BIO 365 ecological networks

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co-teachers: S. Bhandary, L. Cosmo, K. Gawecka, E. Knop, F. Pedraza, M. Román

Course plan

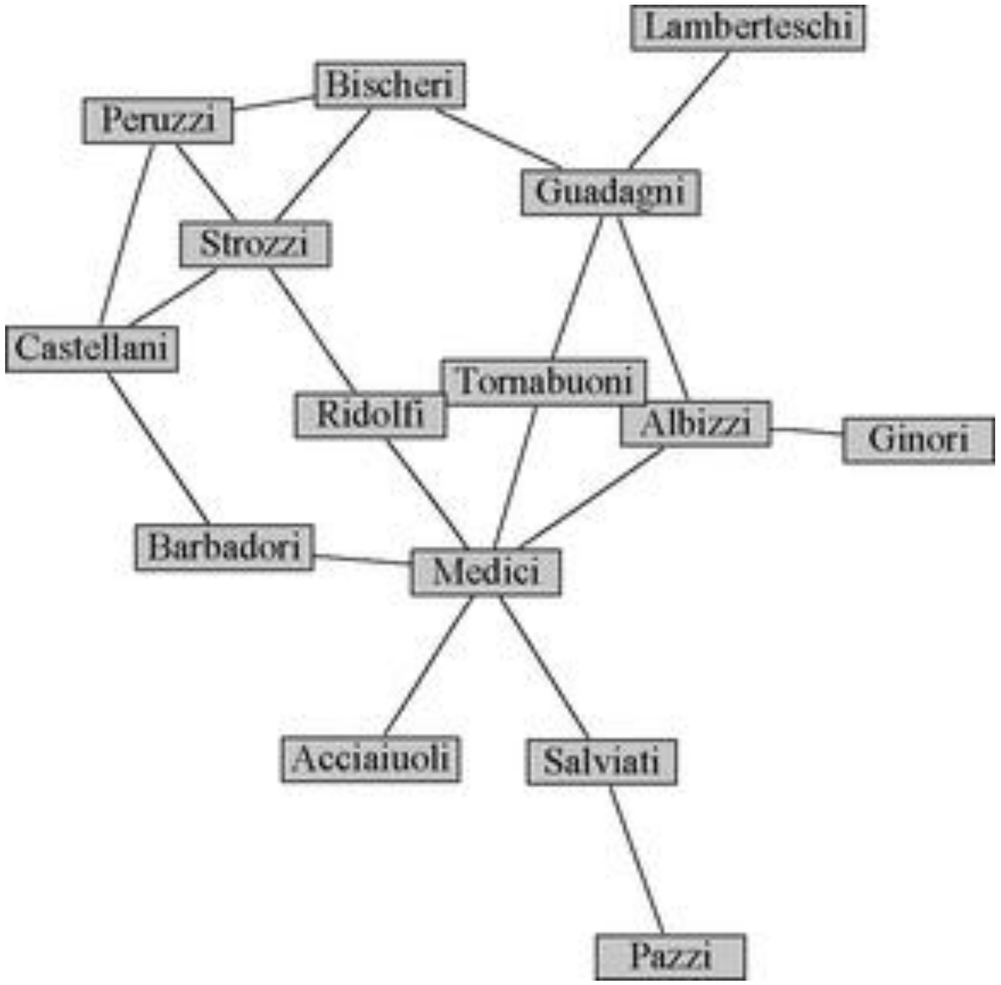
24FS BIO365 Ecological Networks

			Thursday March 14	Friday March 15	Tuesday March 19	Wednesday March 20	Thursday March 21	Friday March 22	Tuesday March 26	Wednesday March 27	Thursday March 28	Tuesday April 9	Wednesday April 10	Thursday April 11	Friday April 12
From	To														
10:15	12:00	LECTURE	Outline and Introduction	The role of species in networks		Topological patterns in ecological networks	Null models	Network robustness		Models of ecological dynamics	Genetic networks		Spatial networks	Coevolution	Open time
	Speaker		Vindigni	Cosmo		Cosmo	Pedraza	Vindigni		Bhandary	Roman		Gawecka	Cosmo	
12:00	13:00		Lunch	Lunch	Lunch	Lunch	Lunch	Lunch	Lunch	Lunch	Lunch	Lunch	Lunch	Lunch	Lunch
	Instructor(s)	EXERCISE	Vindigni	Roman	Knop Grognuz	Bhandary Vindigni	Pedraza	Vindigni	Gawecka Vindigni	Bhandary	Roman	Gawecka Vindigni	Gawecka	Cosmo	Vindigni
13:00	17:00		Toolkit for network analysis	Species-level metrics	Sampling an ecological network	Network-level metrics	Null models	Measuring network robustness	Distribute papers students' short talks	Models of ecological dynamics	Analyzing genetic networks	Students' short talks	Comparing networks in space	Models of evolution	Single-choice exam

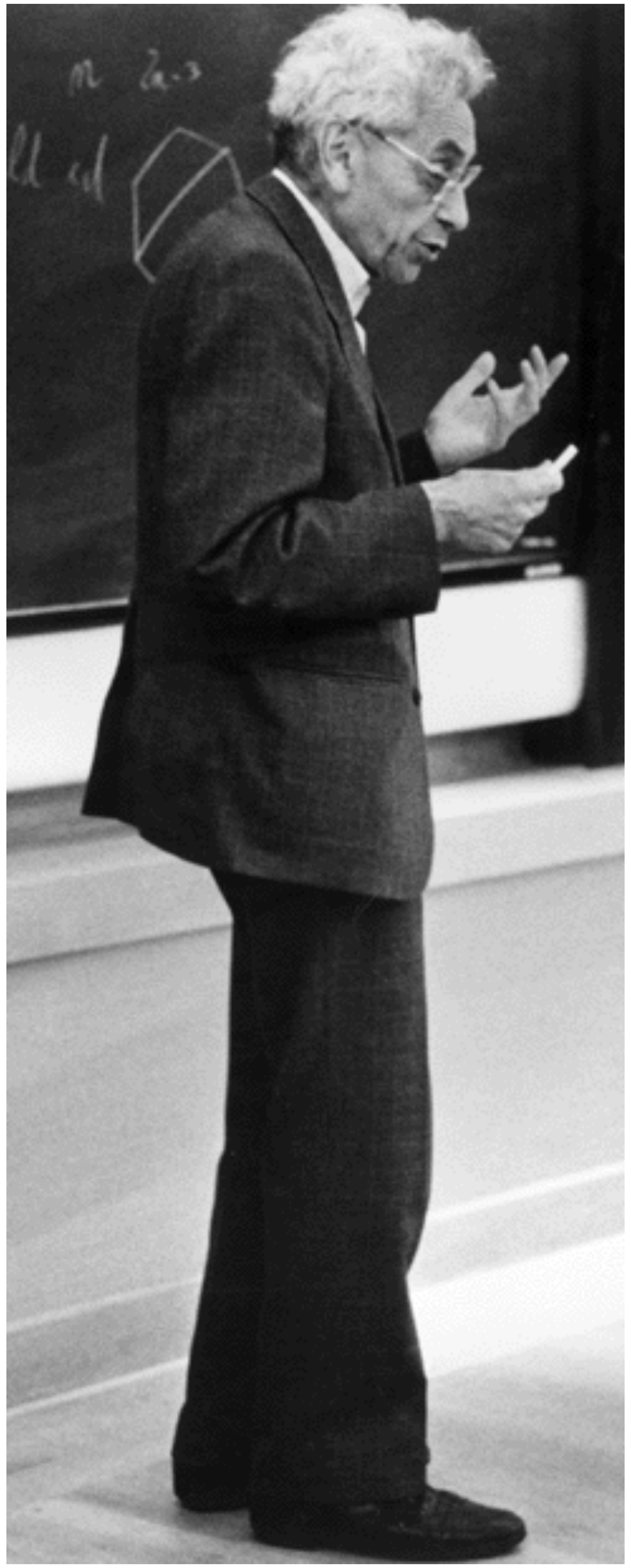
Course grading

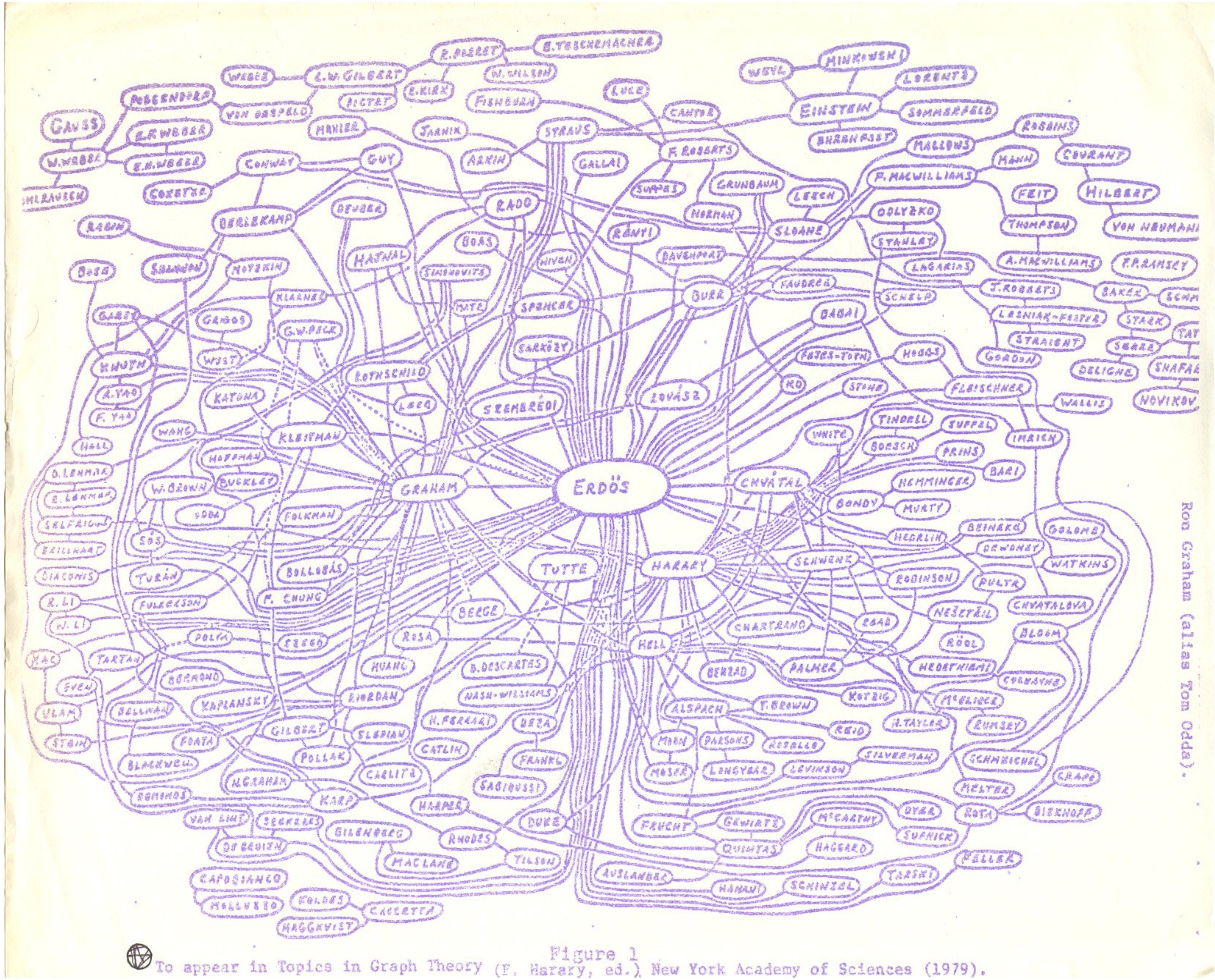
- Practical sessions (RStudio, report, and short-talks): up to 3 points
- Single-choice test sessions: up to 2 points

Marriage network in Florence 15th century



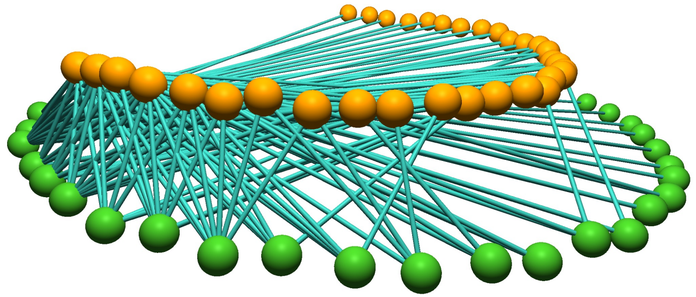
Paul Erdos… and his number





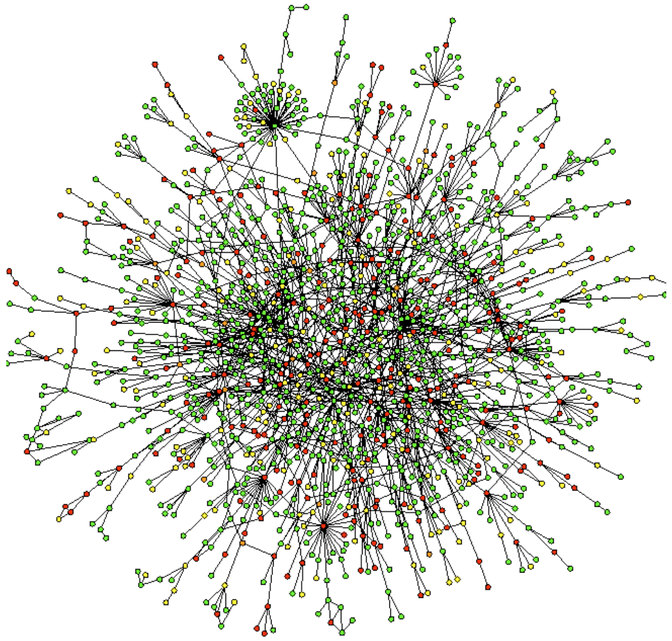
I there anything in the network approach besides the colorful representation?

ecological networks



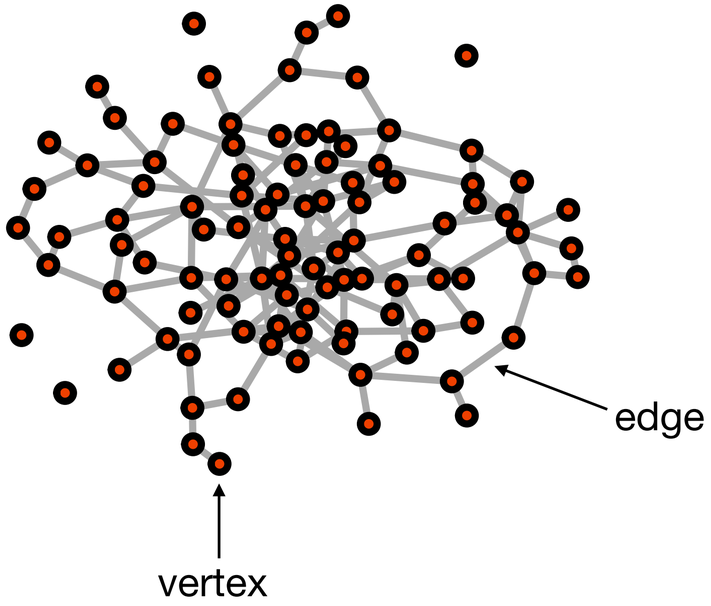
criminal network

protein networks

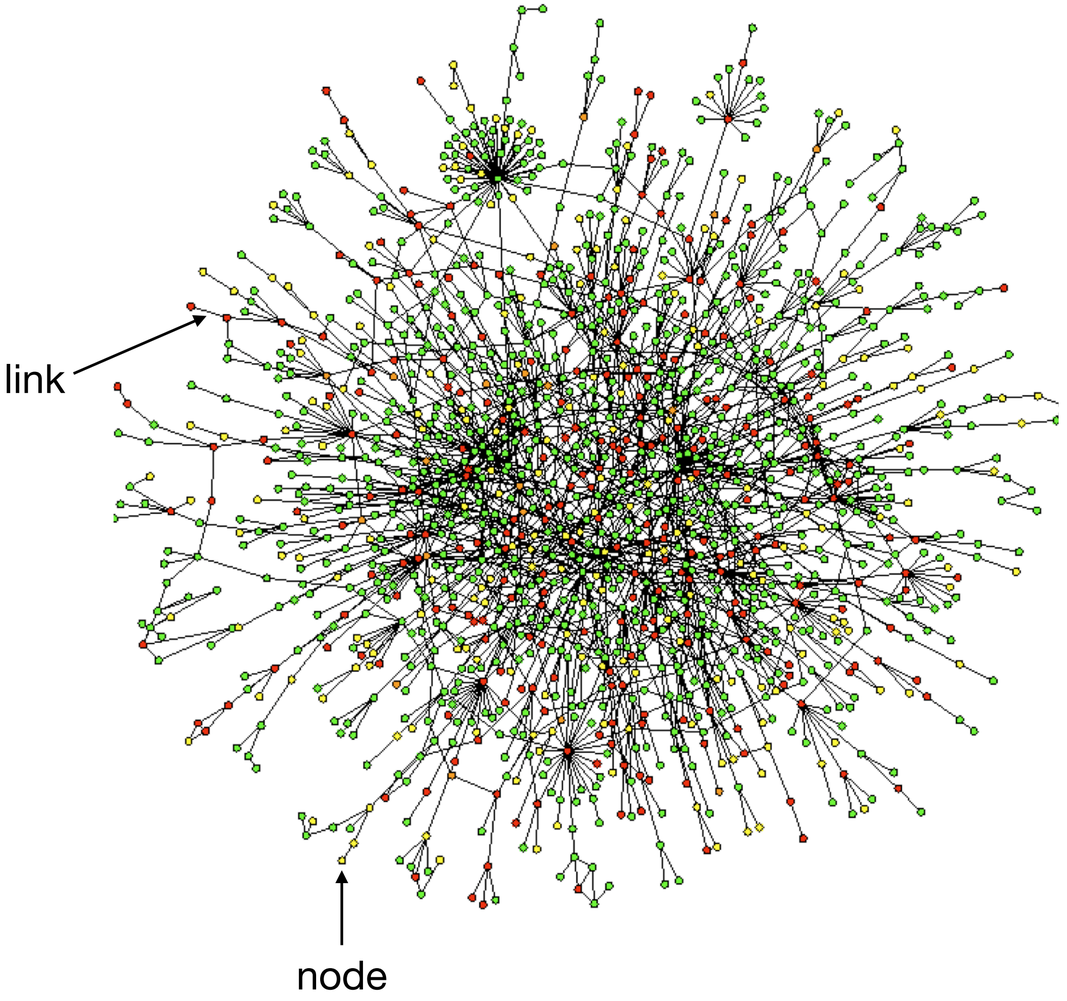


Graph theory and network science

(random) **graph**



network



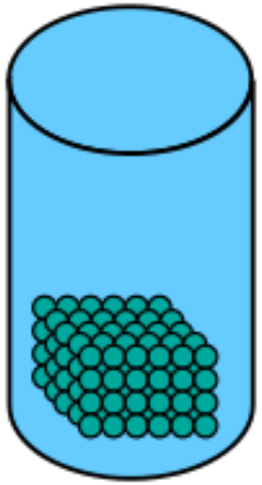
graph = mathematical structure

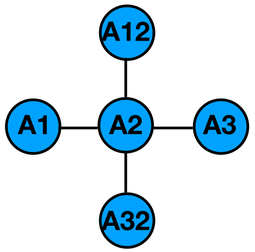
degree = number of links that a given node has to other nodes

Network science combines theoretical results from graph theory with the analysis of empirical data

Phases of matter from the perspective of network science

solid





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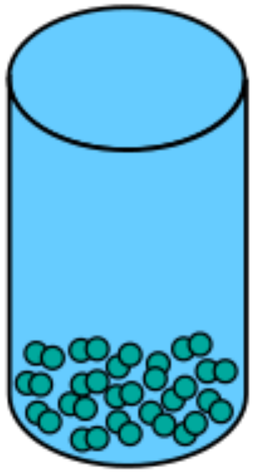
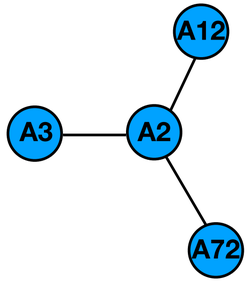
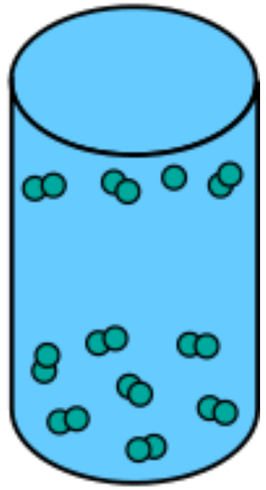
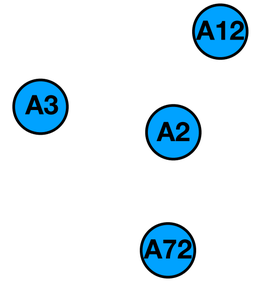




gas





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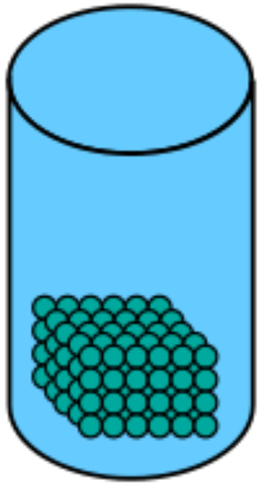

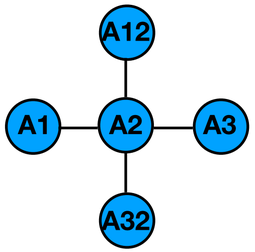

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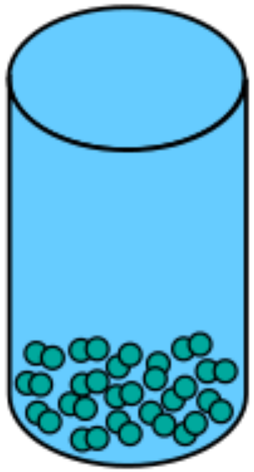

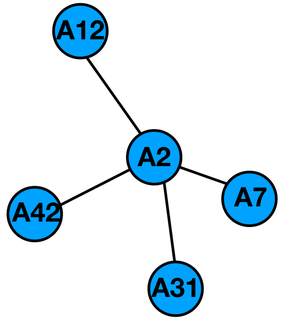

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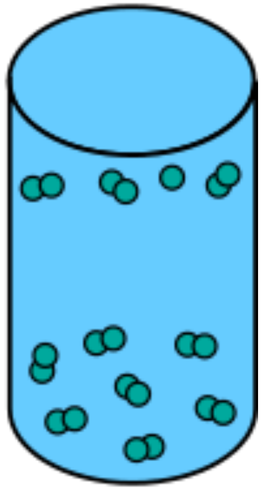

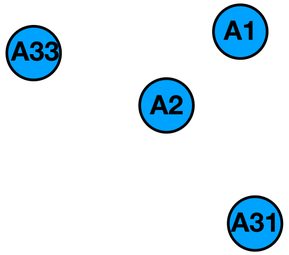

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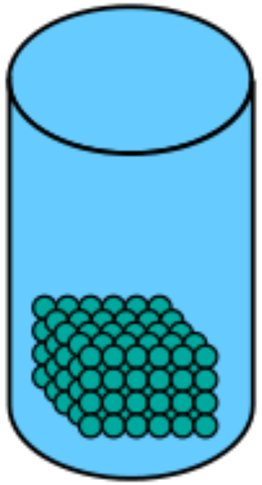

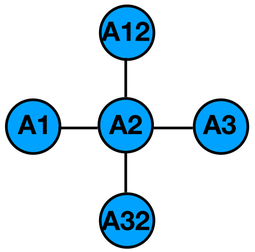

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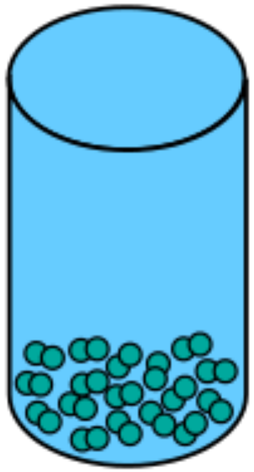

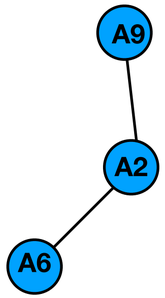

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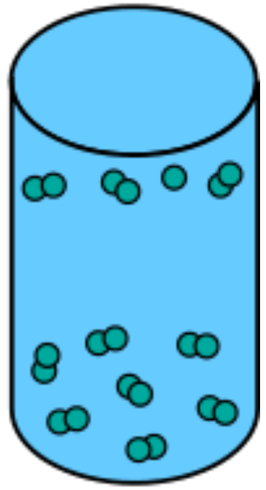

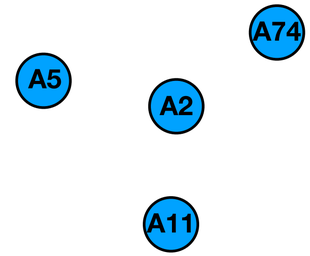

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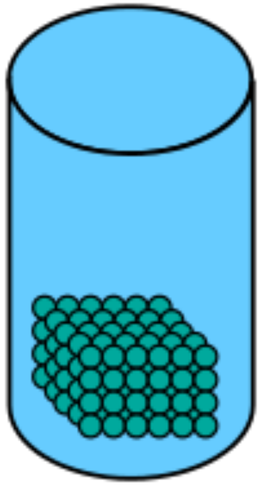

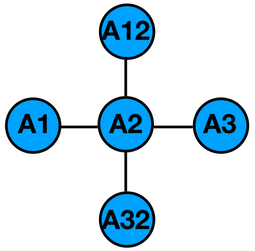

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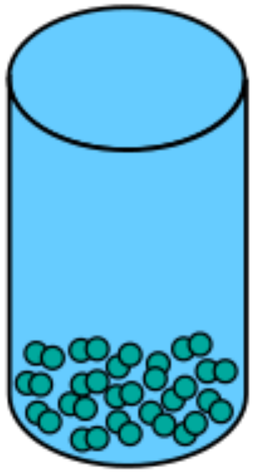

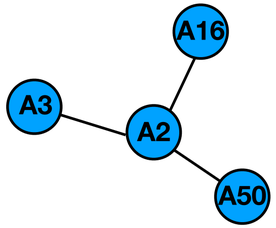

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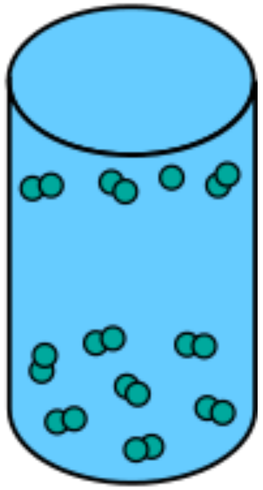

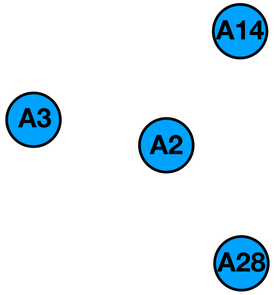

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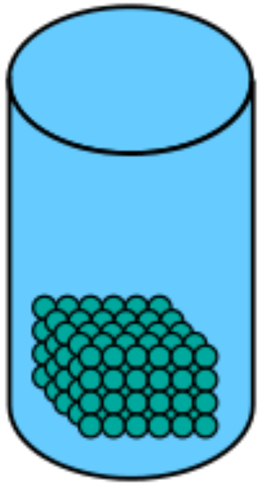
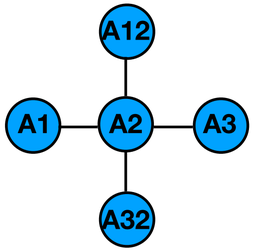
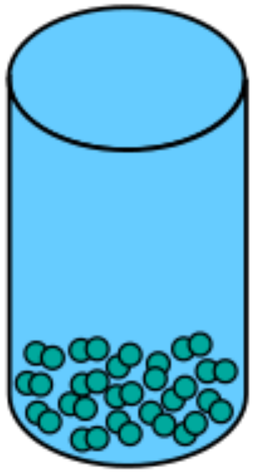
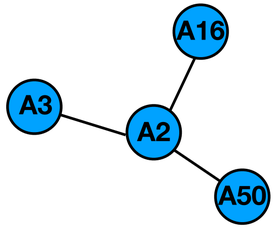




no rewiring

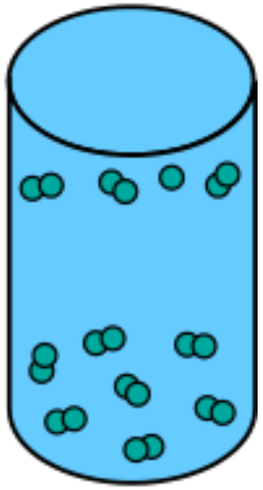
liquid

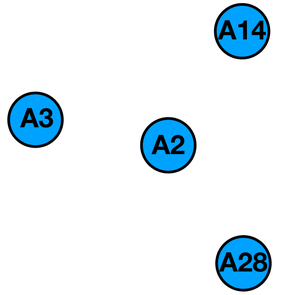




rewiring

gas

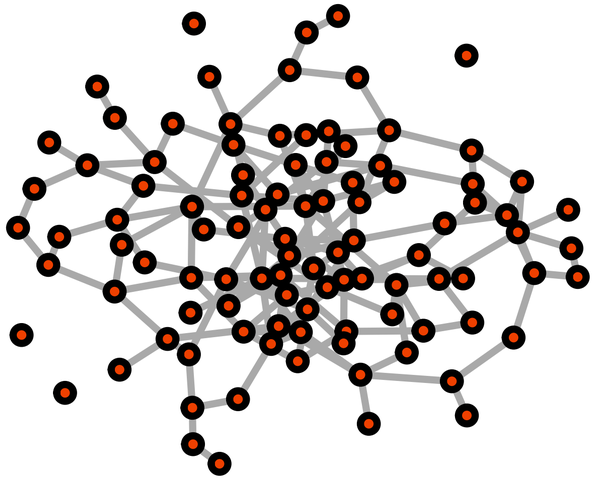




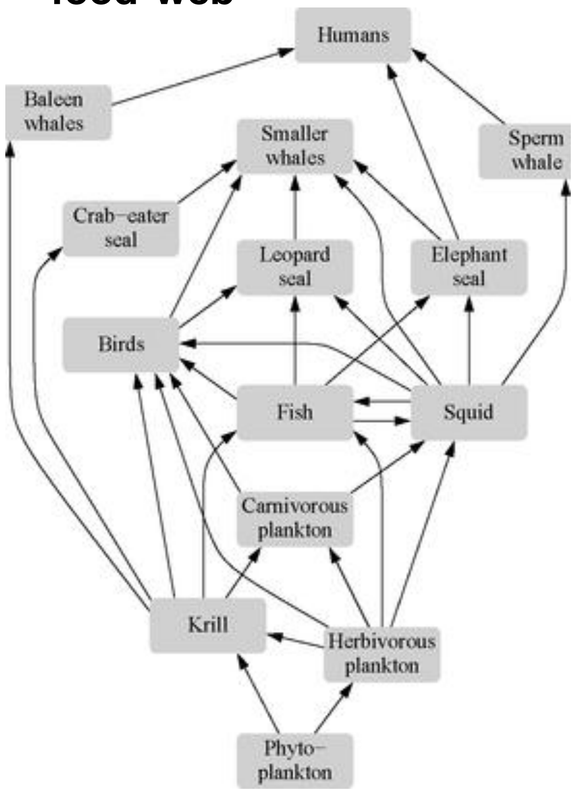
no link

- **information** (sound) and **energy** (heat) propagate differently in the different phases
- once we have defined the **network of interactions** we can model the propagation, e.g., of energy: $\frac{\partial u}{\partial t} = \alpha \frac{\partial^2 u}{\partial x^2}$

From Physics to Network Science



food-web



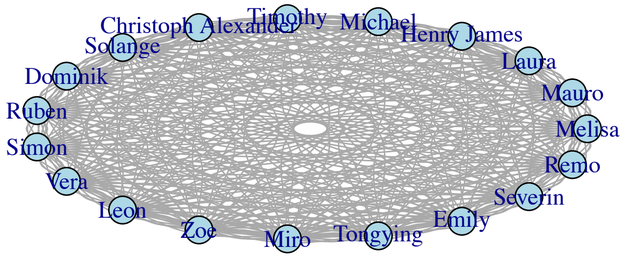
- In **network science** the concept of lattice somewhat dissolves but a distance between notes can can still defined
- **Phases** of **networks** can still defined in terms of connectivity between nodes (giant component)
- Equations of population dynamics or epidemiology can be defined using **networks** as support, for instance Lotka-Volterra or coevolution (see Subhendu's or Leandro's lecture)

from empirical networks
to
models

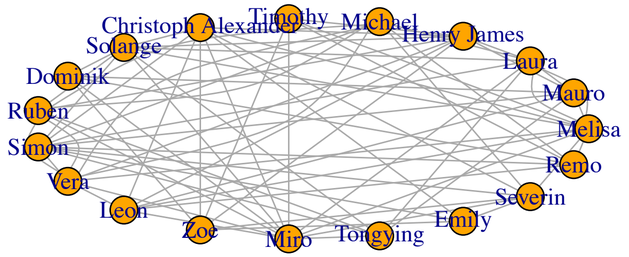
The way we establish links defines the network

student1	student2
Mauro	Miro
Mauro	Tongying
Mauro	Emily
Mauro	Severin
Mauro	Remo
Laura	Melisa
Laura	Mauro
Laura	Henry James
Laura	Michael
Laura	Timothy

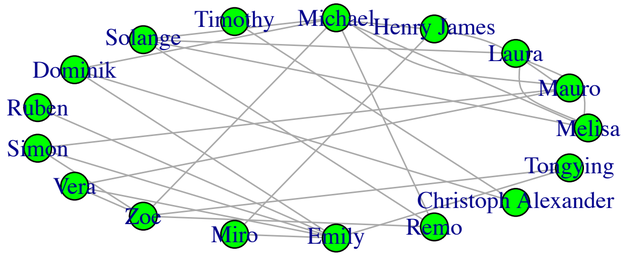
enrolled in OLAT



hypothetical private contacts



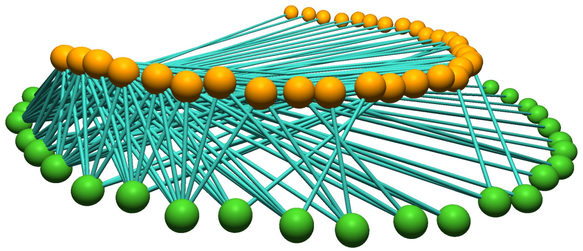
hypothetical friendship



- This is how one builds empirical genetic networks (see Miguel's lecture)
- Removing links progressively is a way to assess network robustness
- In empirical ecological networks we do not record all the actual interactions among species but just those that we are able to detect

Links in ecological networks

In empirical ecological networks we do not record all the actual interactions among species but just those that we are able to detect



From an edge list to a degree distribution

student1	student2
Mauro	Miro
Mauro	Tongying
Mauro	Emily
Mauro	Severin
Mauro	Remo
Laura	Melisa
Laura	Mauro
Laura	Henry James
Laura	Michael
Laura	Timothy

In the process of associating an empirical network to a chosen model necessarily we lose information about some details the original network

1. Configuration model

Given a network with *N* nodes, L links and *degree sequence* $(k_1, k_2, \ldots k_N)$

this model is defined as the possible random rewiring of the network compatible with the same degree sequence

The probability of occurrence of a link between two specified nodes *i* and *j* is

$$p_{ij} = \frac{k_i k_j}{2L - 1}$$

2. Degree distribution

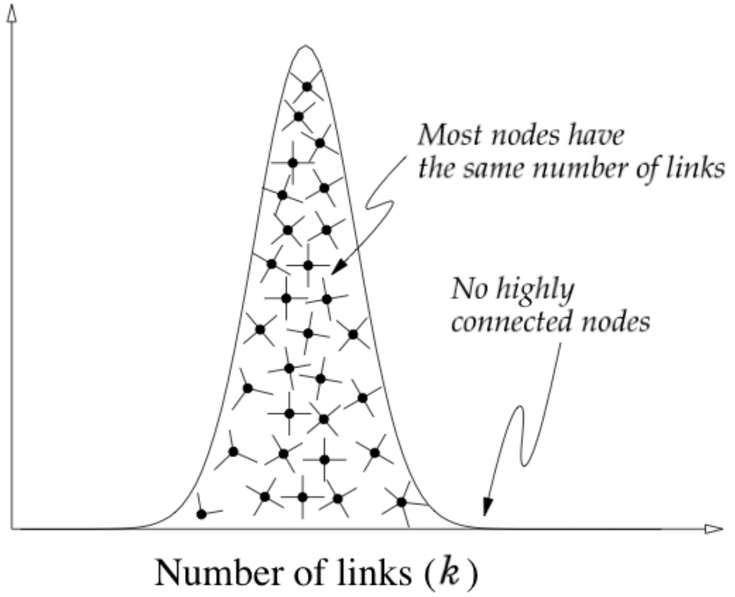
Let n_k be the number of nodes with degree k we define the frequency $P_k = \frac{n_k}{\sum_k n_k}$

to which a probability distribution can be associated $P(k)$

Degree distributions

Erdos Renyi model

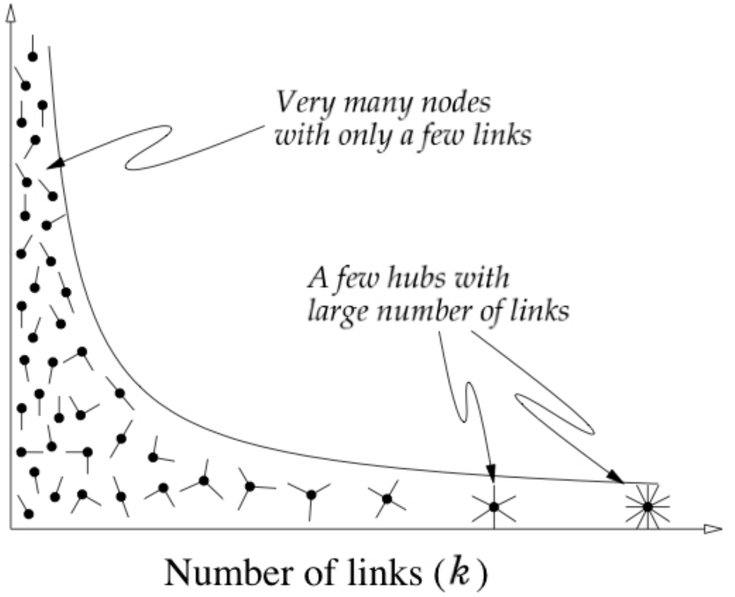
$$P(k) = \binom{N-1}{k} p^k (1-p)^{N-1-k}$$



both $\langle k \rangle$ and $\langle k^2 \rangle$ are finite

Scale free network

$$P(k) = C_0 \frac{1}{k^\gamma}$$

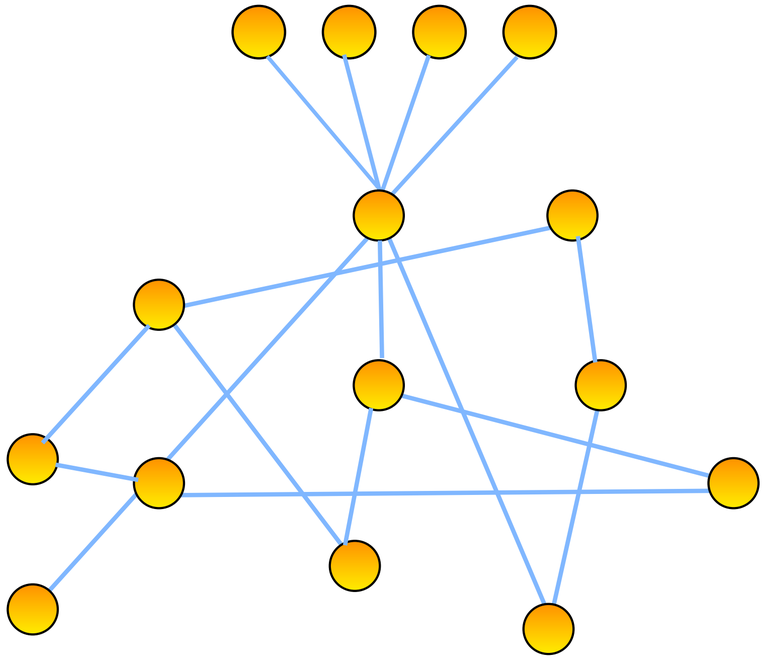


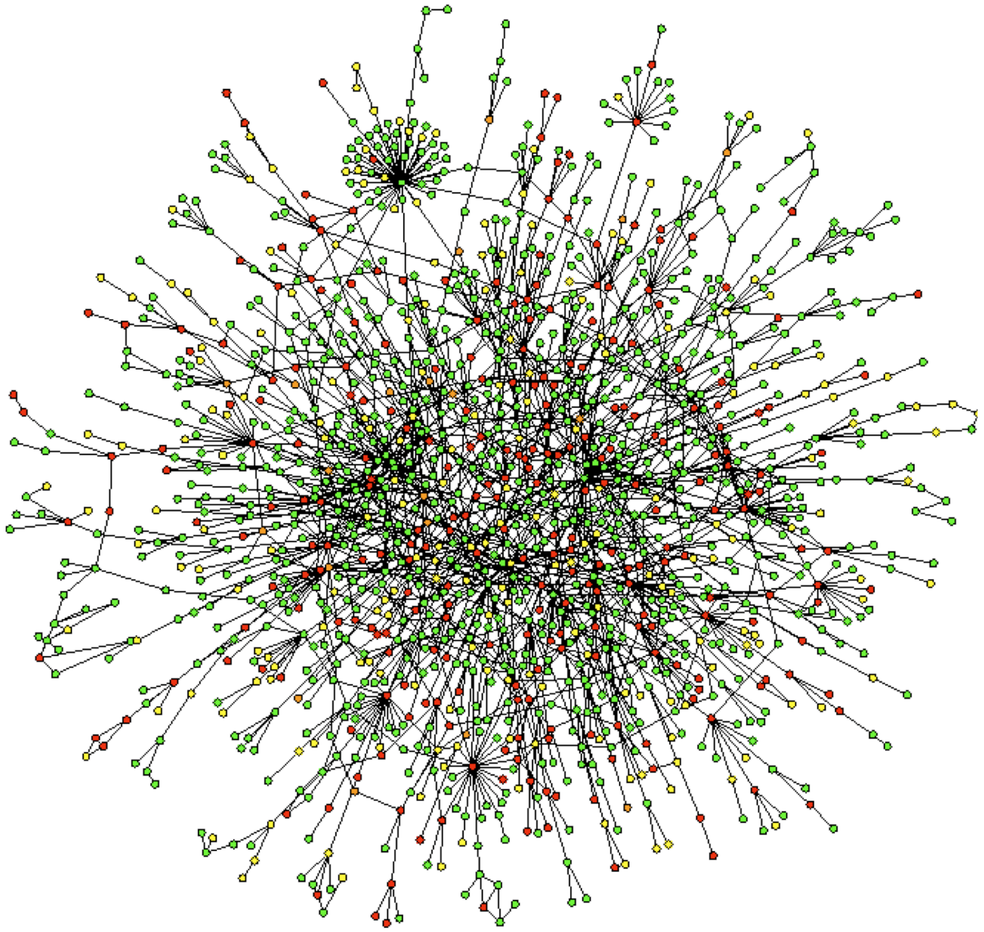
$\langle k \rangle$ finite and $\langle k^2 \rangle$ infinite

for most realistic networks $2 < \gamma \leq 3$

Preferential attachment produce scale-free networks

rich get richer



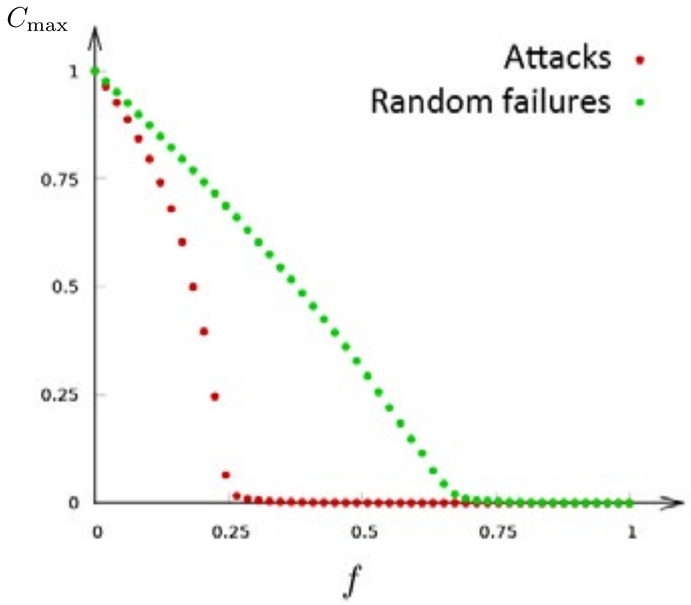


what do we learn
from models

Moments of the degree distributions and robustness

Erdos Renyi model

$$P(k) = \binom{N-1}{k} p^k (1-p)^{N-1-k}$$



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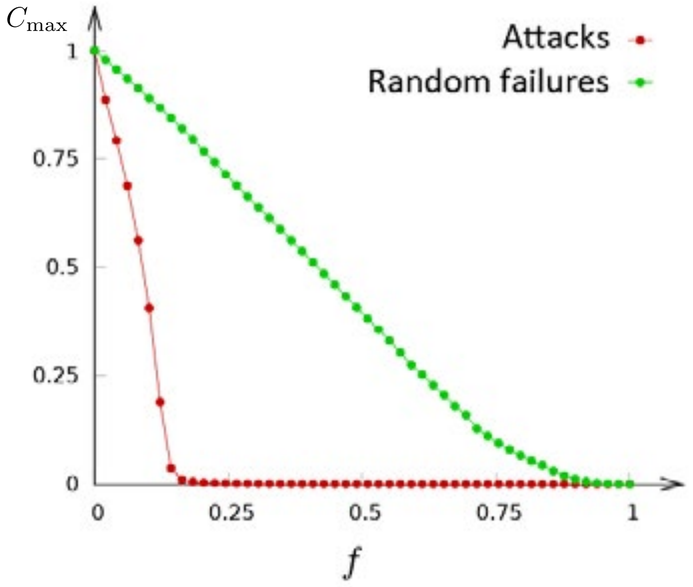
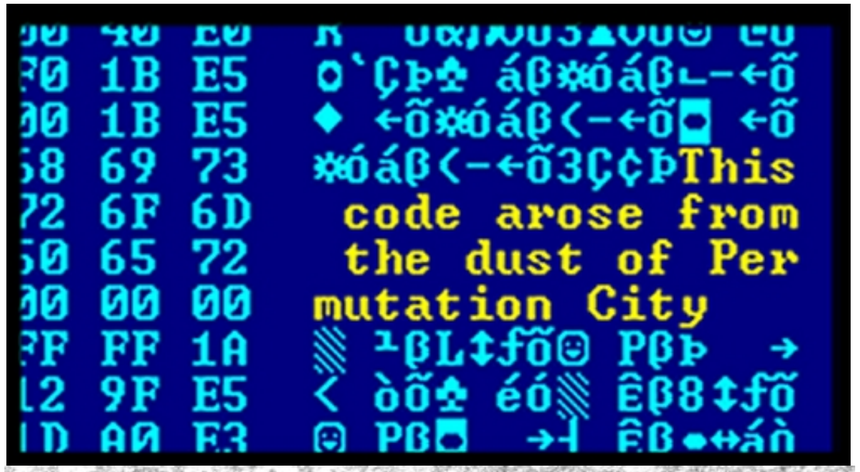
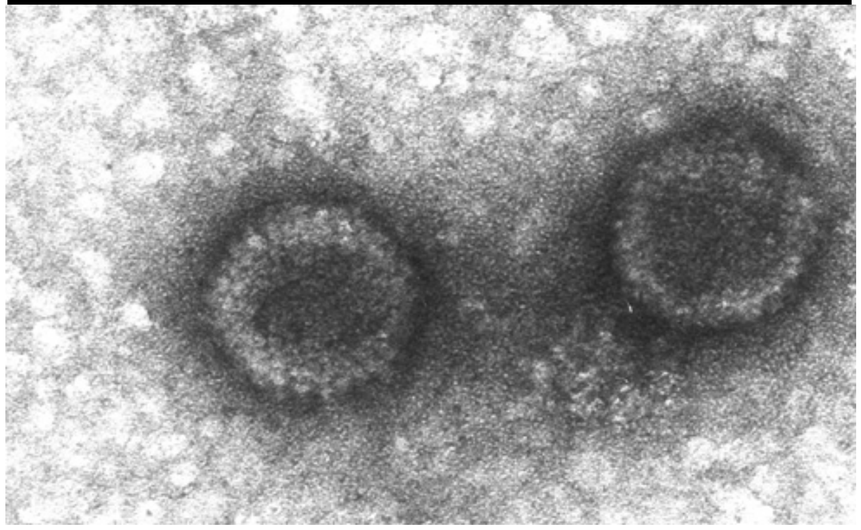


$\langle k \rangle$ finite and $\langle k^2 \rangle$ infinite

How is this related to epidemic threshold of viruses?





infection rate

spreading rate

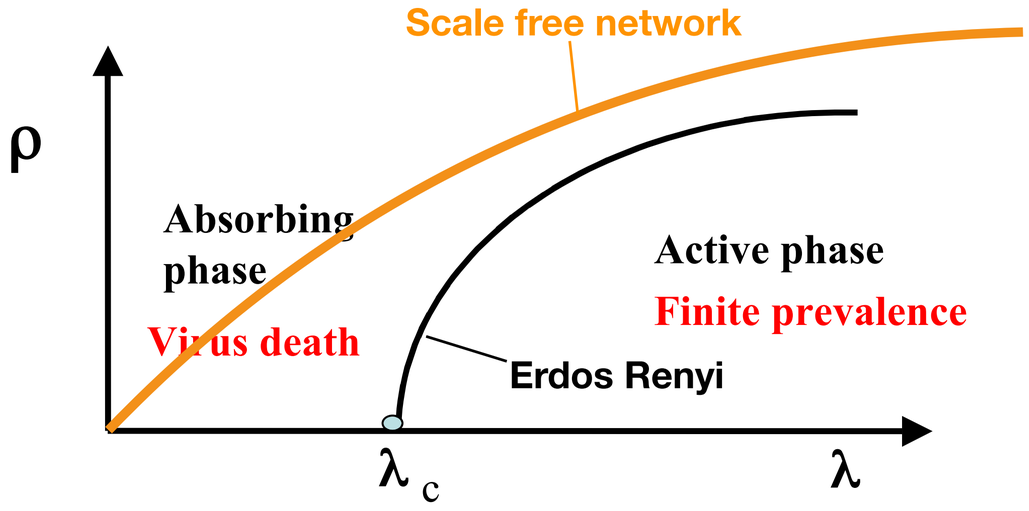
$$\lambda = \frac{\mu}{\delta}$$

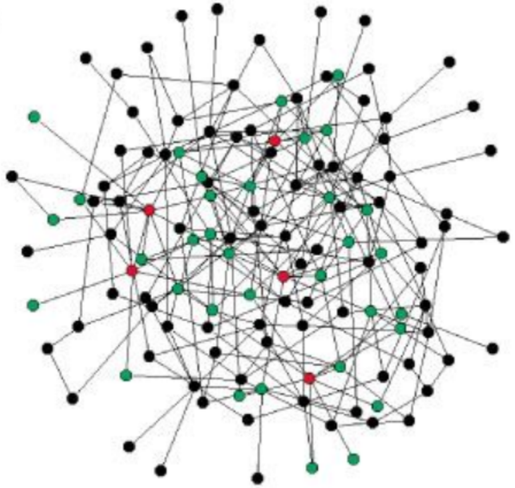
recovery rate

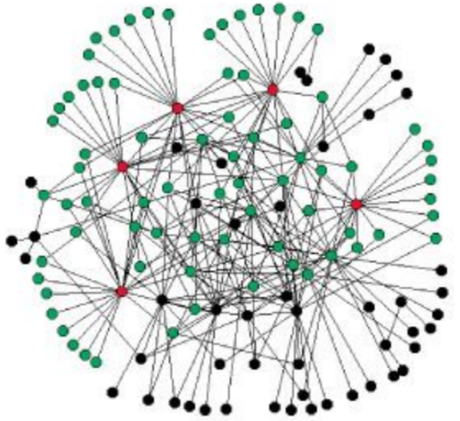
prevalence

$$\rho = 1 - \frac{\delta}{\mu}$$

How is this related to epidemic threshold of viruses?



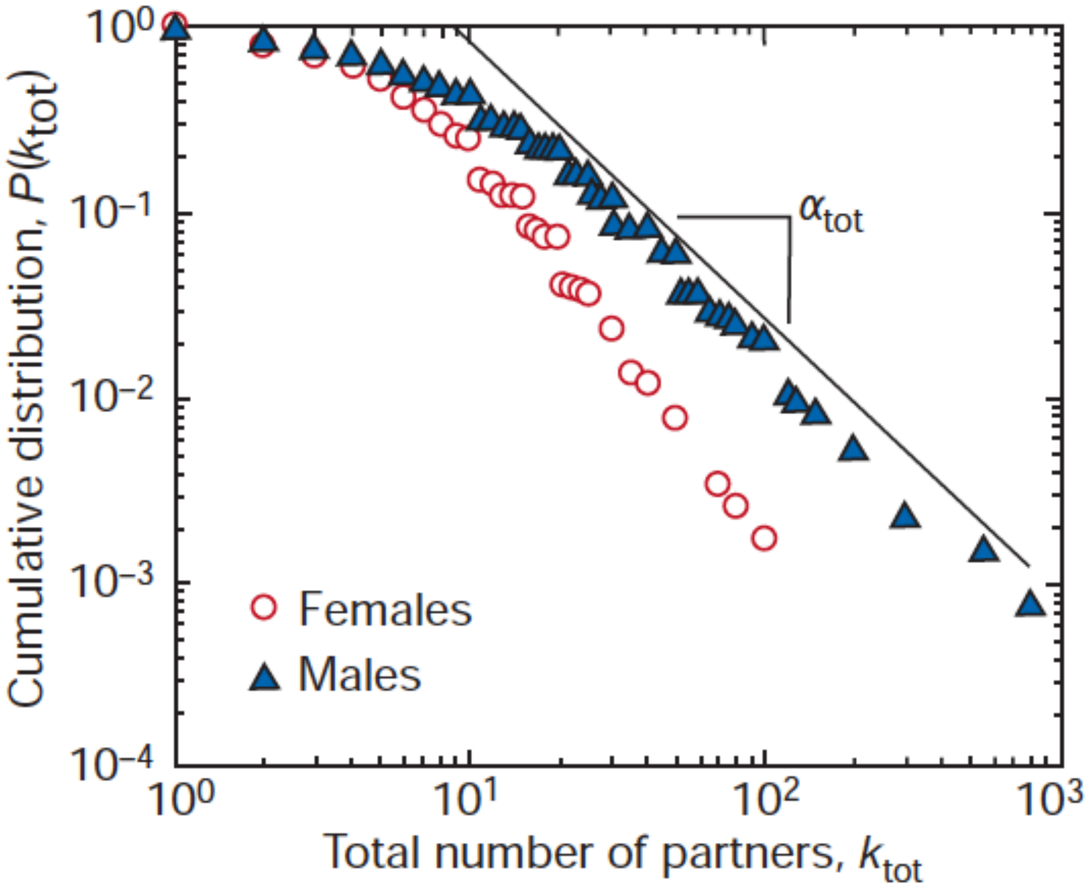


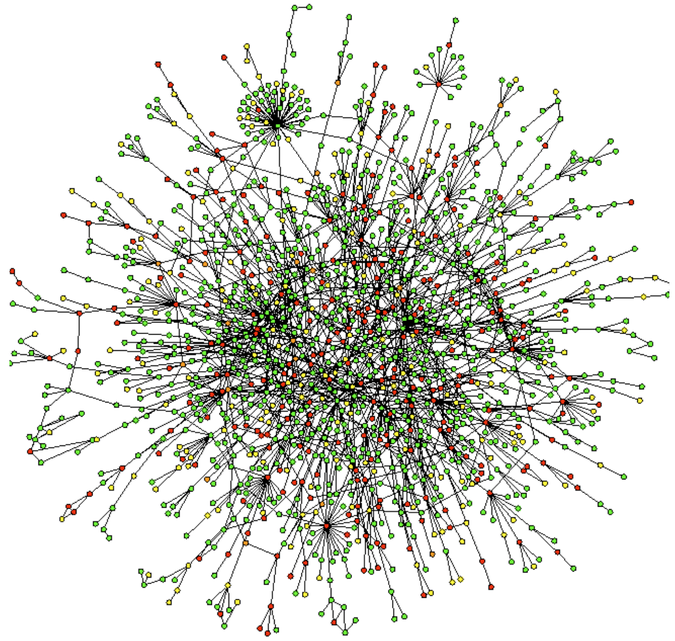


Scale-free

Pastor Satorras and Vespignani (2001)

That explains why sexually transmitted diseases are difficult to eradicate





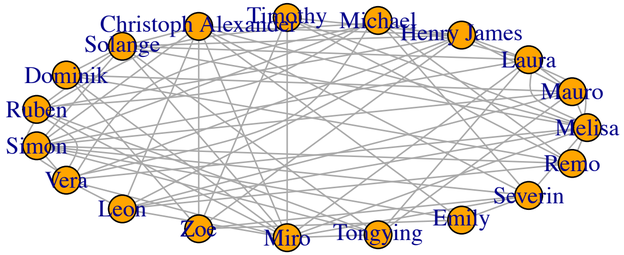
absence of eradication threshold in scale free networks

Lijeros *et al.* (2001)

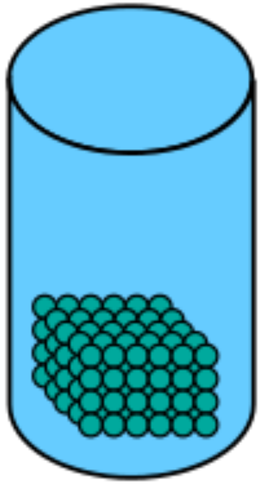
wrapping up:
why the network approach?

From edge list to Chemistry/Physics

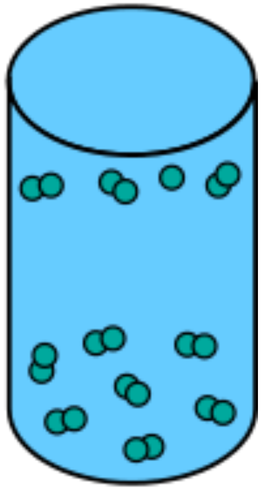
student1	student2
Mauro	Miro
Mauro	Tongying
Mauro	Emily
Mauro	Severin
Mauro	Remo
Laura	Melisa
Laura	Mauro
Laura	Henry James
Laura	Michael
Laura	Timothy

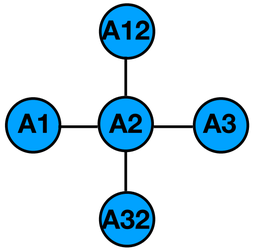


solid



gas





"Chemistry"

node-level metrics

"phase of matter"

"crystal structure"

degree distribution

$P(k)$

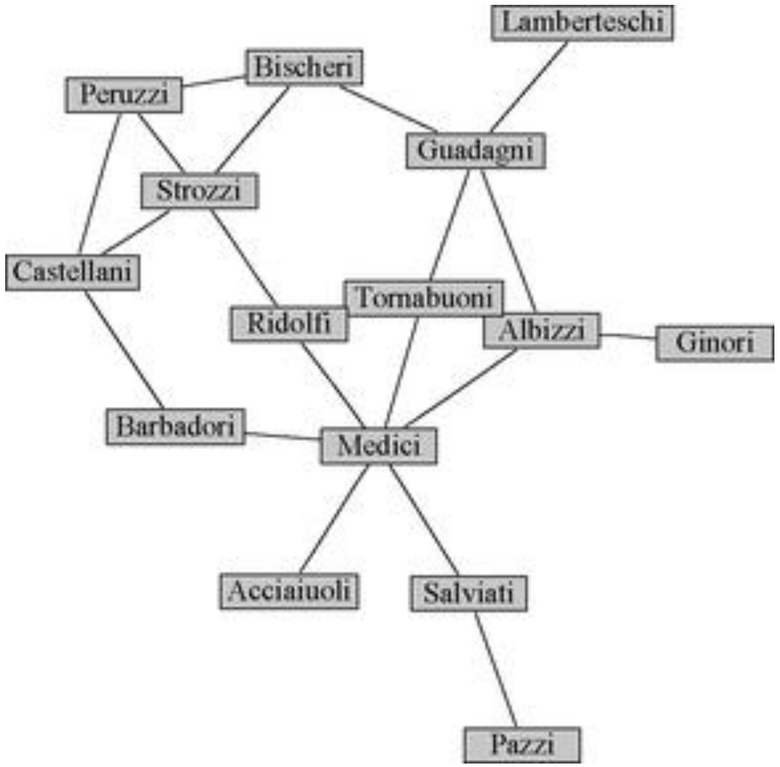
"Physics"

network-level metrics

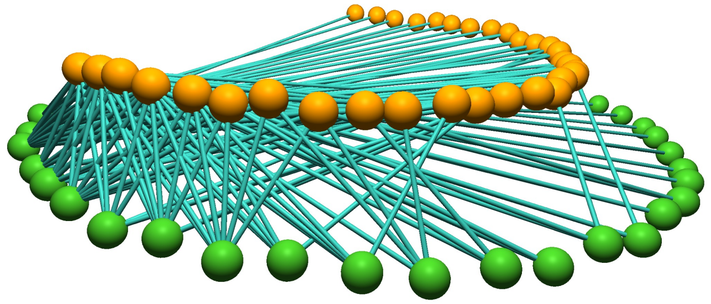
$pV = nRT$

node-level metrics
e.g., Centrality

Q: How much more connected was the Medici family than the Pazzi family?



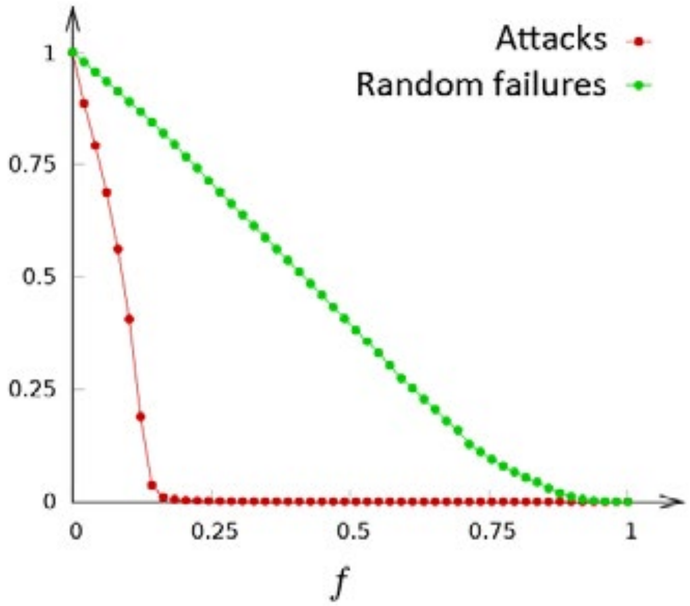
Q: Which species play a **keystone** role in a given ecosystem?



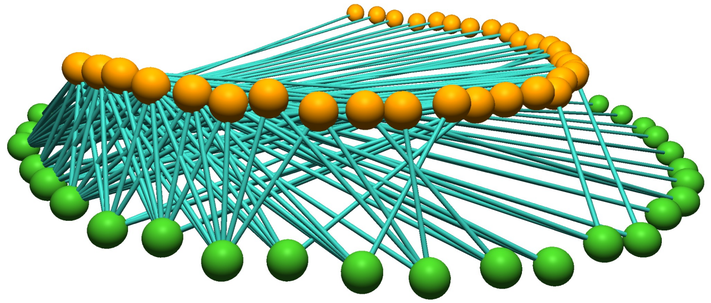
network-level metrics

e.g., critical fraction

Q: How many routers can stop working till the functionality of internet is affected?



Q: How many species
a) can go extinct till an ecosystem collapses?
b) should be reintroduced to restore an ecosystem?



network-level metrics

e.g., critical fraction

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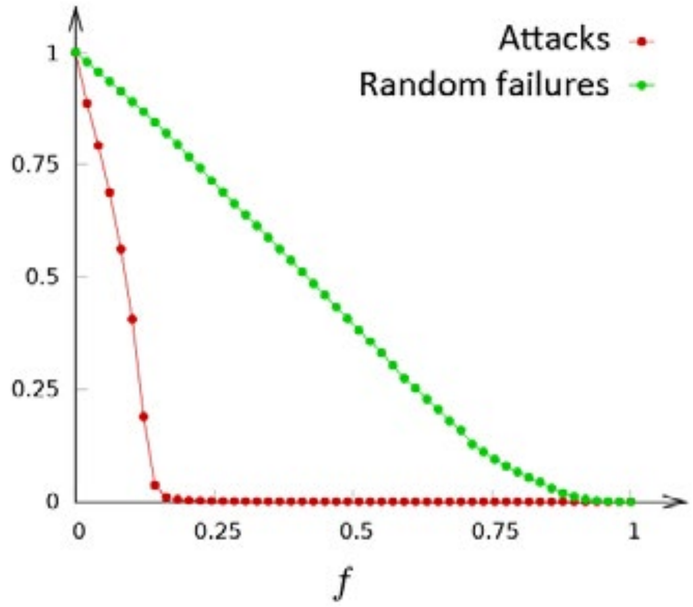

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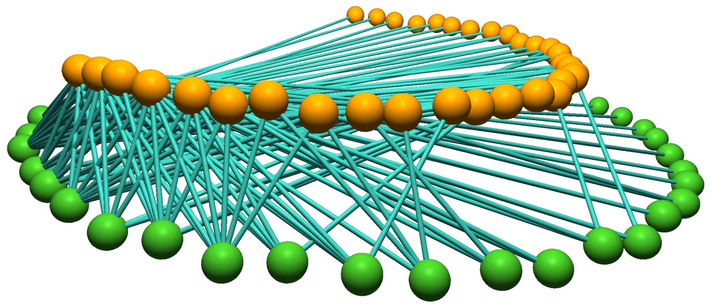

Modeling always implies some degree of randomization, namely loss of details
=> network properties can be related to features of the degree distribution

critical fraction $f_c = 1 - \frac{1}{\frac{\langle k^2 \rangle}{\langle k \rangle} - 1}$

$C = \frac{1}{N} \frac{\left[\langle k^2 \rangle - \langle k \rangle\right]^2}{\langle k \rangle^3}$ **network-level centrality**

24FS BIO365 Ecological Networks

			Thursday March 14	Friday March 15		Tuesday March 19	Wednesday March 20	Thursday March 21	Friday March 22		Tuesday March 26	Wednesday March 27	Thursday March 28		Tuesday April 9	Wednesday April 10	Thursday April 11	Friday April 12
From	To																	
10:15	12:00	LECTURE	Outline and Introduction	The role of species in networks			Topological patterns in ecological networks	Null models	Network robustness			Models of ecological dynamics	Genetic networks			Spatial networks	Coevolution	Open time
	Speaker		Vindigni	Cosmo			Cosmo	Pedraza	Vindigni			Bhandary	Roman			Gawecka	Cosmo	
12:00	13:00		Lunch	Lunch		Lunch	Lunch	Lunch	Lunch		Lunch	Lunch	Lunch		Lunch	Lunch	Lunch	Lunch
	Instructor(s)	EXERCISE	Vindigni	Roman		Knop Grognuz	Bhandary Vindigni	Pedraza	Vindigni		Gawecka Vindigni	Bhandary	Roman		Gawecka Vindigni	Gawecka	Cosmo	Vindigni
13:00	17:00		Toolkit for network analysis	Species-level metrics		Sampling an ecological network	Network-level metrics	Null models	Measuring network robustness		Distribute papers students' short talks	Models of ecological dynamics	Analyzing genetic networks		Students' short talks	Comparing networks in space	Models of evolution	Single-choice exam

Thank you!