

Terrestrial communication networks from archaeological evidences

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IPHES Seminars, IPHES – Tarragona, Thursday 30 November 2017



Why a physicist can (and *should*) seat among archaeologists/paleontologists?

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Who is Alessio Cardillo?





**Universidad
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**Instituto Universitario de Investigación
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Universidad Zaragoza**





ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE



Complex systems and Complex networks



What is a complex system?

Answers

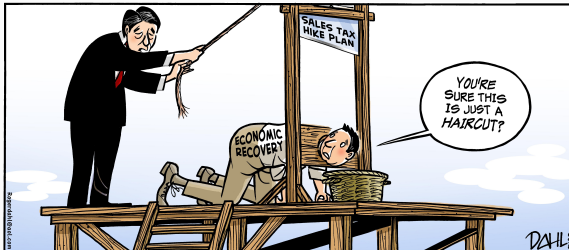
- Complex systems contain many constituents interacting **nonlinearly** (*i.e.* non-predictable);



Complex systems

Answers

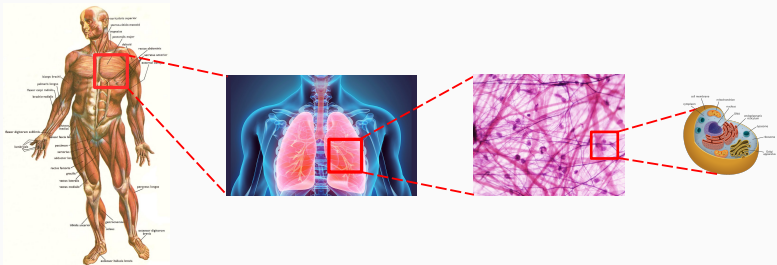
- Complex systems contain many constituents interacting **nonlinearly** (*i.e.* non-predictable);
- The constituents of a complex system are **interdependent**;



Complex systems

Answers

- Complex systems contain many constituents interacting **nonlinearly** (*i.e.* non-predictable);
- The constituents of a complex system are **interdependent**;
- A complex system possesses a structure spanning **several scales**;



Complex systems

Answers

- Complex systems contain many constituents interacting **nonlinearly** (*i.e.* non-predictable);
- The constituents of a complex system are **interdependent**;
- A complex system possesses a structure spanning **several scales**;
- A complex system is capable of **emerging behavior**.



Complex networks in a nutshell



Using networks to study complex systems is like paleontology ...

Complex networks in a nutshell

Once upon a time ...

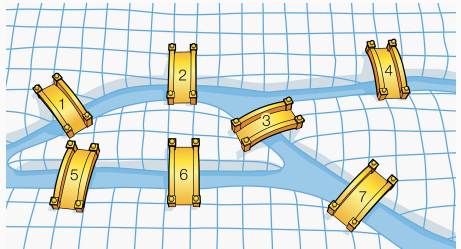
In 173x a mathematical puzzle based on the city of Königsberg was posed.



Complex networks in a nutshell

Once upon a time ...

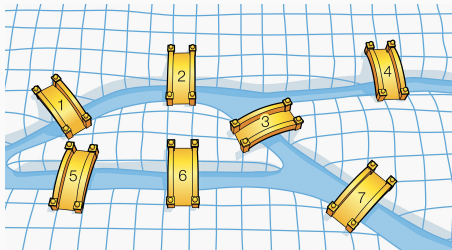
In 1736 a mathematical puzzle based on the city of Königsberg was posed.



Complex networks in a nutshell

The puzzle

Can we find a path that makes us explore the city passing from each bridge just once?

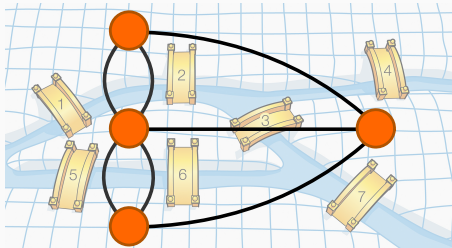


https://en.wikipedia.org/wiki/Seven_Bridges_of_K%C3%B6nigsberg

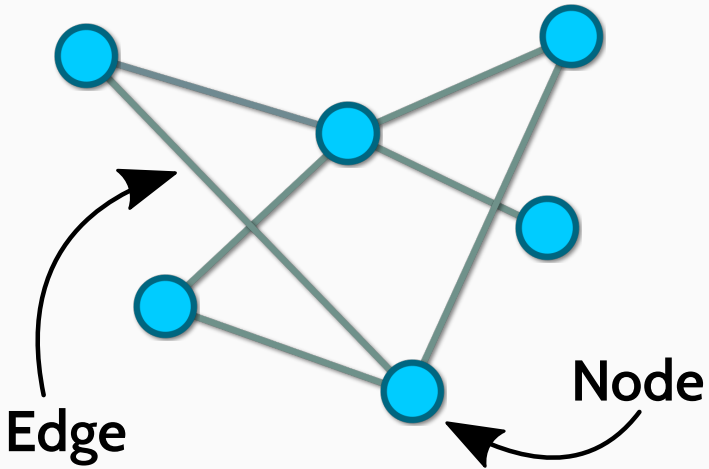
Complex networks in a nutshell

The solution

In 1736 Leonard Euler found the answer and gave birth to [graph theory](#).



Complex networks in a nutshell



Advantages

- Easy mathematical formalism
- Ability to go beyond visual inspection
- Possibility to adopt many techniques from statistical physics/nonlinear dynamics.

A world of networks



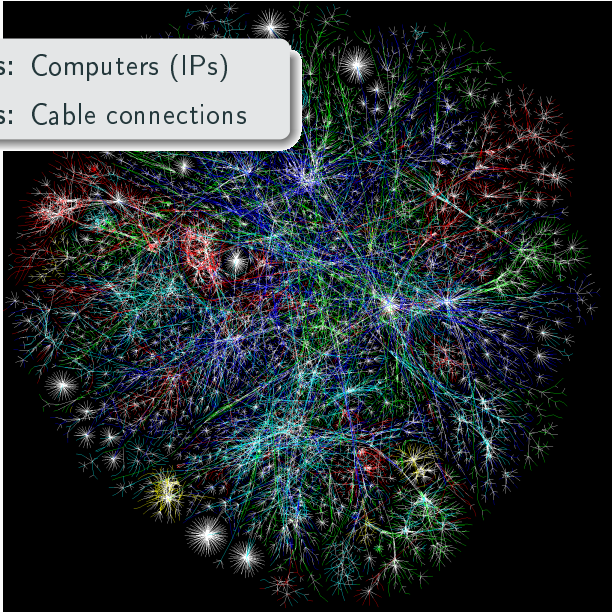
Nodes: People

Edges: Friendship

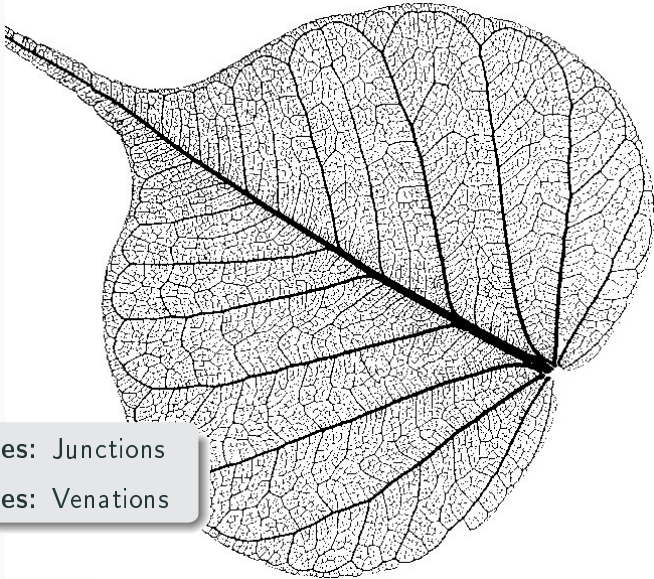
A world of networks

Nodes: Computers (IPs)

Edges: Cable connections



A world of networks



Nodes: Junctions

Edges: Venations

A world of networks



Nodes: Crossings
(locations)

Edges: Streets

[Journal of Archaeological Method and Theory](#)

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Networks in Archaeology: Phenomena, Abstraction, Representation

Authors

[Authors and affiliations](#)

Anna Collar , Fiona Coward, Tom Brughmans, Barbara J. Mills

Article

First Online: 30 January 2015

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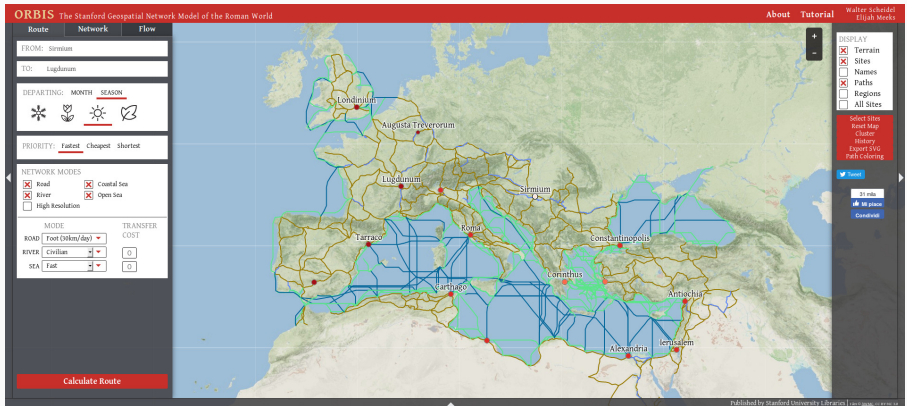
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Citations

Terrestrial communication networks



Previous work



ORBIS project homepage <http://orbis.stanford.edu/>

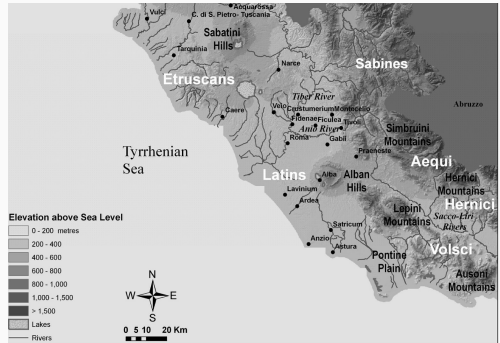
Cases of study: Etruria & Latium Vetus during Iron Age

- Two regions:
Etruria and
Latium Vetus



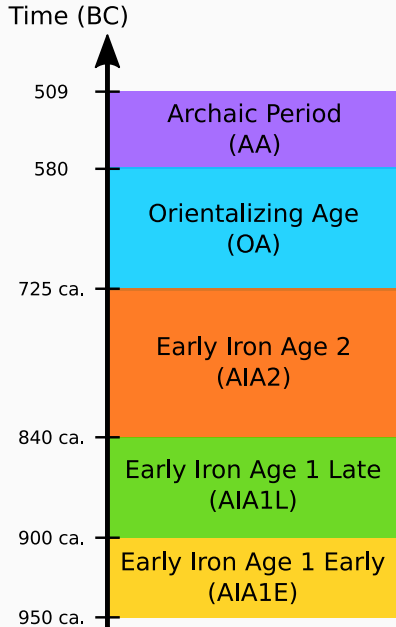
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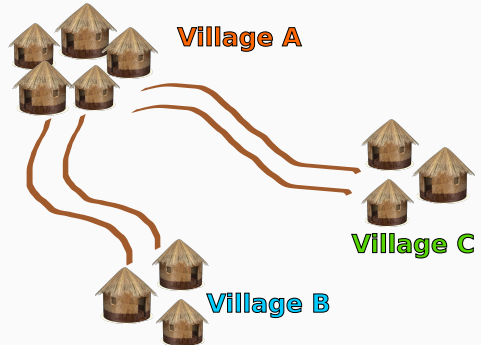
Cases of study: Etruria & Latium Vetus during Iron Age

- Two regions:
Etruria and
Latium Vetus
- Five time snapshots
between (approx.)
950 – 509 BC.



Cases of study: Etruria & Latium Vetus during Iron Age

- Two regions:
Etruria and
Latium Vetus
- Five time snapshots between (approx.)
950 – 509 BC.
- Nodes: settlements
Edges: direct routes
- Nr. of nodes
 $N \in [80, 180]$
(approx.).



Question 1

Is it possible to understand power balances by analysing regional transportation networks?

Cases of study: Etruria & Latium Vetus during Iron Age

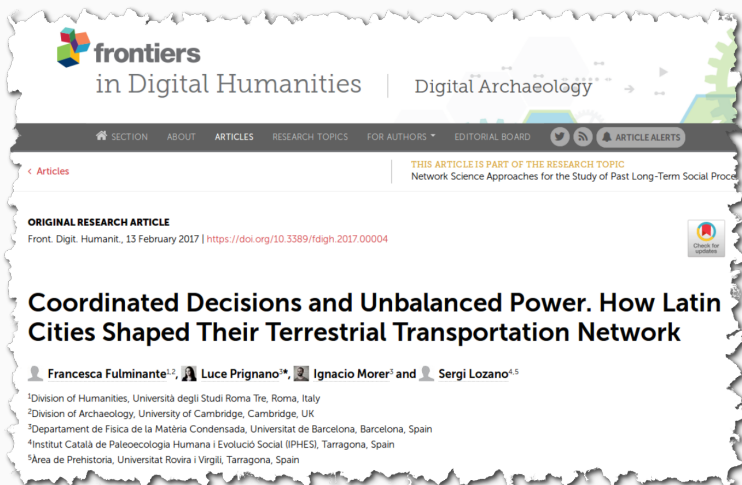
Question 1

Is it possible to understand power balances by analysing regional transportation networks?

Question 2

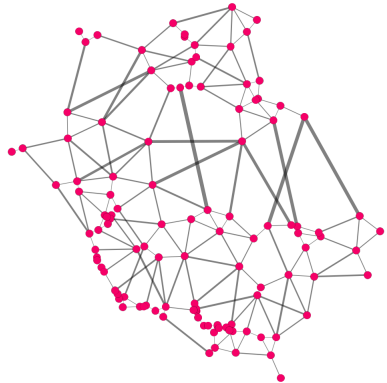
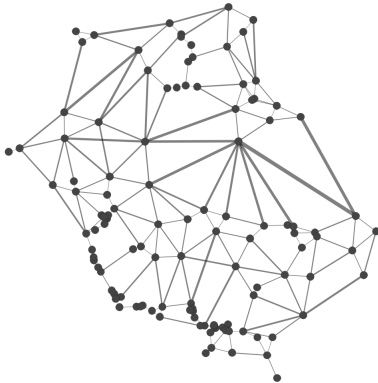
Can we compare processes across regions?
(using formal network science methods)

Cases of study: Etruria & Latium Vetus during Iron Age



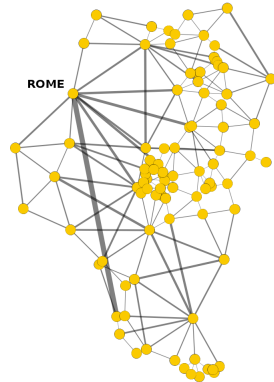
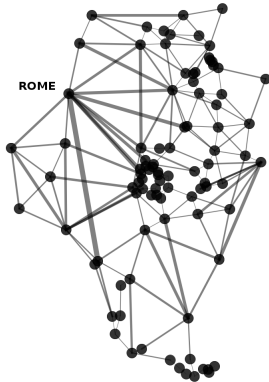
Cases of study: Etruria & Latium Vetus during Iron Age

Etruria (EIA1L)



Cases of study: Etruria & Latium Vetus during Iron Age

Latium Vetus (EIA1L)



Questions:

1. What is the relation between the empirical model and those available in the literature?
2. Which factors influence the final outcome?

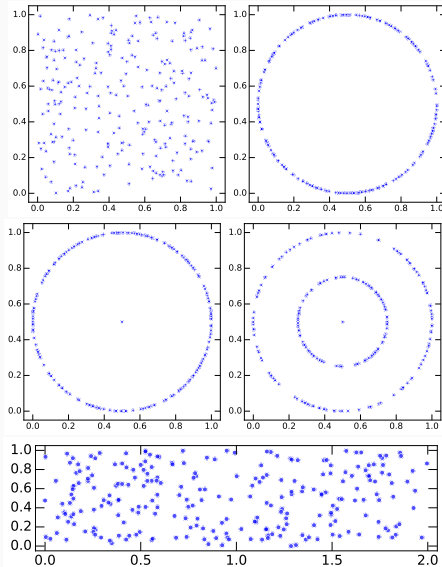
Comparison with other models

Models compared:

1. Minimum Spanning Tree (MST)
2. Delaunay Triangulation (DT)
3. Greedy Triangulation (GT)
4. Gabriel Graph (GG)
5. Model 3 (M3)

- M. Barthélemy, Spatial networks. Physics Reports, 499, 1–101. (2011)
- B. Delaunay, “*Sur la sphère vide*”. Bulletin de l'Académie des Sciences de l'URSS, Classe des sciences mathématiques et naturelles. 6: 793–800 (1934).
- K. R., Gabriel, *et al.* “A new statistical approach to geographic variation analysis”, Systematic Zoology, Society of Systematic Biologists, 18(3): 259–270 (1969),

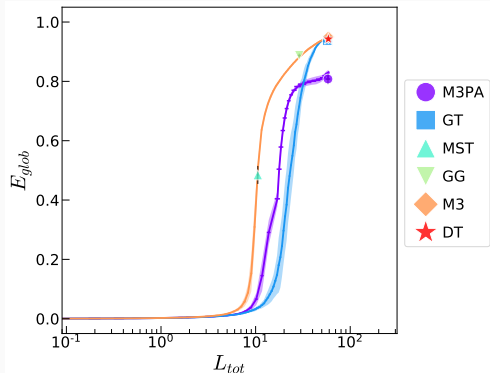
Comparison with other models



Point distributions:

1. Uniform square
2. Circle
3. Circle with center
4. Multicircle
5. Uniform rectangular

Comparison with other models

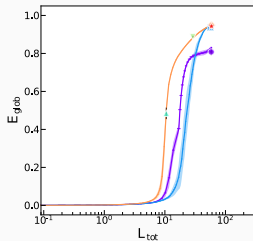


Quantities considered:

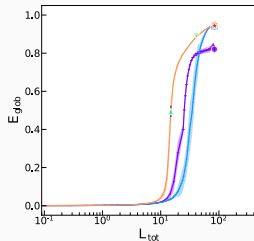
We compare 7 different
topological indicators.

Results

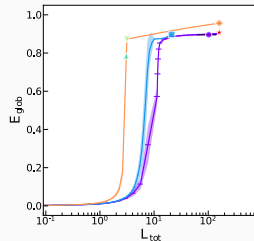
uniform



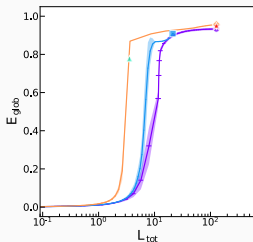
uniform rect.



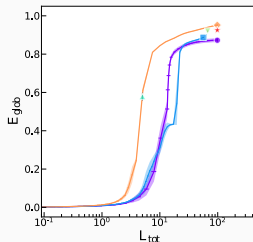
circle



circle center

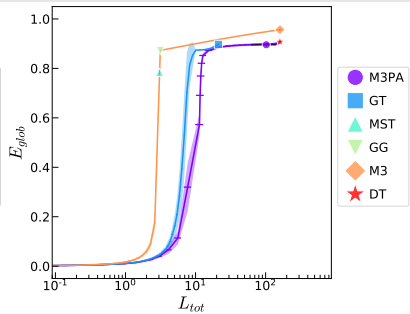
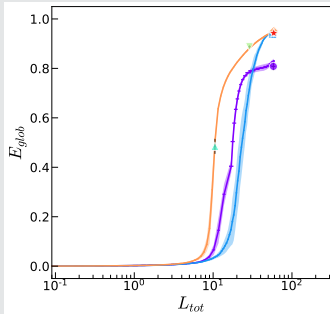


multicircle



Results

uniform vs circle



Questions:

Are Greedy and Delaunay Triangulations the same?

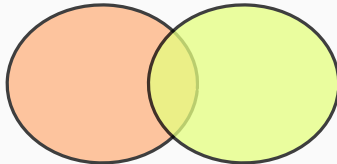
Results

Jaccard score

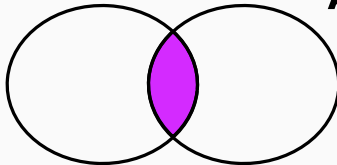
$$J = \frac{|A \cap B|}{|A \cup B|}$$

$$J \in [0, 1]$$

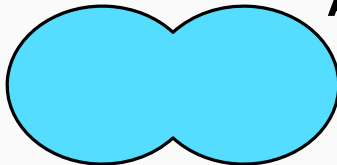
set A **set B**



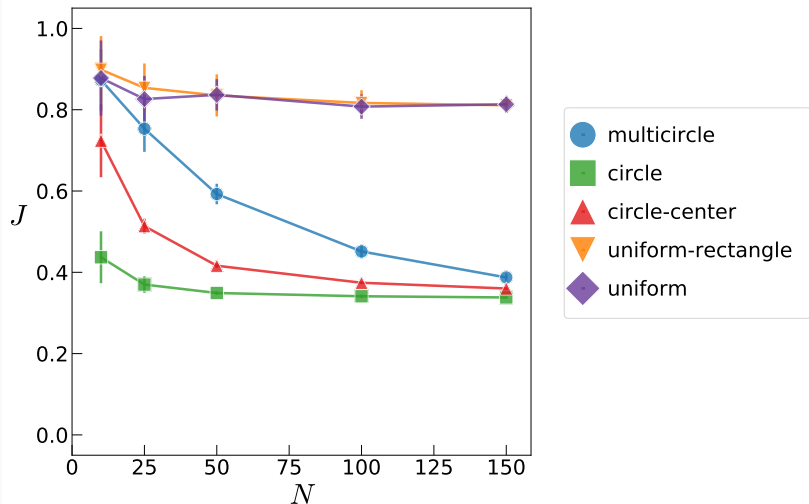
$A \cap B$



$A \cup B$



Results

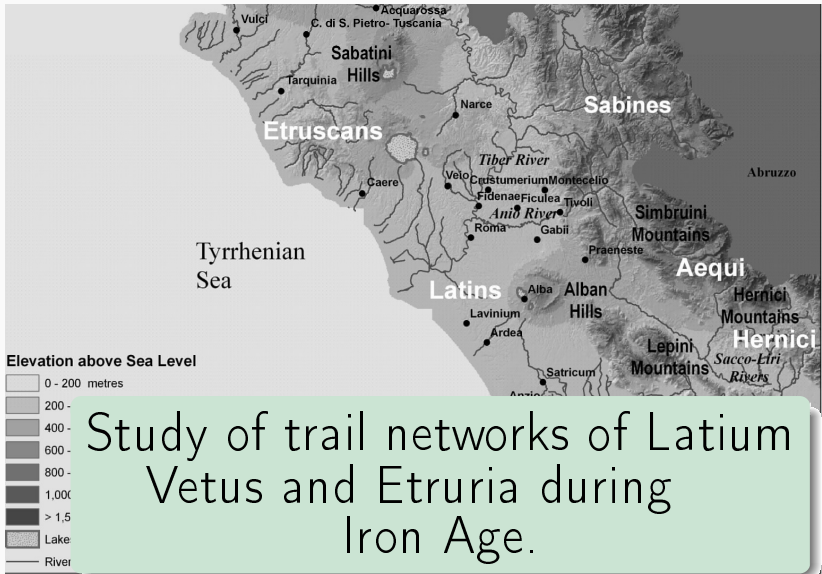


Conclusions

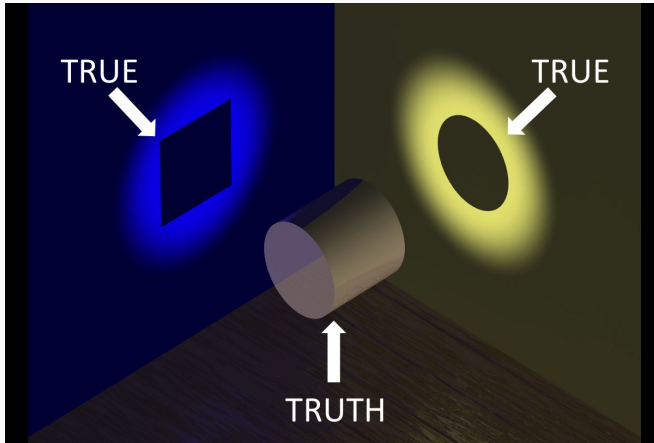


Networks as a tool to explore
complex systems

Take home messages



Take home messages



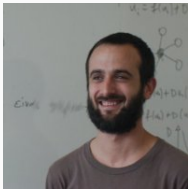
Studying a problem from **another** perspective may help us to unveil hidden truths.

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