Interaction Networks: from Real Networks to Dynamic Graphs

an introduction

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Preamble

- for centuries: reductionist approach
- considers that a phenomenon can be explained by dividing the system in smaller parts and by studying them "independently" (it may work for aliens discovering a car)
- but, many natural systems cannot be understood following that approach: from the study of each element, the global behavior of the system cannot be deduced:

  $\longrightarrow$ e.g. ant colonies

Ant Colonies

- architecture
- agriculture (mushrooms)
- breeding (aphids)

Ant Colonies

Collective Behavior

- obstacles crossing
- collective transportation of loads
- sorting (food, brood)

Collective Behavior

Why?

- what were the evolutive processes that led to insect/animal societies?

    $\rightarrow$ [E. O. Wilson 1975] (sociobiology)

- is the behavior "optimal"? (what should signify "optimal")

    $\rightarrow$ [Krebs & Davies 1984] (evolutionary approach of behavioral ecology)

How?

- Which mechanisms can potentially explain the structures made by the group?

    $\rightarrow$ [P.-P. Grassé 1959, Deneubourg & Goss 1989]

the action of one depends on the actions of its neighbors

- common phenomenon in wild life
- independent of the complexity degree of the individuals

allelomimetic behavior $\Leftrightarrow$
communications/interactions

Emergence $\leftrightarrow$ Interactions

- these collective behaviors are said emergent
- **Emergence** is behind the *"the whole is more than the sum of its parts"* (Aristote?)
- it results from the **interactions** between the entities composing the system.
- **Complex Systems**: a large number of entities interacting with each other and with their environment.
- better undersanding complex systems $\Rightarrow$ designing holistic models of real systems (i.e. models including interactions)
- the study of these **interactions**/**interconnections** through **models** is the main topic of this course.

Networks are everywhere
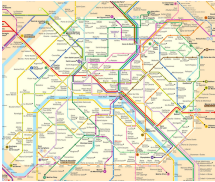
- urban transportation network: buses, metro lines
- rail network: trains
- internet
- social network
- (tele)communication networks: GSM, 4G, Wifi
- energy network: power grid
- sewer/wastewater network
- human/animal/insect societies
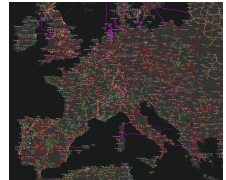
Network?

What is a network?

- a set of **elements** (homogeneous or not) connected by **links**
- a network is a structure allowing flow circulation
- flows:
    - exchange of ideas, money
    - transport of people, goods, energy, information
    - diffusion of molecules, news, emotions
- flows sometimes need vectors (car, ship, mosquito, plane, human, etc.)
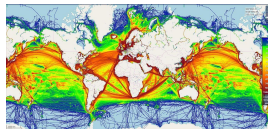
$\rightarrow$ Some Examples

Maritime Networks
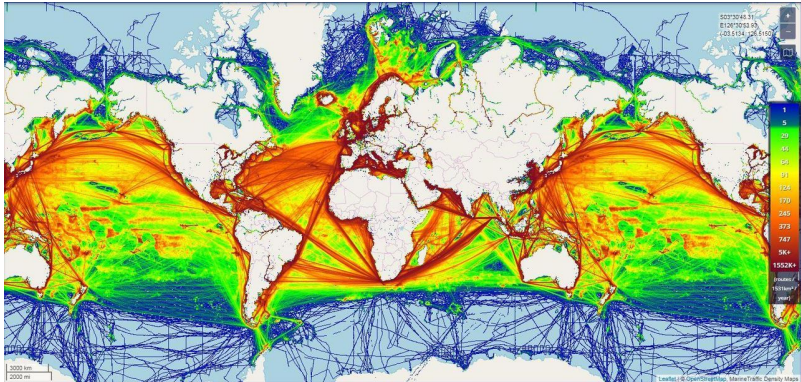
colors: density of ships along maritime roads

- within these networks we can find: ships, harbors, containers, shipping companies, crews, maritime roads, raw materials, manufactured goods
- topic of interest ↔ elements to consider

Maritime Networks
Few Questions

- How long does it take to ship goods from one harbor to another one?
- What would be the consequences of the opening of the arctic sea to maritime flows?
- What are the most important maritime roads?
- In case of a conflict in some geographical area, if the traffic is stopped, what are alternative routes for delivering goods? What would be the additional delay?
- What are the differences between harbors? Just a question of size/traffic?
- could it be possible for two companies to be complementary on some maritime roads?
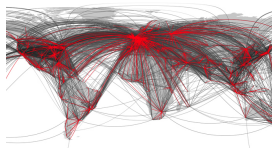
Air Traffic Network
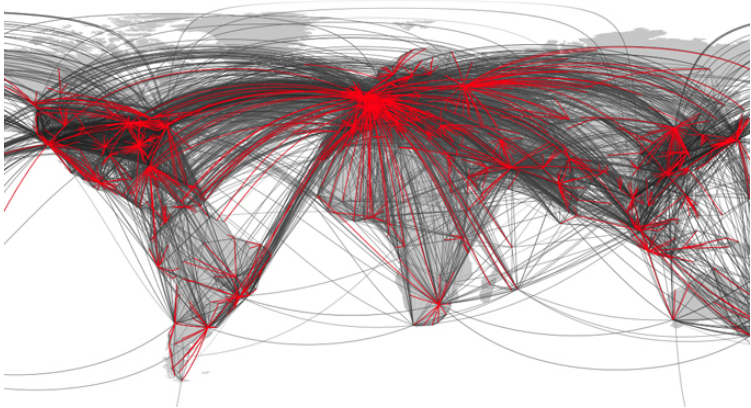
- within these networks we can find: planes, airports, passengers, companies, crews, goods

Air Traffic Networks
Few Questions

- How long does it take to go from one airport to another one?
- What could be the modification of the global air traffic if we add an airport in some particular place?
- What may happen if the number of passengers increases a lot?
- How fast an epidemy could spread over the world through such type of networks?
- What was the evolution of air traffic network over the last twenty years?
- What would be the response of the network if some geographical area cannot by flight over anymore?

Web (Internet)
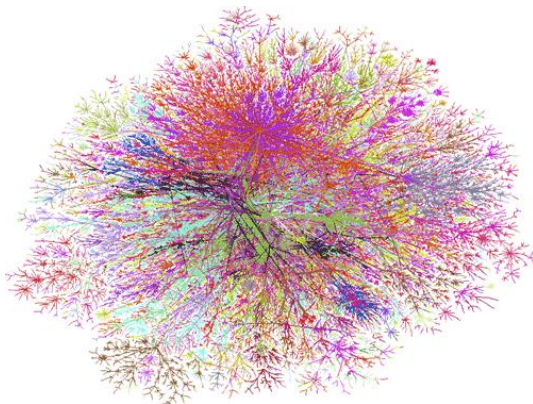
- within these networks we can find: web pages, servers (including databases), routers, queries, switches, communication protocols

Web (Internet)
Few Questions

- Which are the most visited web sites?
- The development of the web is fully decentralized (no planification)

  $\longrightarrow$ What is the speed of its development?

  $\longrightarrow$ Do we have an idea of the size of the network in 2, 5 or 10 years?

- Is it be possible to isolate part of the network?
- What are the main roads within that network? (paths on which the traffic is higher than anywhere else)

Urban Networks
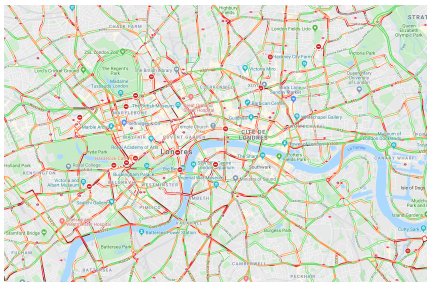
London city
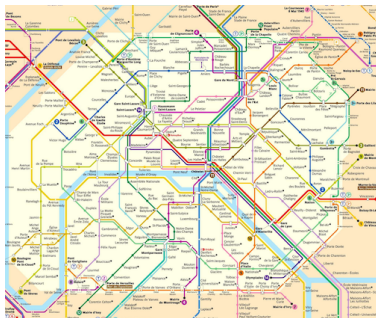
Paris metro lines

- different types of networks: rails networks, metro networks, street networks, country-scale road networks
- within urban street networks we can find: streets, cars, buses, crossroads, people, pedestrians, buildings (school, factories, residential districts), fires (red lights, semaphores)

Urban Networks
Few Questions

- When, where and why traffic jams occur in a particular city?

- If some streets are closed, starting from one place is it always possible to reach any other place in the city?

- Which are the most crowdy places?

- Given on street/district, is there a pattern for the traffic? Periodicity?

- Does it exist a central place in the city?

- In case of major problem, how can the city be evacuated?

Social Networks
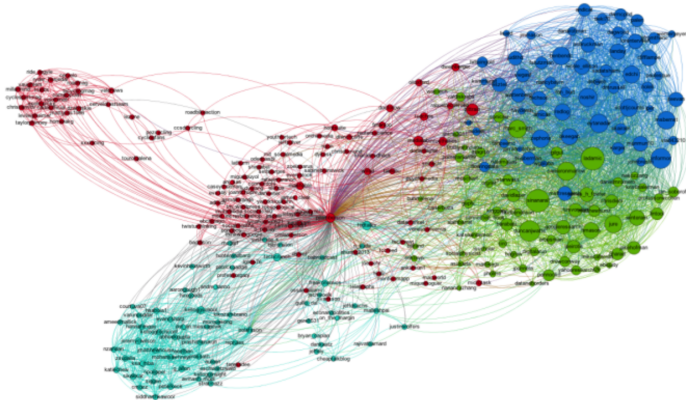
- within social networks we can find: web pages, messages, pictures, videos, users, links between elements (like, follow, friend)

Social Networks
Few Questions

- Which are the users with the maximum number of... like, friends, followers?
- What is the traffic corresponding to a given keyword/hashtag?
- Does there exist a set of keywords/hashtags common to a specific group of people (users)?
- How fast an information (message, video, picture) spread over a significant number of users?
- Who are the source of popular new hashtags?

# Mobile/Sensor Ad Hoc Networks
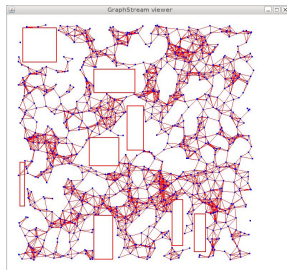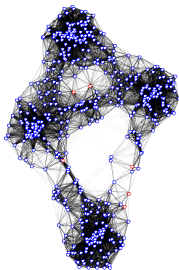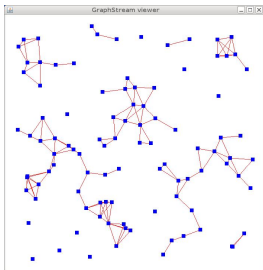
- An **ad hoc** network is a spontaneous network made or communicating devices.
- Such networks need neither infrastructure, nor control, nor supervision.
- If some elements are mobile they are called mobile ad hoc networks a.k.a. **MANETs**

- Within mobile/sensor ad hoc networks we can find: classical computers, smartphones, sensors.

Mobile/Sensor Ad Hoc Networks
Few Questions
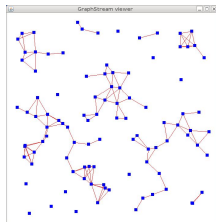
- How to efficiently gather sensed data? (Sensor networks)
- Is the network connected?
- How to efficiently broadcast an information to all the machines?
- How to route some information from one machine to another one since the connections are changing all the time?

Human and Animal Societies

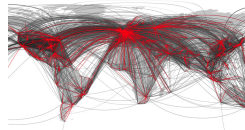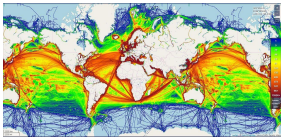- Within human and/or animal societies we can find: living beings.
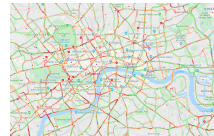
Human and Animal Societies
Few Questions

- How are these societies organized?
- Do there exist some communities?
- How to detect them?
- How does the group work?
- What are the underlying mechanisms explaining the movements? (starlings, fishes, sheeps)

Time matters

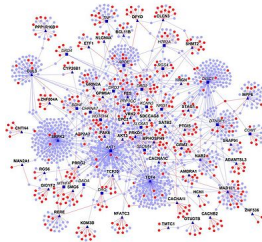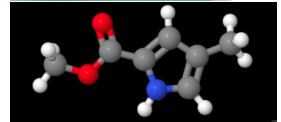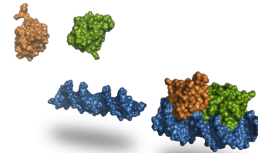All these networks **change with time** $\Longrightarrow$ they are **dynamic**

Maritime Network	Air Traffic Network	Urban Network
marinetraffic.com	flightradar24.com	sytadin.fr

Many other **Networks** and **Questions**

Answering **questions** means **building models**

Networks ⟷ Graphs

Network

- a set of **elements** connected by **links**
- networks are structures traversed by flows

Graph

- a set of **nodes/vertices** connected by **edges** or **arcs** (directed edges)

  ⟹ graph is a relevant formalism for representing relations between entities

- thus, *good candidates for modeling networks*

References

- Reductionism:
  `https://en.wikipedia.org/wiki/Reductionism#In_science`
- Complex Systems:
  `https://en.wikipedia.org/wiki/Complex_system` (and the associated bibliography)
- Prigogine, Ilya (1997). `The End of Certainty`, The Free Press, New York.
- Bak, Per (1996). `How Nature Works: The Science of Self-Organized Criticality`, Copernicus, New York, U.S.
- Networks: Newman, Mark (2010). `Networks: An Introduction`, Oxford University Press.