

089194 - COMPLESSITÀ NEI SISTEMI E NELLE RETI (COMPLEX SYSTEMS AND NETWORKS)

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- **5 cfu**
- **half-semester** (2 half-semester of 1 semester)
- **in Italian** (but teaching notes are in English)
- **exam:** written (theory and exercises) + *[optional]* oral (paper discussion)
- **webpage** (with downloadable teaching notes):
<https://piccardi.faculty.polimi.it/csr.html>



COMPLEXITY AND COMPLEX SYSTEMS

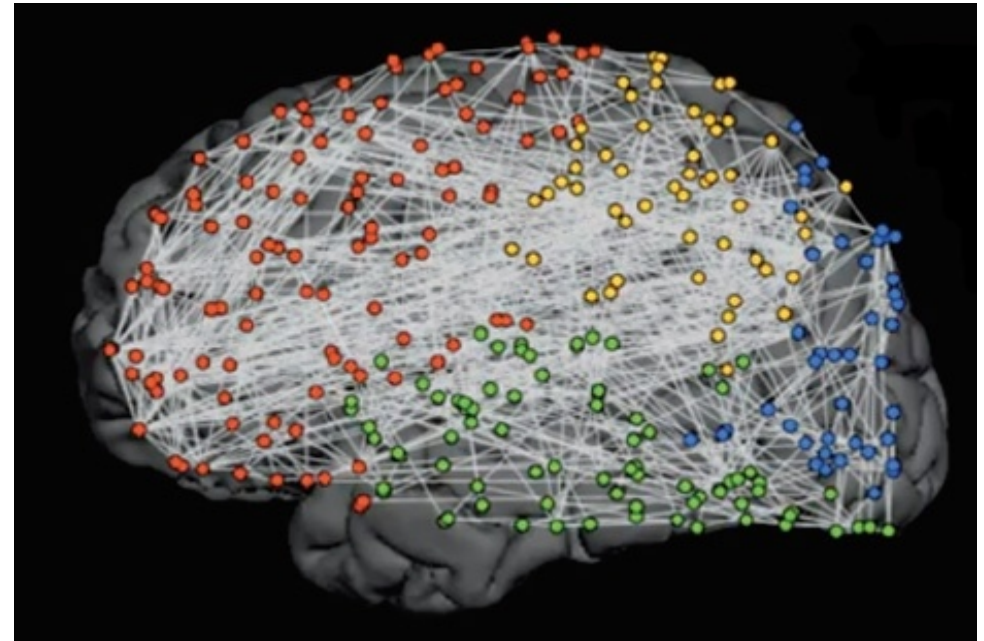
What is a **complex system**? What do we mean by **complexity**?



- There are no **rigorous definitions** which all scholars agree on.
- Nor general methods for **measuring complexity** are available.
- But there is consensus on a few **crucial features of complex systems**.

A complex system:

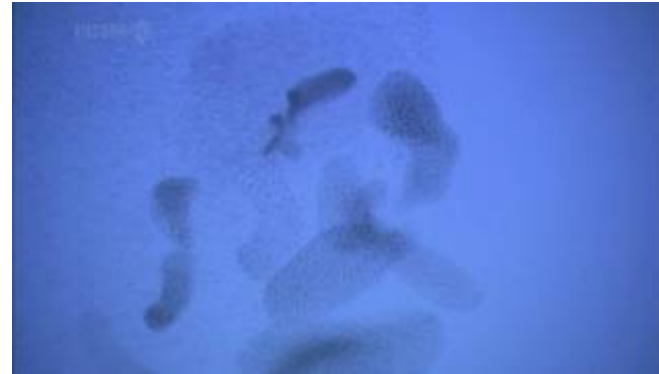
- is composed of **many parts** (agents, modules, individuals,...) ...
- ... **interacting each other** (they exchange information, material, energy, ...) ...
- ... giving rise to **self-organized** ("emergent") **collective behaviours**, which
 - *are not planned* by a designer or supervisor
 - *cannot be trivially understood* from the behaviour of a single (isolated) part



COMPLEXITY IN NATURAL SYSTEMS (LIVING OR NOT)



ant colonies...



starling flocks...



neural activity...

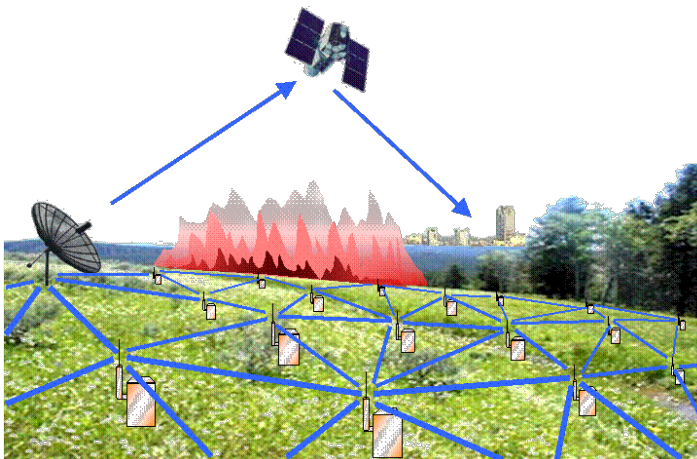


meteo phenomena...

COMPLEXITY IN TECHNOLOGICAL SYSTEMS



synchronization of oscillators...



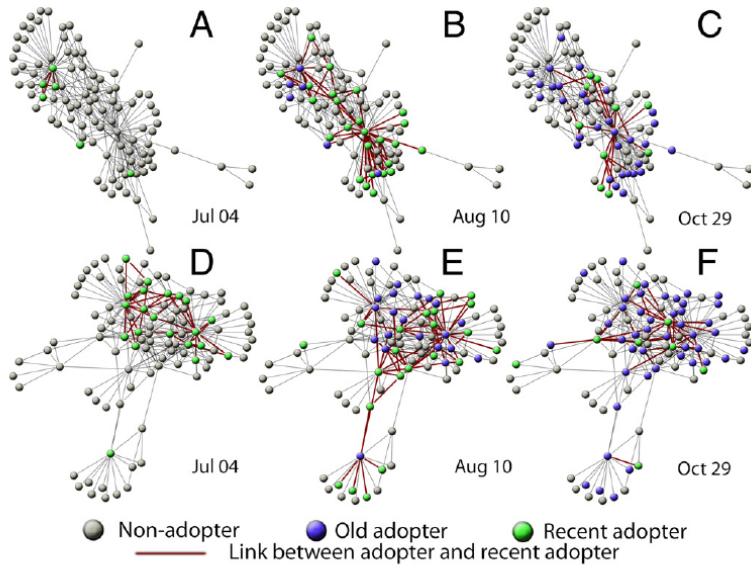
consensus in sensor networks...



black-out cascades in power networks...

COMPLEXITY IN SOCIO-ECONOMIC SYSTEMS

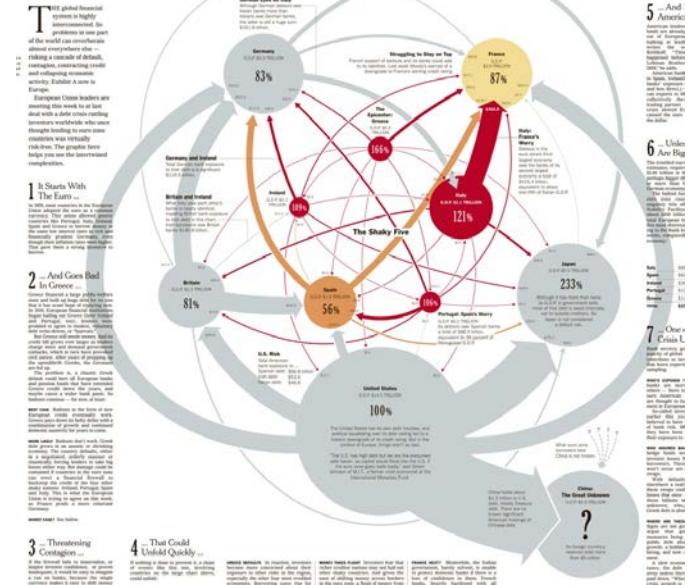
propagation of diseases-ideas-products in social networks...



self-organized protest movements...

It's All Connected: A Spectator's Guide to the Euro Crisis

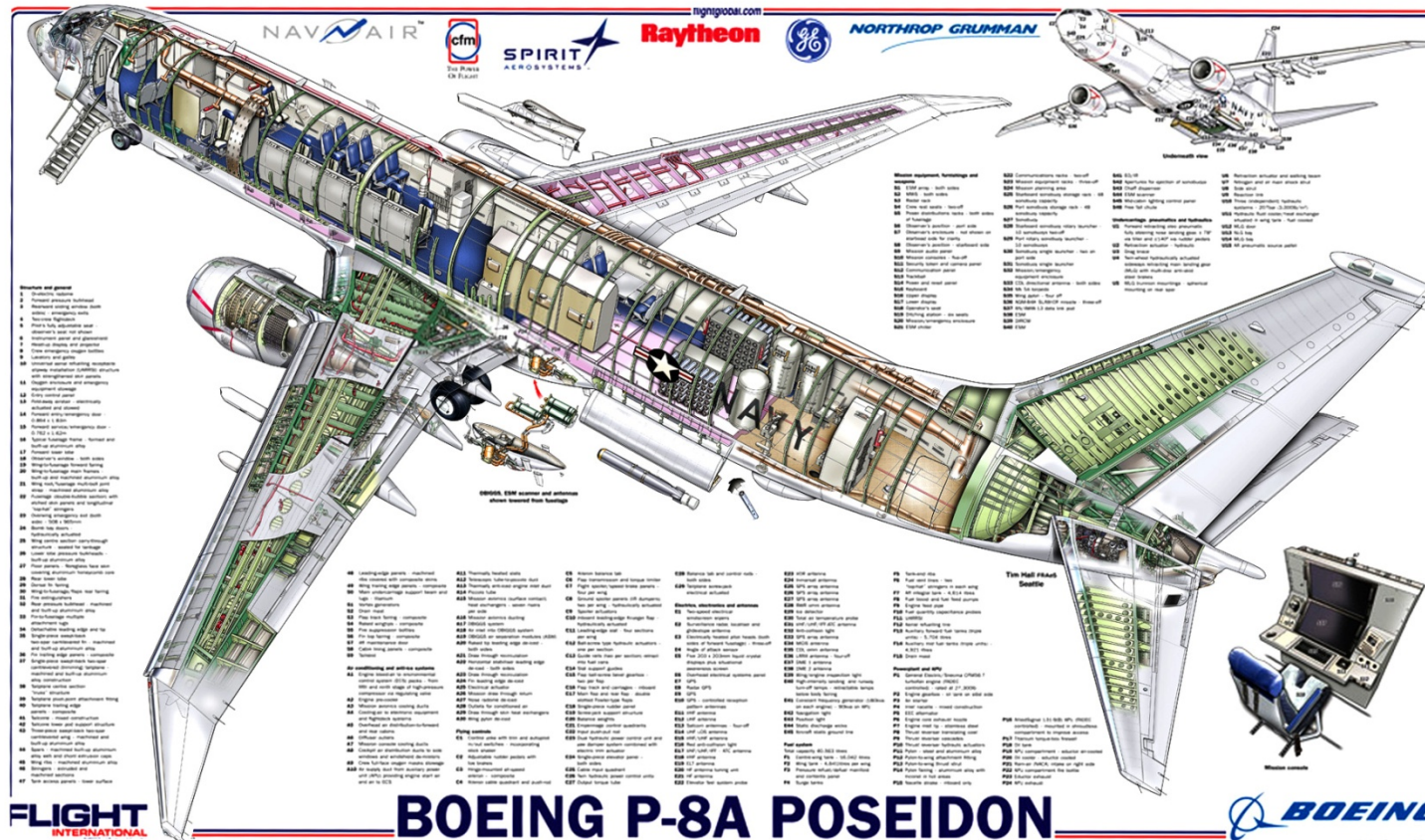
Charting the web of debt exposure among sagging economies.



cascade failures in financial networks...



COMPLEX OR COMPLICATED ?

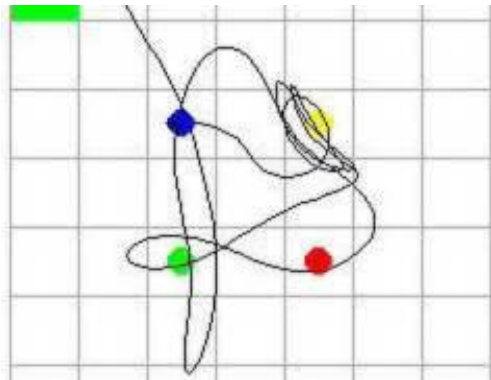


An airplane is composed of many parts interacting each other - but the overall behaviour is (mostly...) planned and predictable (luckily!).

The "ingredients" of complexity: NONLINEARITY

A **COMPLEX SYSTEM** is composed of **NONLINEAR PARTS**.

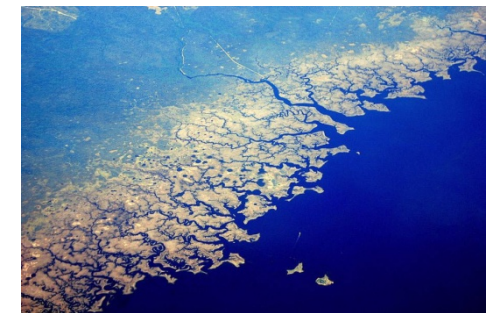
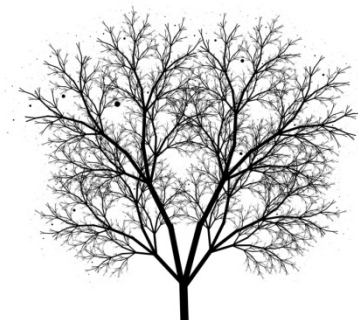
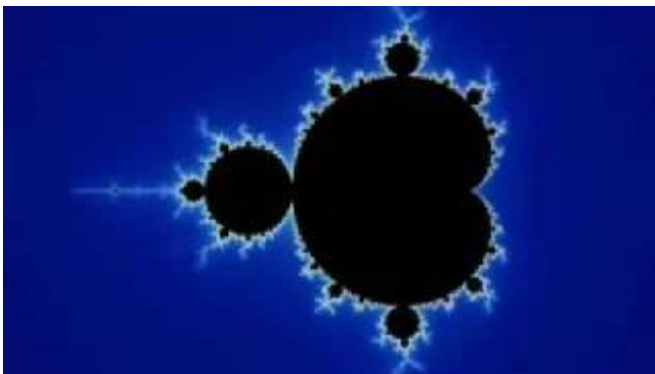
A **single nonlinear system** may have extremely intricate behaviour:



sensitivity to *initial conditions*...



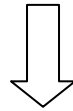
"*unpredictable*" dynamics...



fractal geometries...

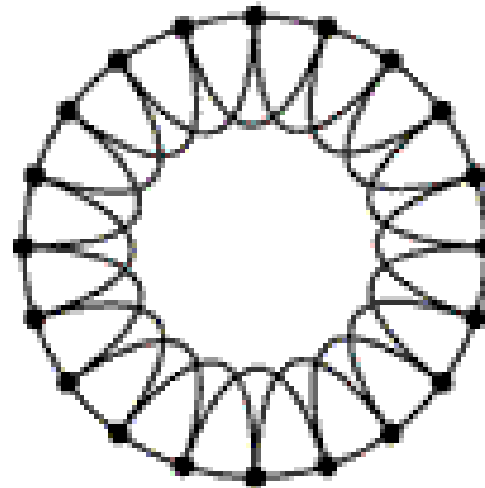
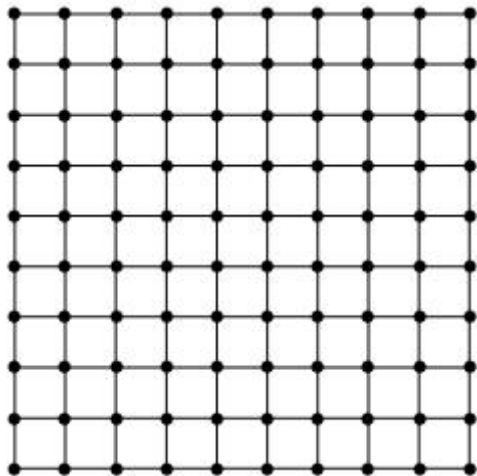
The "ingredients" of complexity: THE NETWORK OF INTERACTIONS

The parts of the system interact through a **network**.

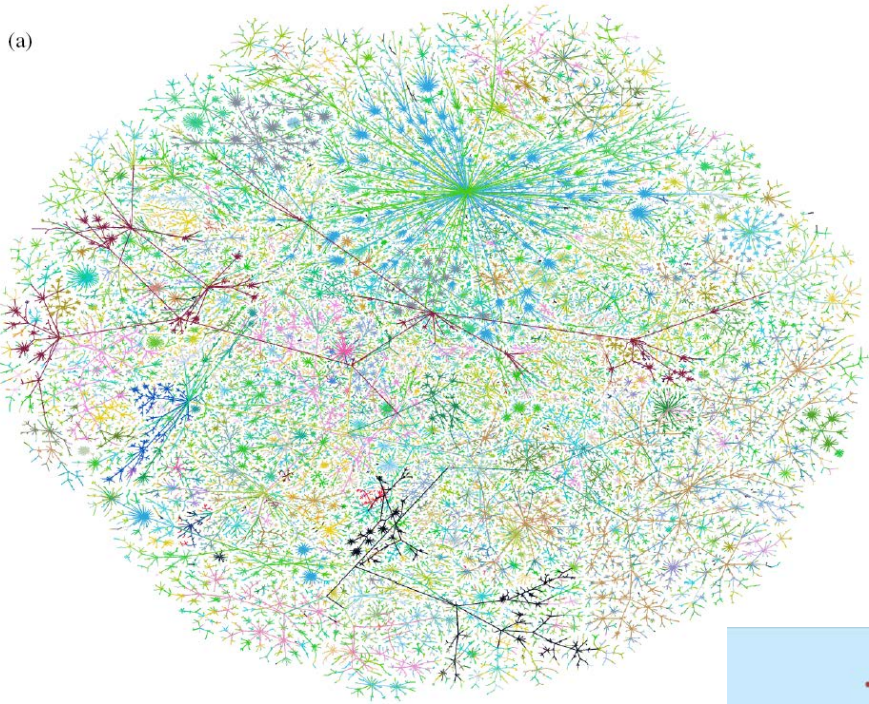


The **structure** of the network
does have influence on the system behaviour.

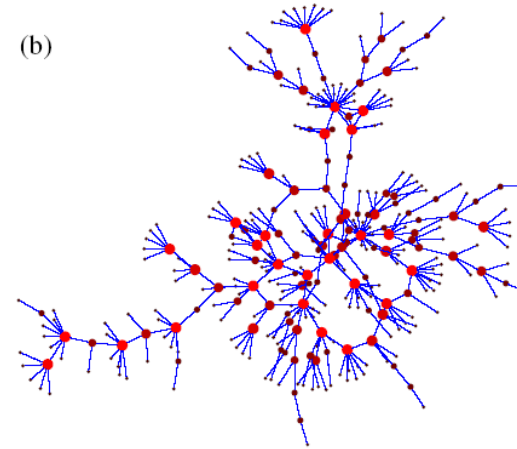
"regular" networks: each part interacts with near parts only...



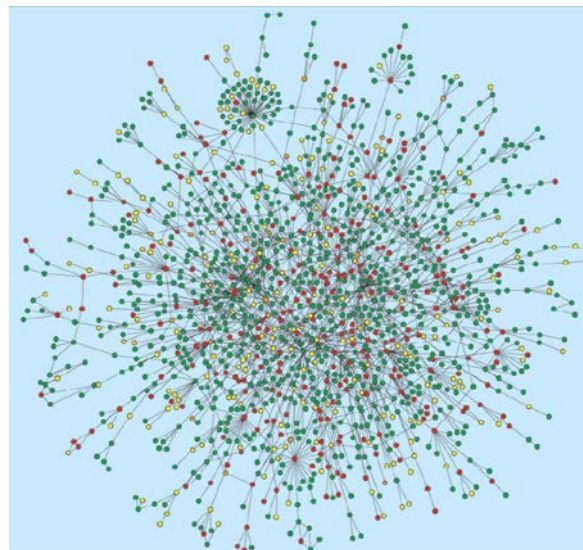
*Real-world networks (natural, technological, socio-economic)
have completely different structure...*



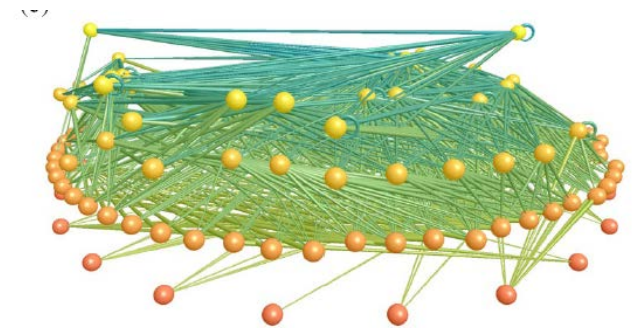
internet...



*disease
propagation...*



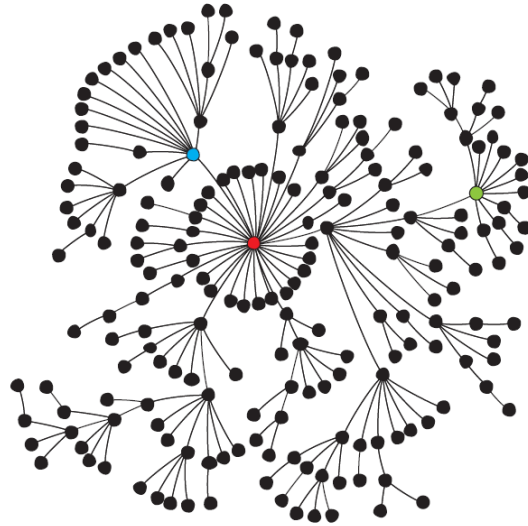
proteins...



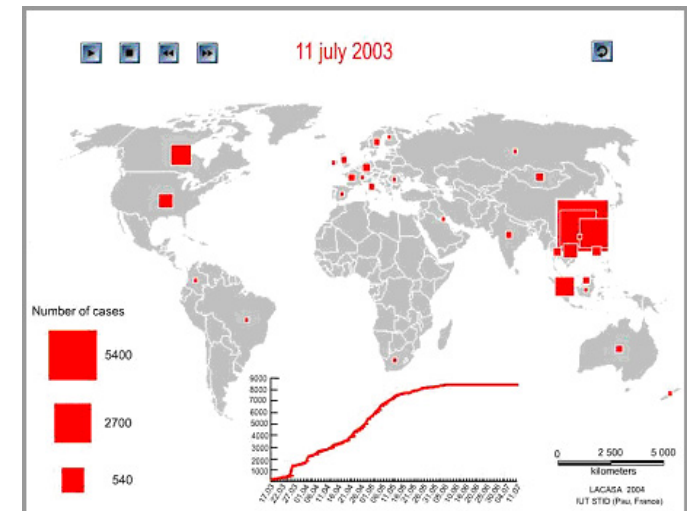
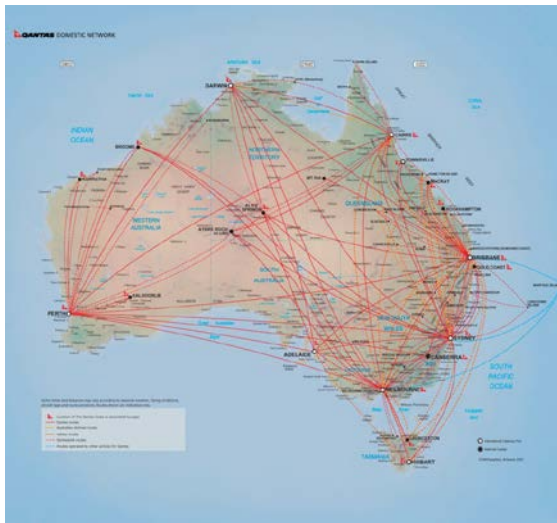
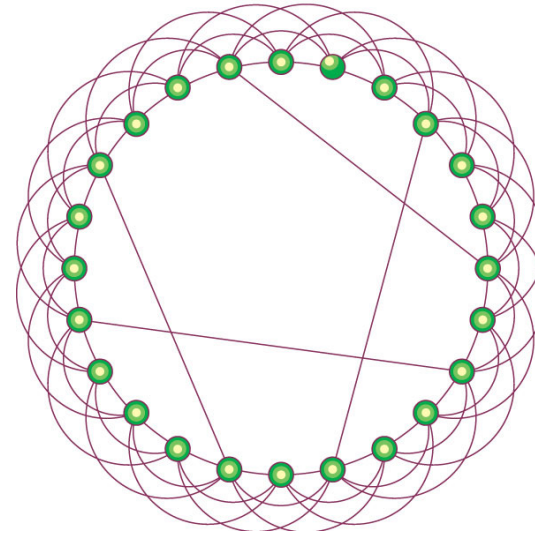
ecosystems...

Two important properties of most **real-world networks**:

the number of interactions
is **inhomogeneous**
(**scale-free nets**)



there are
long distance connections
(**small-world nets**)



Despite the importance and ubiquity of the concept of complexity in modern science and society, **no general and widely accepted means of measuring the complexity of a physical object, system, or process currently exists.**

The lack of any general measure may reflect **the nascent stage of our understanding of complex systems**, which still **lacks a general unified framework** that cuts across all natural and social sciences.

O. Sporns,
<http://www.scholarpedia.org/article/Complexity>

