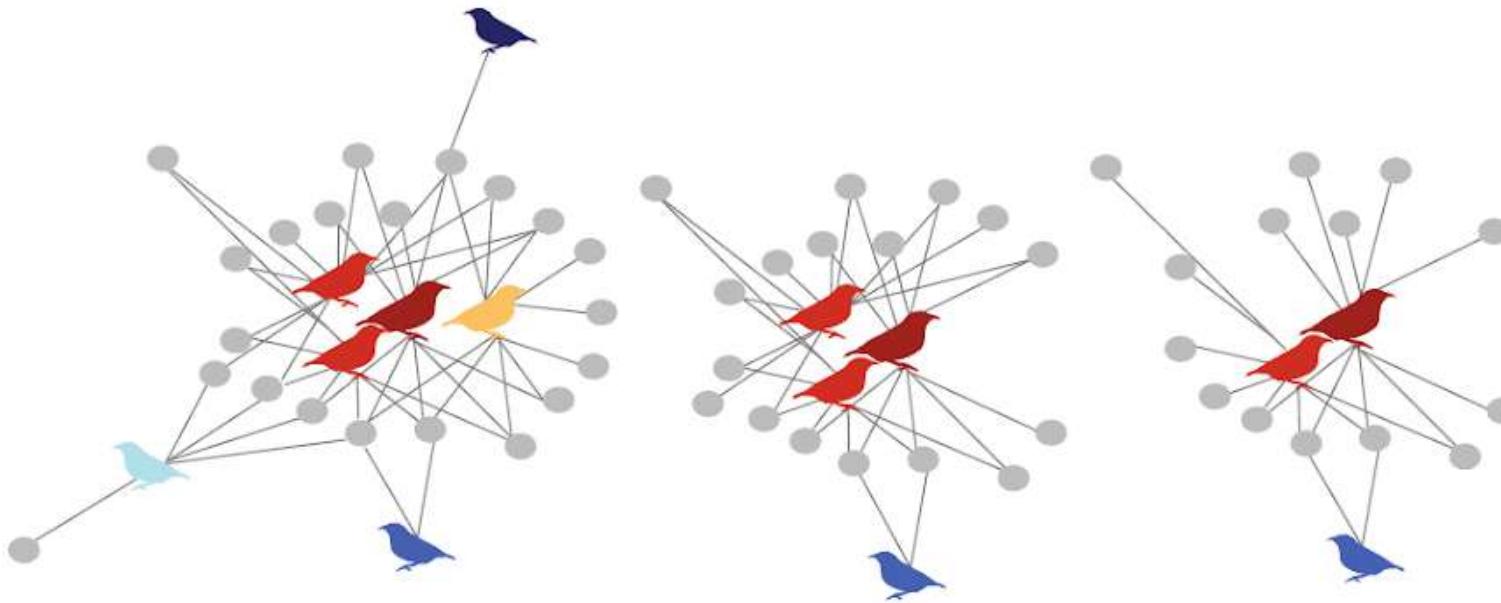
✓ Média das centralidades

✓ Amplitude das centralidades



# Processos evolutivos e a centralidade

Network evolves over time



Gustavo Burin



Tiago Quental

# Processos evolutivos e a centralidade

1. Baixas taxas de extinção



Gustavo Burin

2. Altas taxas de diversificação



Tiago Quental

# Aula 2: Estrutura

- A trindade: conectividade, modularidade e distância
- Assimetrias e sobreposição
- Centralidade
- **Resumo**

**Estrutura** → **Muitas possibilidades**

