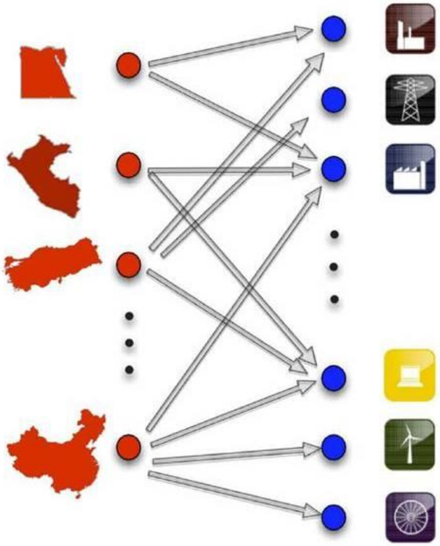
From bees and flowers to international trade networks (and other economical systems)

A complex network approach to economical systems

Laura Hernández



Plan of the talk

- Introduction: what are we (physicists) doing here?
- What is a complex system? And why do we care about them?
- Complex Networks: a useful tool to study complexity
- Mutualistic ecosystems. The notion of nestedness.
- Applications to economical systems: import-export networks, industry location networks,
- Perspectives/discussion

Why?

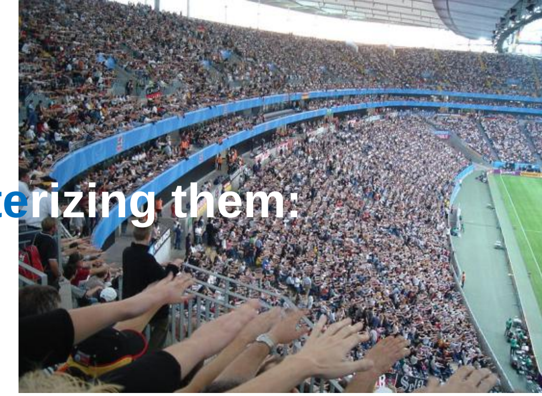
- We are interested not only in the objects but in *the processes*.
  Theories of Phase Transitions and Critical Phenomena.
  Notions of scaling, universality, renormalization.

- Awareness of the pertinence of the scale at which the phenomena are described.

  YES, we are aware that humans are different from electrons...

- Notion of "model": same word naming different concepts in physics and in other disciplines (eco, bio)

What is a complex system?



Lack of a unique definition, but a list of properties characterizing them:

- Number of elements: many, in general
- Type of interactions: non linearity, high correlations
- Emergent behaviour : self organization

no leader
no plan
no master

- No hint about this organization by studying the properties of the components (the whole ≠ sum of the parts)

- Multiscale phenomena, interaction between different scales.
- Feedback loops

A complex economical system

Easier to say what is not...

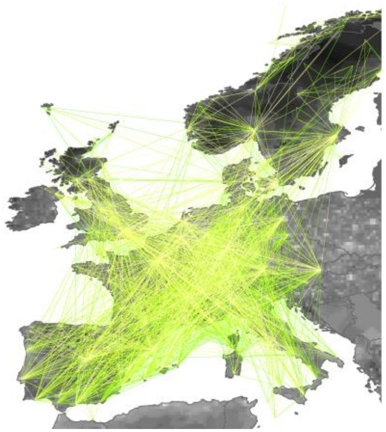
Complex ≠ Complicated !

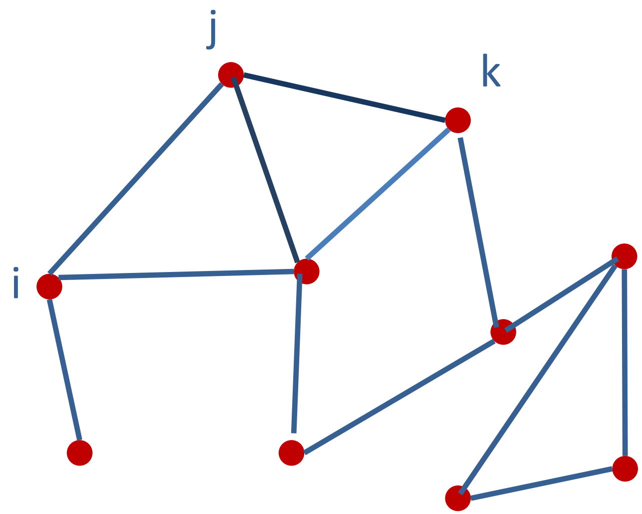
Complex Networks

Abstract mathematical representation to account for very different systems in very different domains:

- nodes (vertices) → elements of the system
- links (edges) → interactions between the elements

airport connections



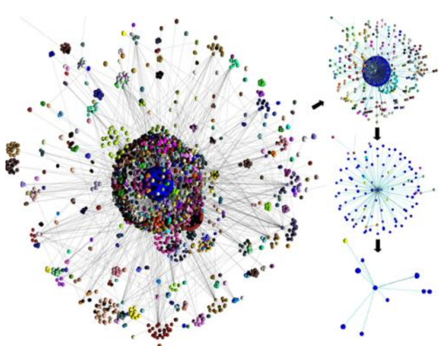


social links

<u>Adjacency matrix</u>

$$A_{ij} = \begin{cases} 1 & \text{if i and j connected} \\ 0 & \text{otherwise} \end{cases}$$

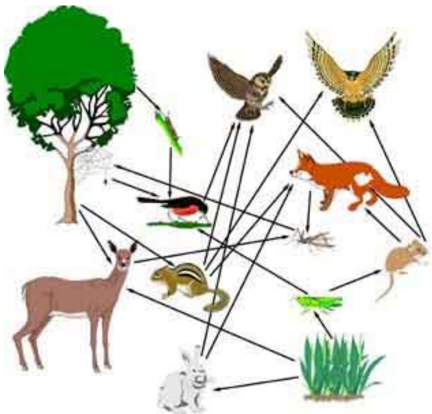
www network



Different types:

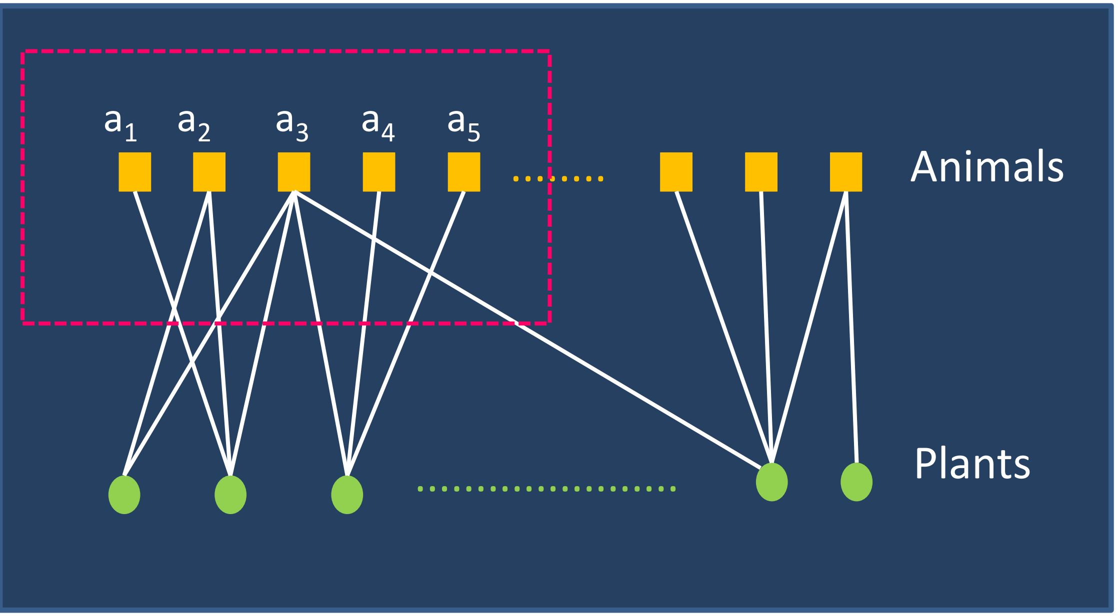
- symmetric
- weighted
- directed

trophic network

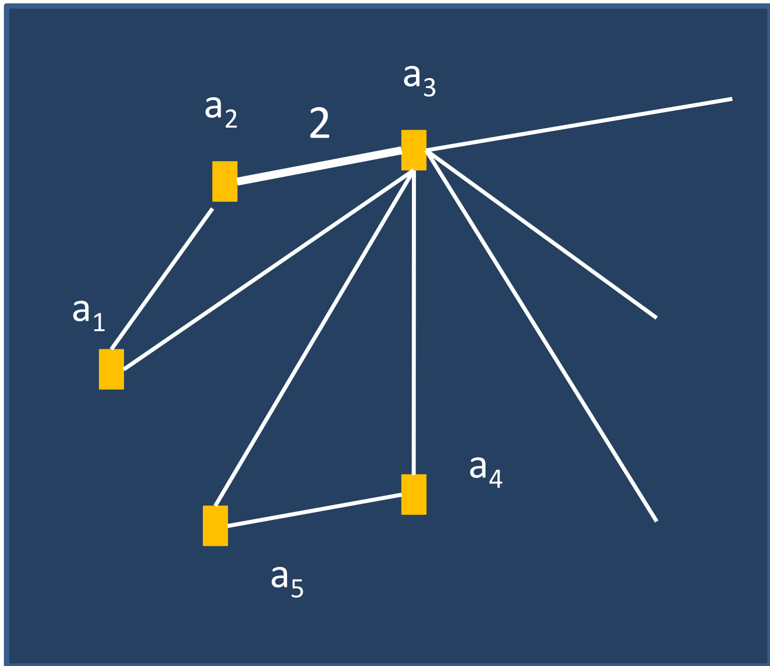


Mutualistic ecosystems

Bipartite networks (adjacency matrices): two different kinds of vertices (animal and plant species); interactions only allowed between vertices of different kind



Projected graph in the animal sub-space → weighted network



$$K_{p,a} \in \{0,1\}$$

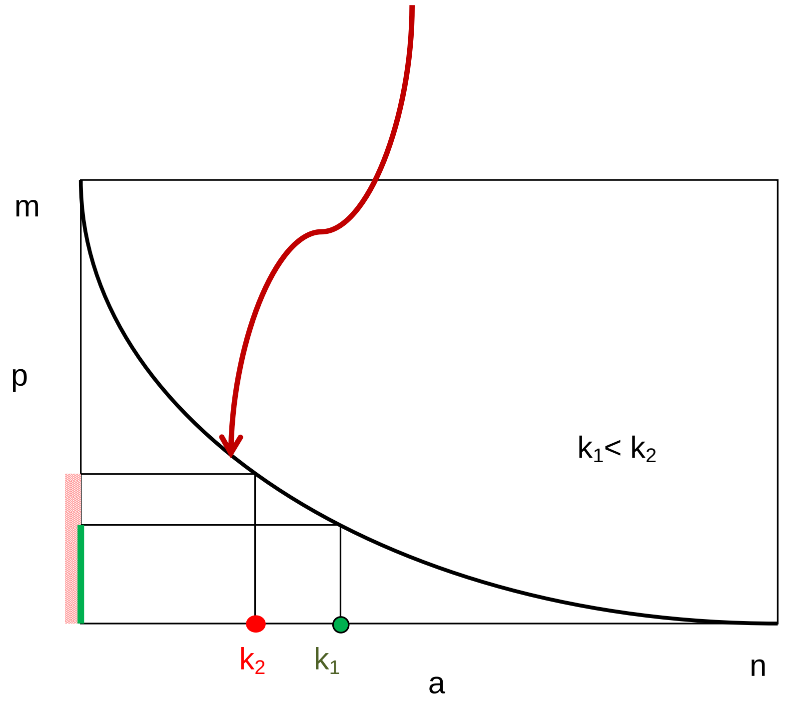
$$D^P(p) = \sum_{a=1}^{n} K_{p,a}$$

Nestedness

Ordering the matrix by decreasing degree of one guild, → same order for the other guild.

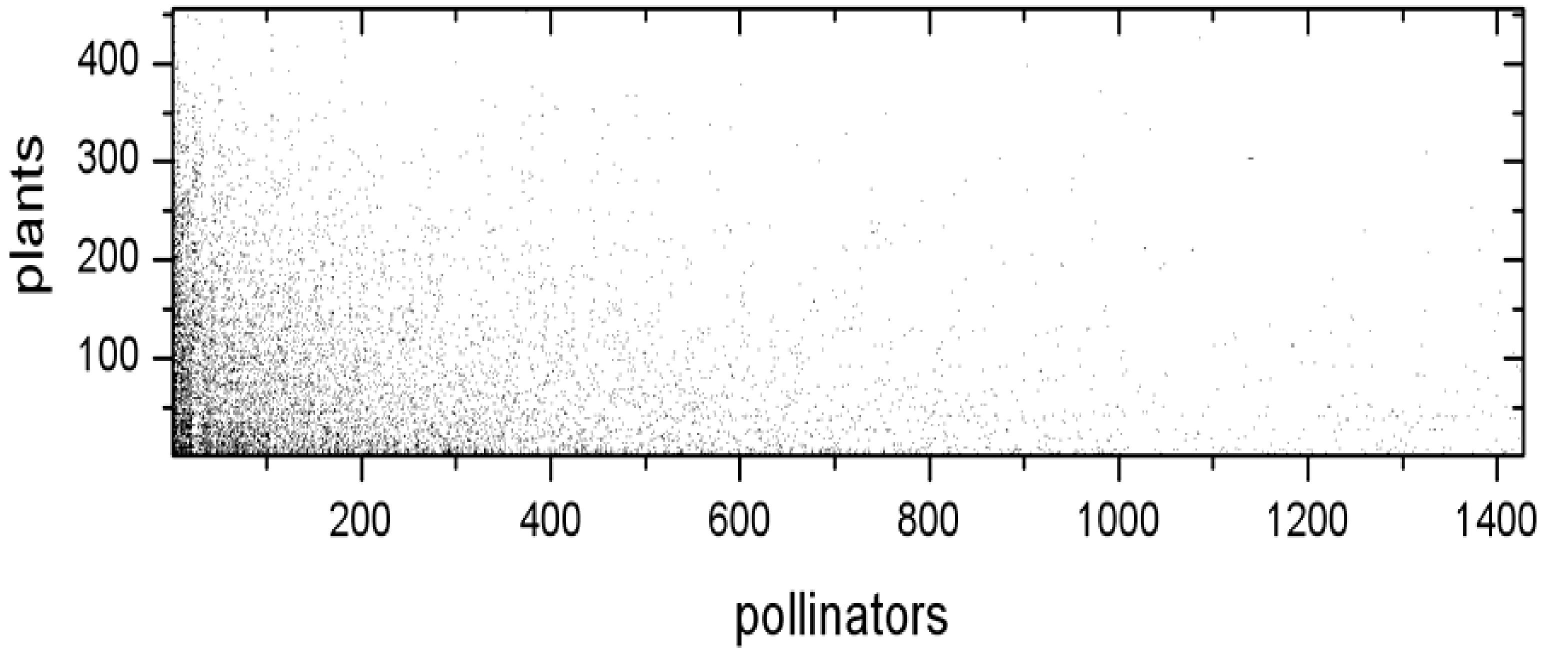
For a perfectly nested system (ordered): the set of plant (animal) species associated to a given animal (plant) is included in the set of plant (animals) species associated to the previous ones.

IPN: isocline of perfect nestedness,
f(n,m,ϕ), with ϕ: density of contacts



A natural system

C. Robertson, Science Press Company, Lancaster, Pennsylvania, USA (1929)



The ecosystem is composed of “specialists and generalists” species

First measurement of nestedness:

Atmar-Patterson « temperature » (T_{AP})

(Oecologia 96,373 (1993) , The Nestedness Temperature Calculator, AICS Research Inc. University Park, NM and The Field Museum Chicago (1995))

Measuring nestedness

- **Atmar and Patterson « temperature » (APT) :** A geometrical characterization of the adjacency matrix that measures the departure of the real system from the IPN.
APT ~ 0 indicates a nested system while APT ~ 100 correspond to a disordered system.

Problem: T_{AP} very sensitive to the n/m ratio, the density of contacts...

- **An operational nesting coefficient based on robustness.**

Burgos, Ceva, LH, Perazzo, Comp. Phys. Comm. **180** 532 (2009)

The system can suffer from ***random*** or ***targeted*** attacks

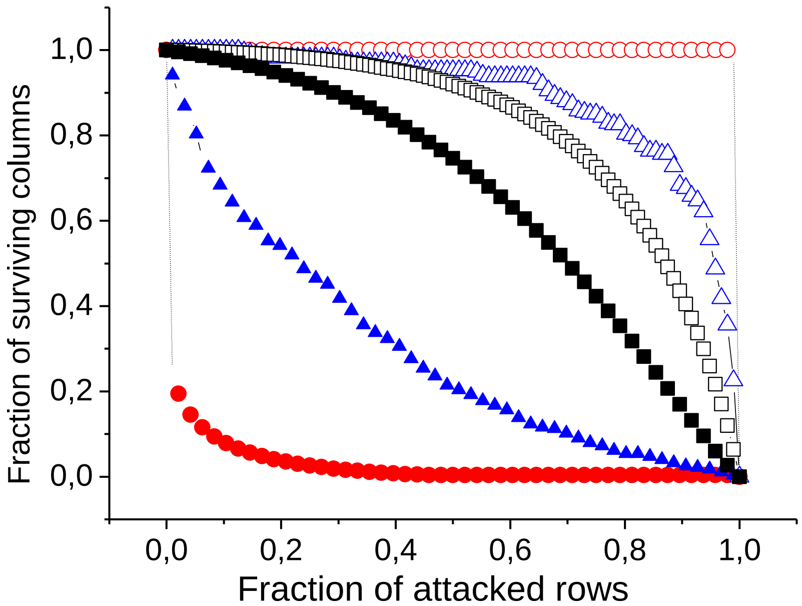
For an ordered system, two extreme targeted strategies

- Starting from the smallest k (- →+)
- Starting from the largest k (+ →-)

The resistance of the system to the attack (robustness of the network), depends on its organisation → it can be used to measure its degree of order

Attack tolerance curve (ATC):

It gives the fraction of survival species as a function of the fraction of the attacked counterpart: $f_s(f_k)$



● : perfectly nested, ■ : random state, ▲ : real system

Attack strategy

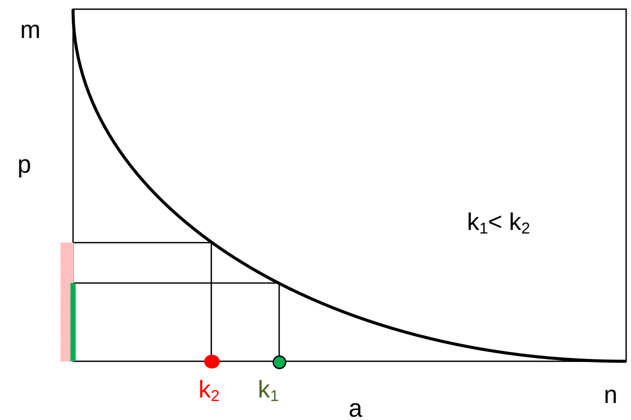
Open symbols: $(- \rightarrow +)$

Full symbols: $(+ \rightarrow -)$

Robustness coefficient

$$R^{+\to-(-\to+)} = \int_0^1 f_s(f_k)\,df_k$$

for a perfectly nested system



one obtains:

$$R^{-\to+} = 1 \quad \text{and} \quad R^{+\to-} = \phi$$

The nesting coefficient

$$N_{c(r)} = \frac{R_{c(r)}^{-\to+} - R_{c(r)}^{+\to-}}{1-\phi}$$

N=1 for perfectly nested system

N<<1 for random system

Some values for real systems

Adjacency matrix	ϕ	T_{AP}^{*}	N_c	N_r
Clements	*3.4%*	*0.16*	*0.61*	*0.49*
Robertson	*2.3%*	*0.06*	*0.65*	*0.58*
Kato	*1.9%*	*0.11*	*0.75*	*0.57*

Why nestedness? The SNM Algorithm

Medan, Perazzo, Devoto, Burgos, Zimmermann, Ceva, Delbue, Journal Theor. Biol. **246** p510, (2007)
Burgos, Ceva, Perazzo, Devoto, Medan, Zimmermann, Delbue, J.T.B. **249,** p307, (2007)
Burgos, Ceva, L.H., Perazzo, Devoto, Medan, Phys Rev. E, **78, p**046113 (2008)

Objective:

Trial of different dynamical rules and their corresponding equilibrium states

inputs: n,m , density of contacts (ϕ), random initial adjacency matrix.

Basic requirements:

- Local rules.
- Description of the partially ordered situations found in nature
- Asymptotical approach to the perfectly nested state given by the corresponding IPN.

Basic Assumption:

The number of interacting species is fixed $\longrightarrow$ No extinction is allowed

Contact Preference Rule (CPR)

The allocation of contacts will be performed according to the CPR to be tested:

- SNM-I : a swap is accepted if the new counterpart's degree ***is higher than*** the old one
- SNM-II : a swap is accepted if the new counterpart's degree ***is lower than*** the old one

General remarks

- ***Biological plausibility:*** SNM-I promotes the contact with generalists (enhanced competition vs. increased efficacity and longevity)

- ***SNM-I and preferential attachment*****:** No growing process here, and completely local rule.

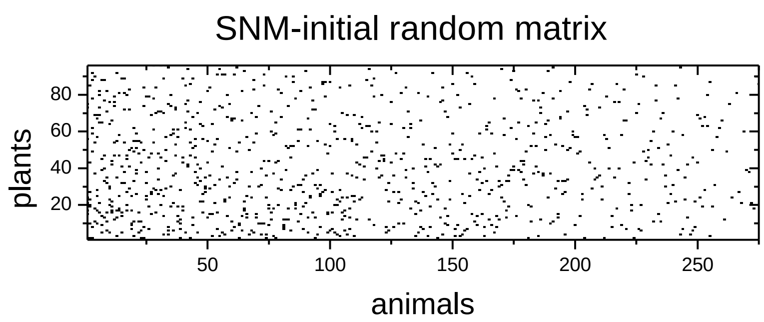
1-step of the SNM dynamics

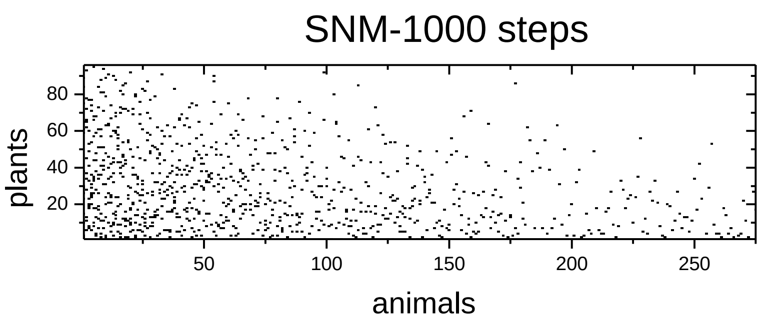
1. choose alternatively a row (column) at random
2. in that row (column) locate two columns (rows): one with 0 and the other with 1
3. perform a swap between 0 and 1, provided the CPR is verified
4. choose a row (column) at random and continue iterating

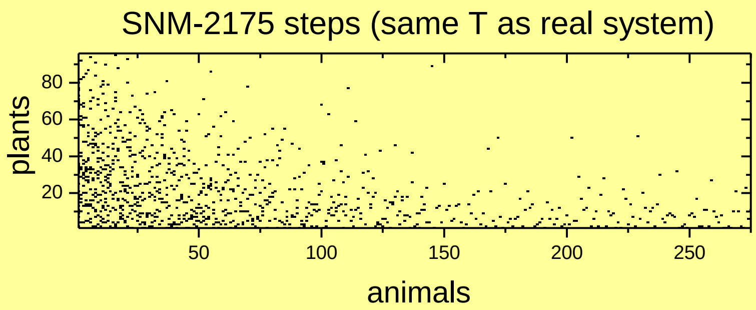
Stopping criteria

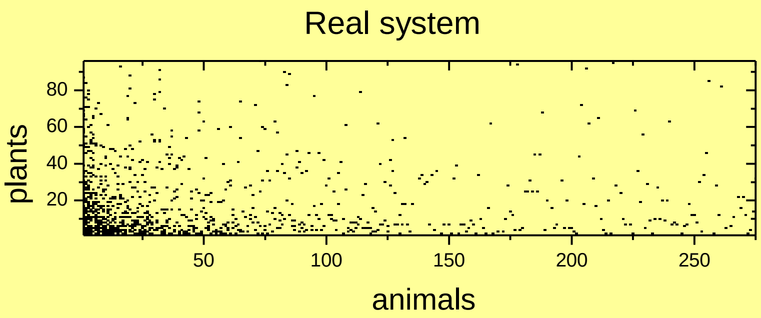
- Same T_{AP} as the corresponding real system
- Agreement with the degree distribution of the real system

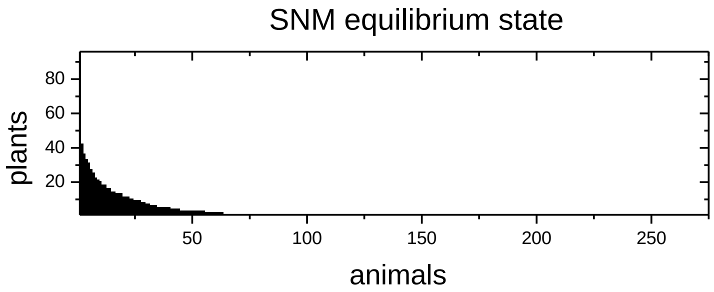
SNM-I / Clements and Long system





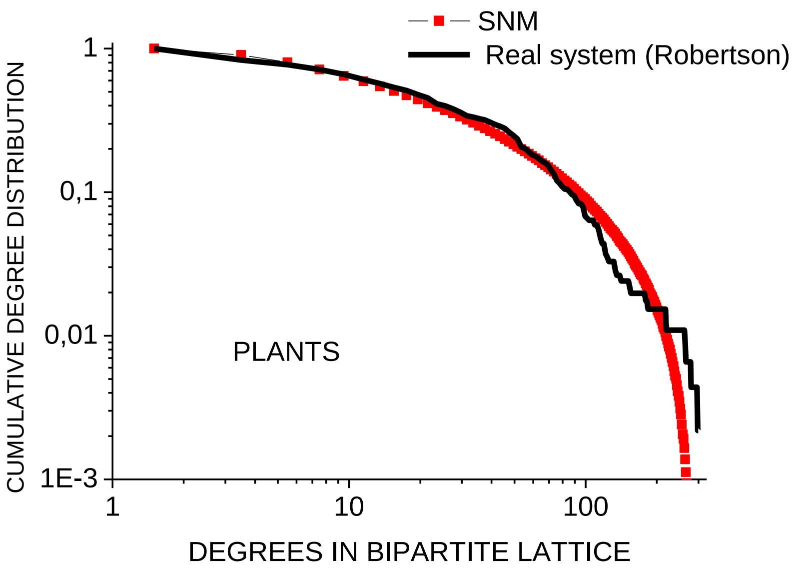


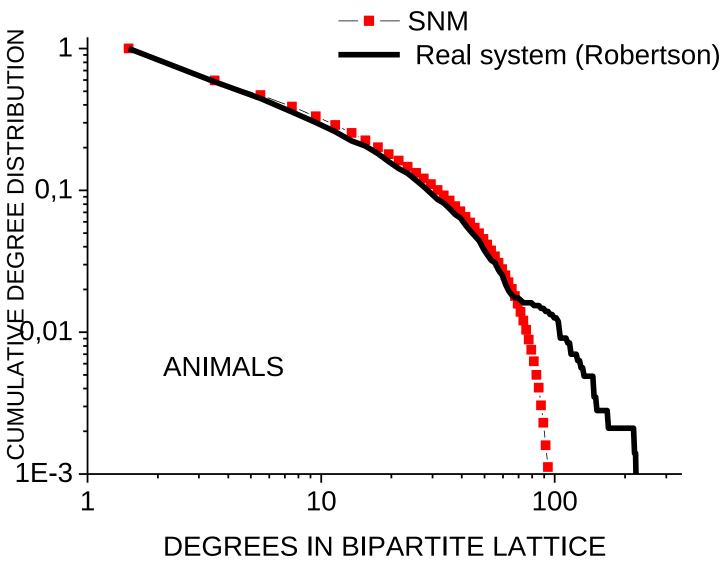




Degree distributions

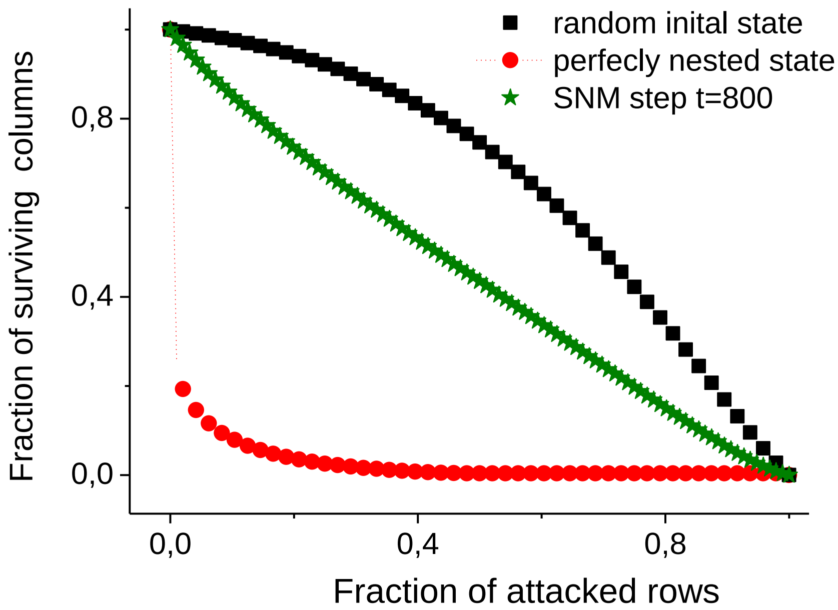
Comparison between real and simulated system:



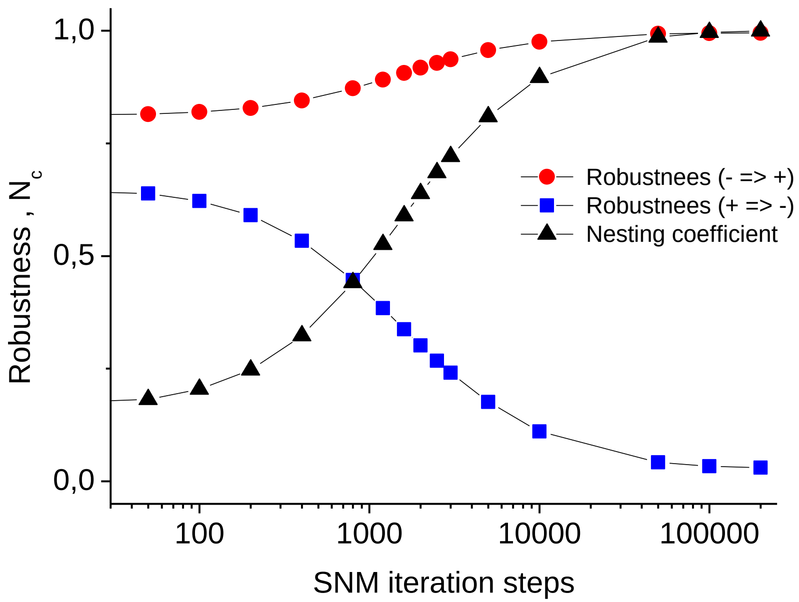


Transition from the initial random state to the ordered nested state

ATC



Robustness, nesting coefficient



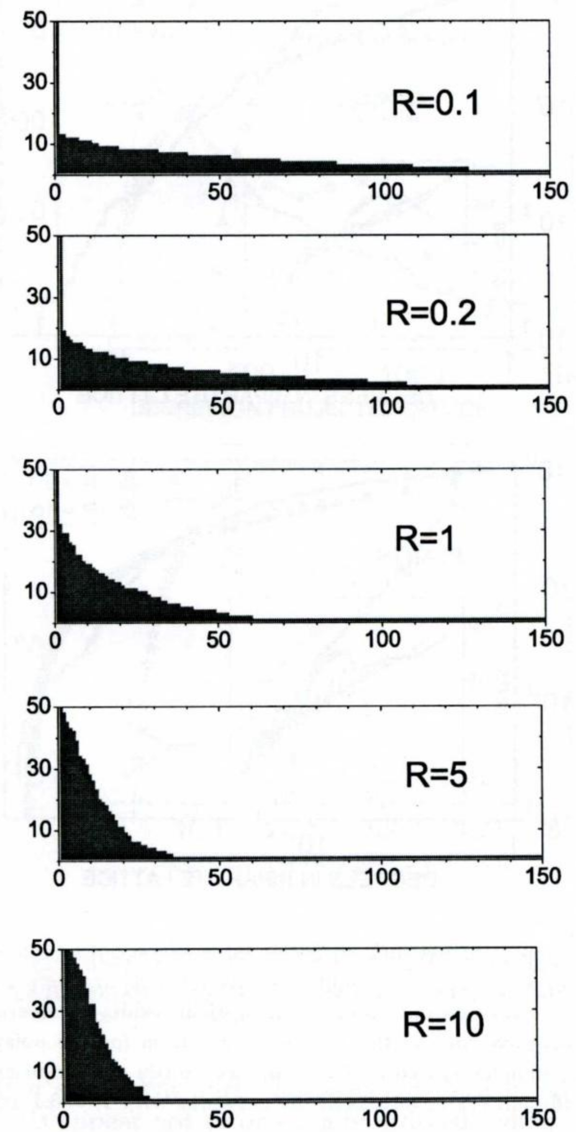
in all cases, averages over 200 initial random networks

Asymmetric SNM: model for mutalistic social systems

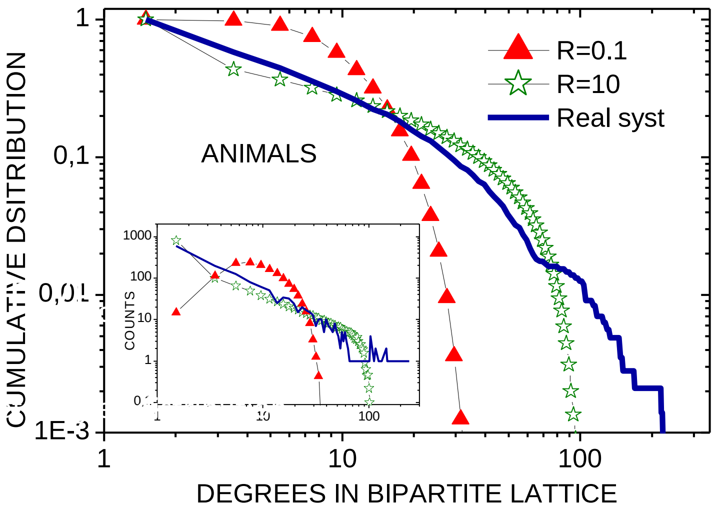
Burgos, Ceva, LH, Perazzo, Devoto, Medan Phys Rev E, **78** 046113 (2008)

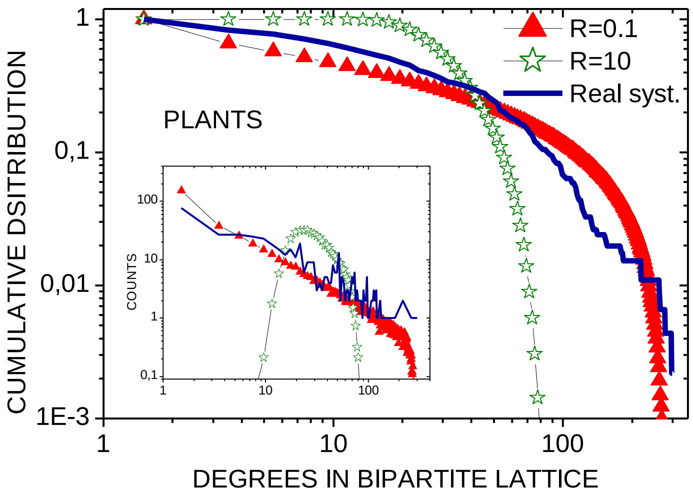
$R=P_r/P_c$, P_r , P_c updating frequency of rows and columns respectively

5×10^6 iterations, all converged



The asymmetric SNM: ecological vs. social systems





Economical Complexity

Basic Ideas:

“The Atlas of Economic Complexity “: Hausmann, Hidalgo, et al. Harvard (pdf online)

raw materials + machines + labour

Products

knowledge:

direct : related to individuals (learnt in books, school...)

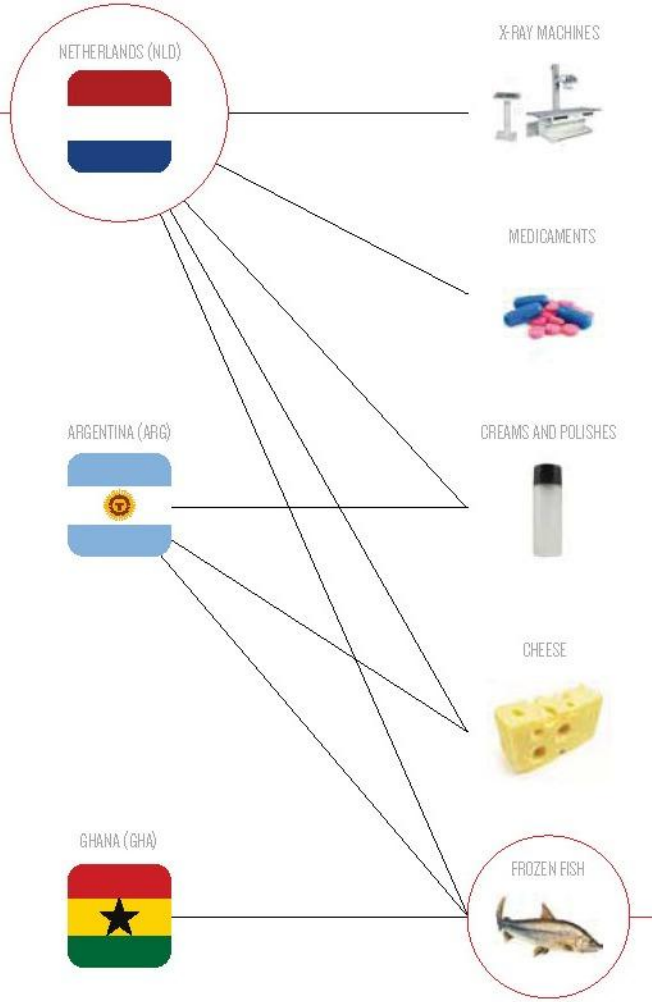
tacit: embedded in society

The amount of knowledge embedded in a society does not solely depend on the amount of knowledge each individual holds. It mainly depends on the interactions among those individuals: their ability to combine this knowledge to make use of it → ***complexity***

The complexity of an economy is related to the multiplicity of useful knowledge embedded in the society. This is reflected in the society’s productive output.

Bipartite Network's approach

diversification
of a country

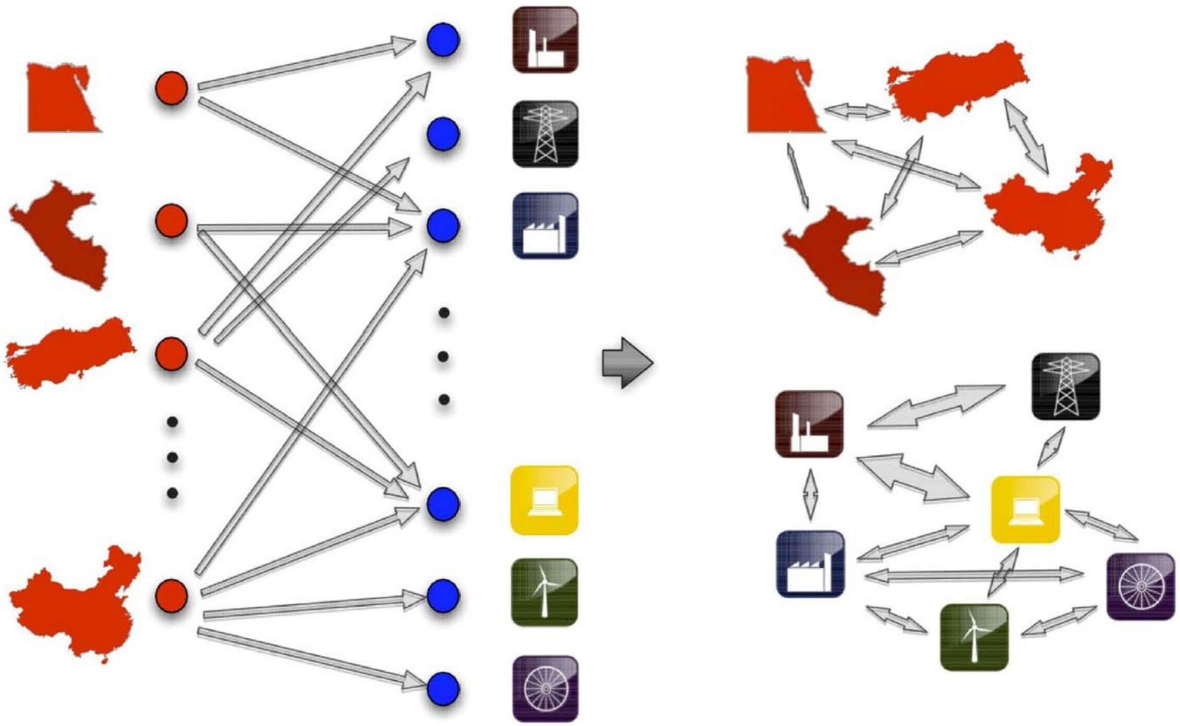


Bipartite matrix: $M_{cp} \in \{0,1\}$

ubiquity of
a product

important : not only how many but which one?

Tools for analysing bipartite networks : The projected networks



$$W^{C}_{c,c'} = \sum_{p} K_{c,p} K^{T}_{p,c'} (1-\delta_{c,c'})$$

$$W^{P}_{p,p'} = \sum_{c} K^{T}_{a,p} K_{c,p'} (1-\delta_{p,p'})$$

Tools for analysing bipartite networks : the reflection method

The degree of each country (a) or product (α) in the bipartite matrix :

$$k_{a,0} = \sum_{\alpha} M_{a\alpha} \qquad \kappa_{\alpha,0} = \sum_{a} M_{a\alpha} \qquad (1)$$

One can build the following N-iteration process:

$$k_{a,N} = \frac{1}{k_{a,0}} \sum_{\alpha} M_{a\alpha} \kappa_{\alpha,N-1} \qquad \kappa_{\alpha,N} = \frac{1}{\kappa_{\alpha,0}} \sum_{a} M_{a\alpha} k_{a,N-1} \qquad (2)$$

The first terms are easy to interpret:

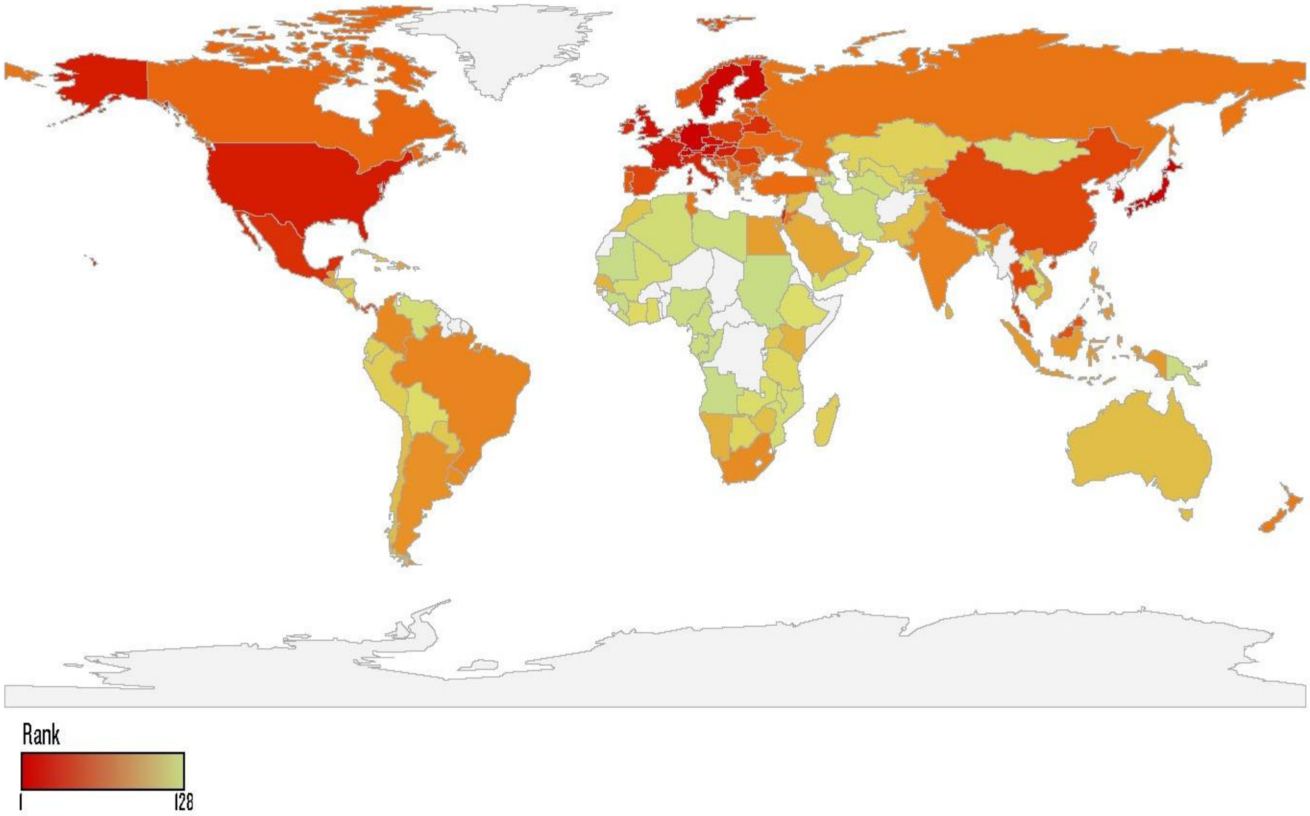
$$k_{a,1} = \frac{1}{k_{a,0}} \sum_{\alpha} M_{a\alpha} \kappa_{\alpha,0} \qquad \kappa_{\alpha,1} = \frac{1}{\kappa_{\alpha,0}} \sum_{a} M_{a\alpha} k_{a,0} \qquad (3)$$

average ubiquity of products made by country a

average diversification of countries that produce product α

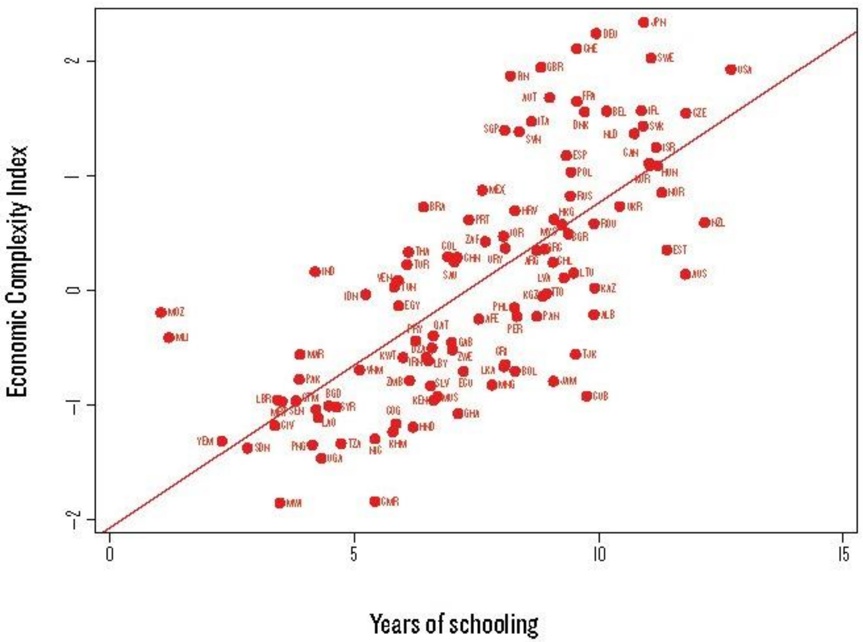
Economical Complexity Index: ECI

Iterating (2) for N $\rightarrow\infty$, one gets un eigenvalue problem, using the second largest eigenvalue (the largest is 1) one can build the ECI, which is used to rank the countries.

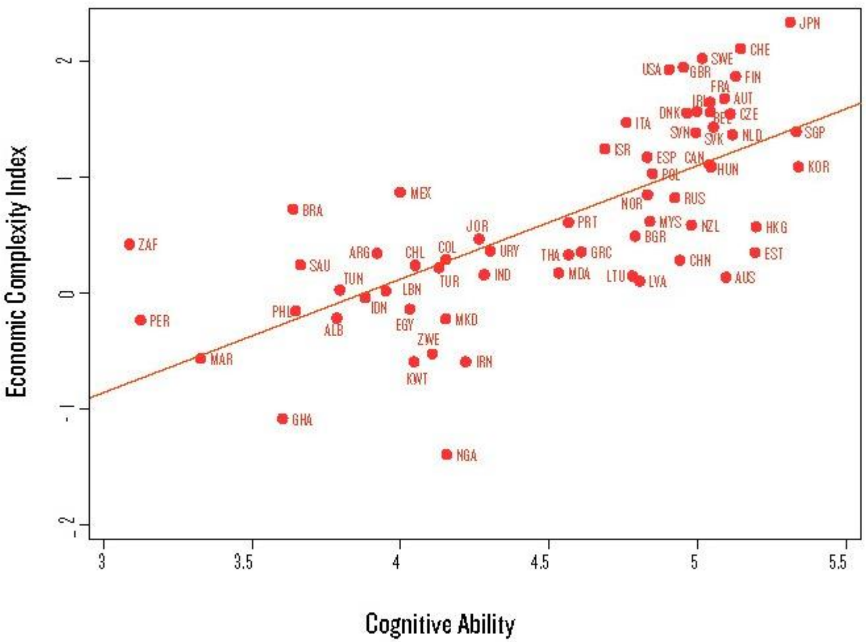


Comparison with other indices

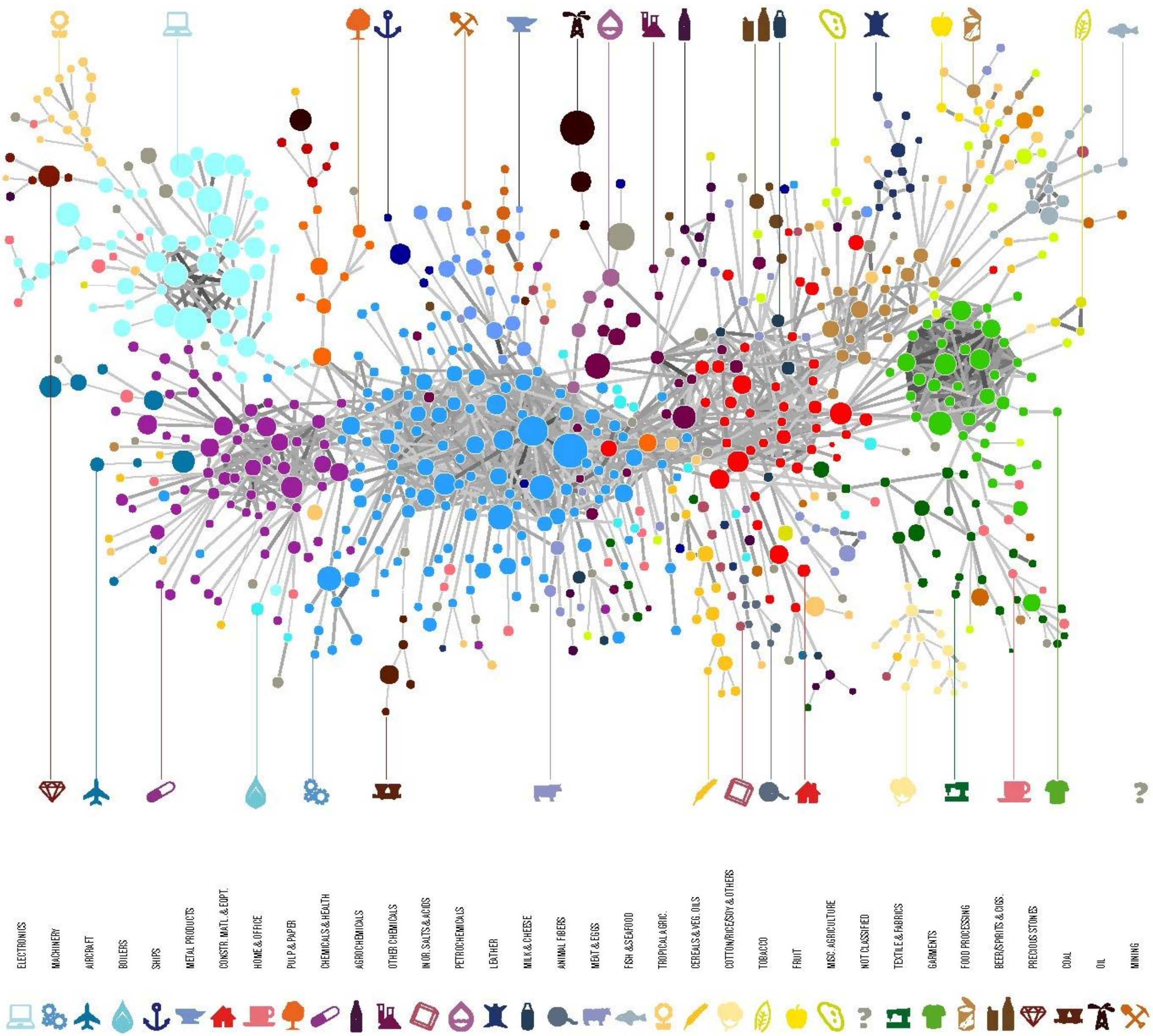
Relationship between Years of Schooling and the Economic Complexity Index (ECI) for the year 2000.



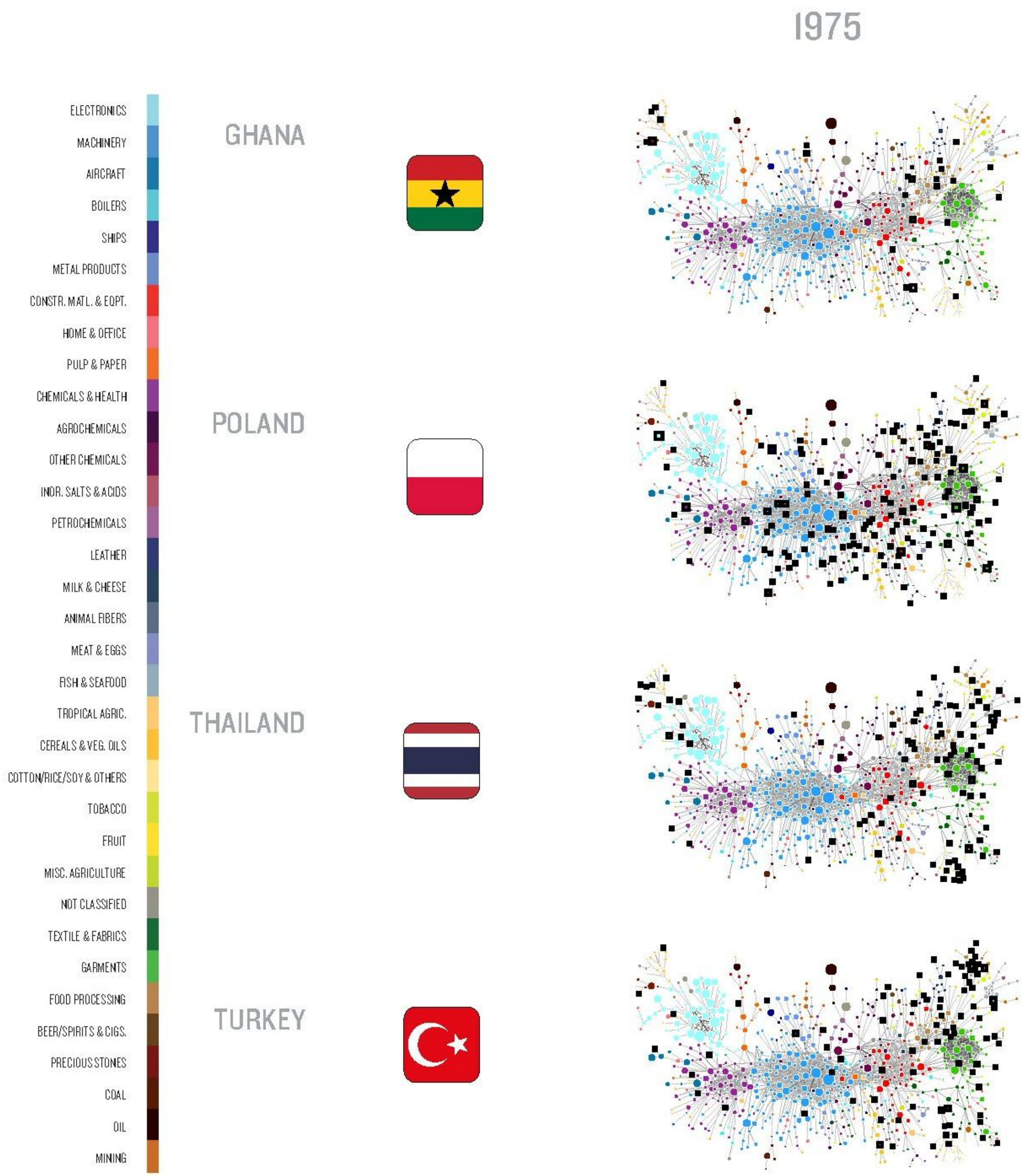
Relationship between Cognitive Ability and the Economic Complexity Index (ECI) for the year 2000.



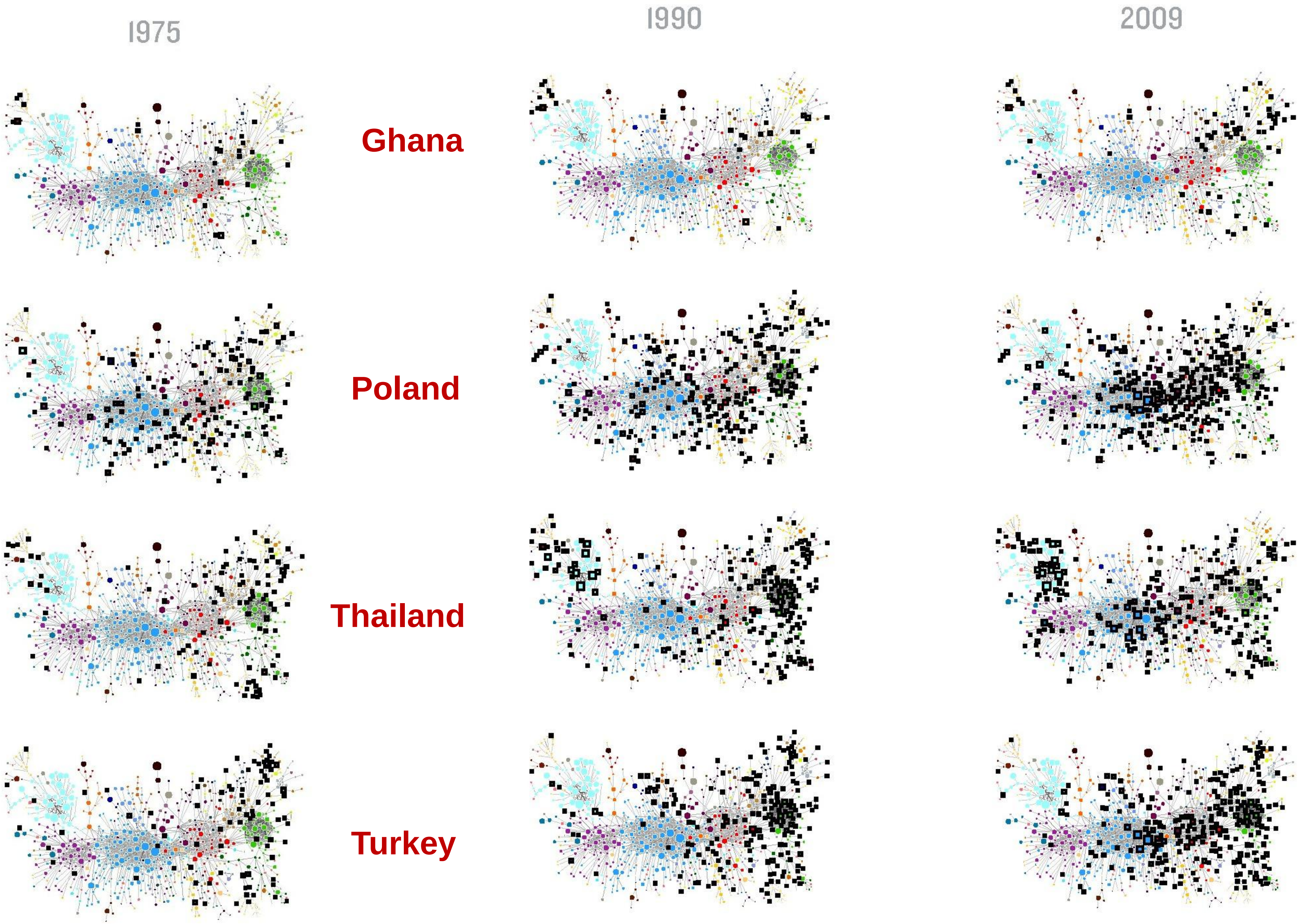
Communities in product space



As two co-exported products carry similar knowledge: a hint to infer new products to come



1975
ELECTRONICS
MACHINERY
AIRCRAFT
BOILERS
SHIPS
METAL PRODUCTS
CONSTR. MATL. & EQPT.
HOME & OFFICE
PULP & PAPER
CHEMICALS & HEALTH
AGROCHEMICALS
OTHER CHEMICALS
INOR. SALTS & ACIDS
PETROCHEMICALS
LEATHER
MILK & CHEESE
ANIMAL FIBERS
MEAT & EGGS
FISH & SEAFOOD
TROPICAL AGRIC.
CEREALS & VEG. OILS
COTTON/RICE/SOY & OTHERS
TOBACCO
FRUIT
MISC. AGRICULTURE
NOT CLASSIFIED
TEXTILE & FABRICS
GARMENTS
FOOD PROCESSING
BEER/SPIRITS & CIGS.
PRECIOUS STONES
COAL
OIL
MINING
GHANA
POLAND
THAILAND
TURKEY

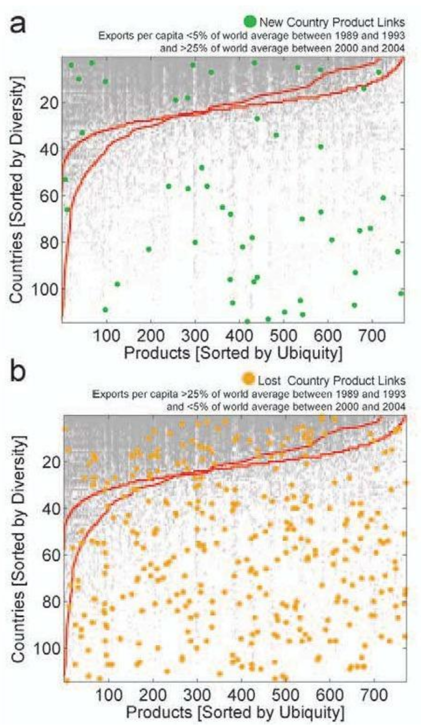


1975
1990
2009
Ghana
Poland
Thailand
Turkey

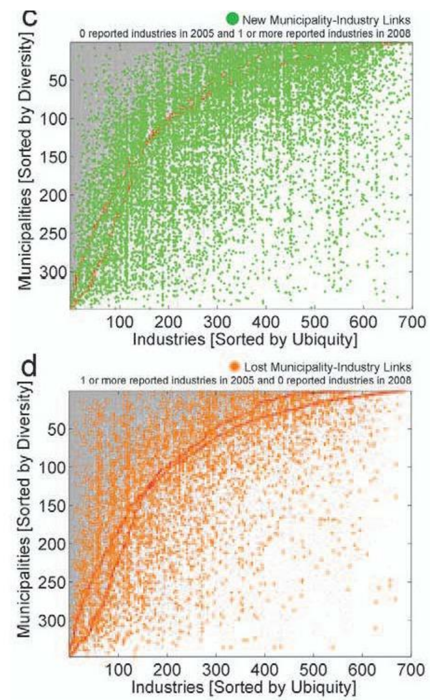
Nestedness in economical networks

Bustos, Gomez, Hausmann, Hidalgo PlosOne 7 e49393 (2012)

Study of the worldwide country-product network and national municipality-product network in Chile



grey: state in 1993
green : appeared (1993-2000)
orange: disappeared (1993-2000)



international

local (Chile)

Perspectives/discussion

- Study of the robustness of the system, using ATC. A way to compare robustness of different countries/regions?

- Usefulness of magnitudes issued from ecology: ecological diversity

$$\boxed{S_{pp'} = \frac{W_{pp'}}{D_p + D_{p'}}}$$

D_p : degree in the projected network

- SNM to study stability of nestedness according to some CPR

- Application to the study of the organisation of other kind of economical systems?

UNIVERSITÉ de Cergy-Pontoise

Complexity in social systems: from data to models

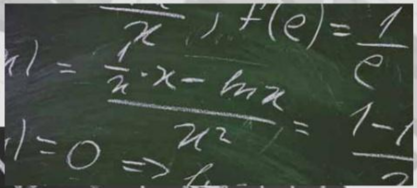
27-28 juin 2013

This interdisciplinary meeting, organised by LPTM (CNRS-UCP) and CAMS (CNRS-EHESS), aims at bringing together specialists that, coming from different fields, are interested in complex phenomena taking place in social systems. Special emphasis will be put on the interplay between data and models.

Université de Cergy-Pontoise - Site de Saint-Martin, 2 av. Adolphe-Chauvin à Pontoise

Organizing committee

Christian Borghesi, LPTM, UCP
Laura Hernández, LPTM, UCP
Jean-Pierre Nadal, CAMS-EHESS/ LPS-ENS



Service communication UCP - Avril 2013 - Photos : Shutterstock

Invited speakers

- **Marc Barthélemy,** CEA, France
- **Jean-Philippe Bouchaud,** Capital Fund Management, Ecole Polytechnique, France
- **Stéphane Cordier,** MAPMO, Université d'Orléans, France
- **Santo Fortunato,** Department of Biomedical Engineering and Computational Science (BECS), Aalto University, Finland
- **Emmanuel Lazega,** Sciences-Po, Paris, France
- **Yamir Moreno,** Institut for Biocomputation and Physics of Complex Systems (BIFI), Zaragoza University, Spain
- **Alain Polguère,** ATILF UMR 7118 CNRS-Université de Lorraine, Nancy, France
- **Irena Vodenska,** Boston University, U.S.A.

http://complexity-in-social-systems.u-cergy.fr

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Thank you for your attention!