Human digital traces

mobility, sewage and social media

Dr. Francesco Durazzi

francesco.durazzi2@unibo.it

Looking for traces

- Information about human behavior is useful in many research field, but:
- Privacy concerns
- High costs

The *digital era* offers new ways to get a statistical glimpse on human-related data -> **it's not psicology**

Trace: a measurable quantity which describes the subject behaviour (without necessarily the intent of the subject)

Disclaimer: a health perspective

Focus on epidemiological surveillance:

Pre-warning about pathogens

Quantifying the impact on society

Predicting possible scenarios

Measure the effectiveness of control measures

How to? **Systematic collection, analysis and interpretation of data**

e.g. genomics, animal mobility flows, opinions on online social networks…

DIGITAL TRACES
Characteristics of online social network data

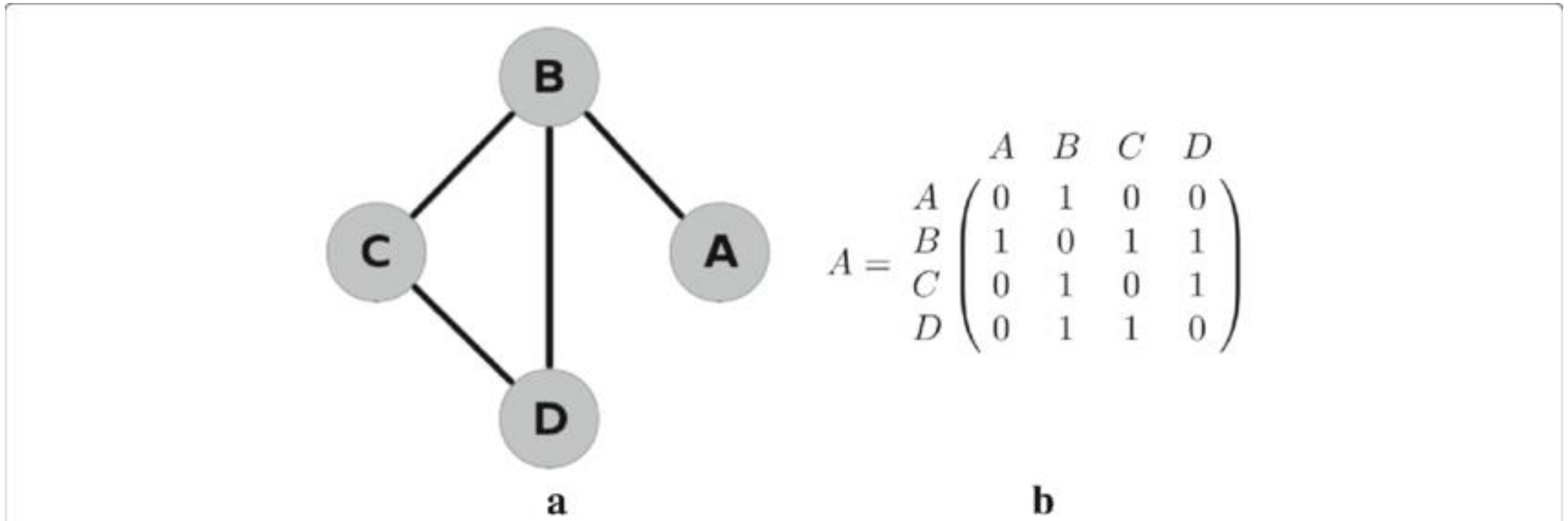
- Real-time view on society
- Different types of data together: text, location, timestamp, images
- Straightforward network structure with different types of interactions

Networks in a nutshell

Graph G(V,L): finite set V of *n* elements (nodes, vertexes) and set of *k* couples of nodes (links, edges)

A network/graph can be defined through its *adjacency matrix* -> compute centrality measures

e.g. connectivity degree k_i: row/column sum (number of neighbours of a node)



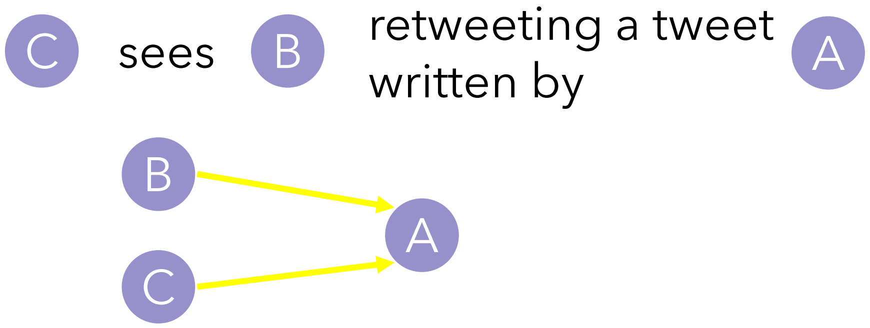
Retweet network (X platform)

A→B if user A **retweets** user B.

Weight: number of retweets.

Interpretation: agreement.

The edge is always between the retweeting user and the writing user: the intermediate retweet structure is hidden. One tweet form a star-like graph, so the final network is an aggregation of star-like modules. Densely connected modules can be thought of people sharing the same ideas.



Network analysis

- Centrality measures
- Community structure
- Linking network structure to other attributes: text, geo-localization

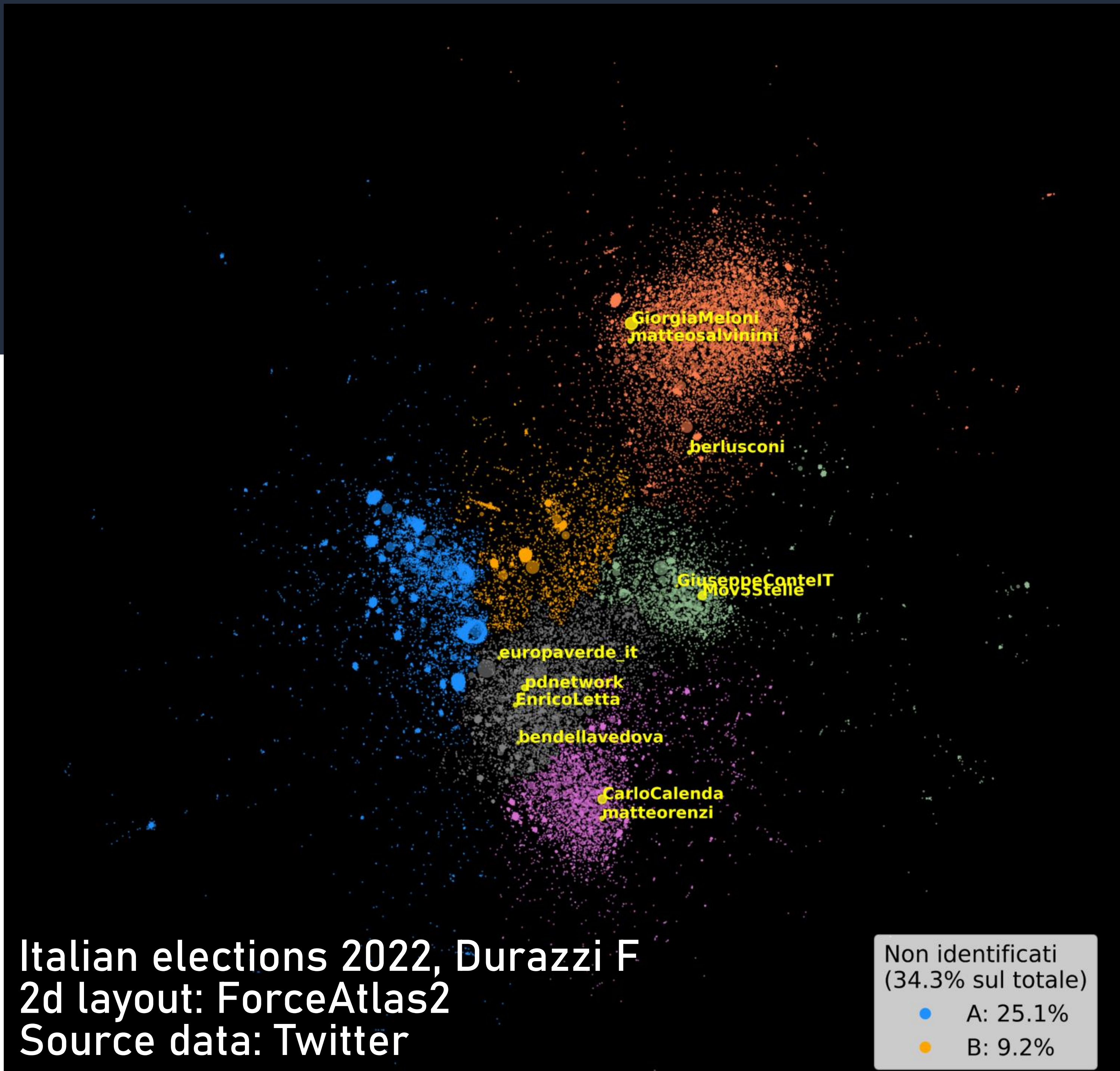
Community detection

Objective: find groups of users maximizing the intra-community modularity Q

$$Q_{ij} = A_{ij} - \frac{k_i k_j}{2m}$$

In plain words, maximize the number of edges inside the community w.r.t. those expected by chance

See more details on my Linkedin



Not just networks: text embeddings

Mapping text into vector spaces allows Machine Learning and Artificial Intelligence applications:

- Clustering
- Classification
- Regression
- Vector operations (eg sum/difference, average)

Vocabulary lookup table

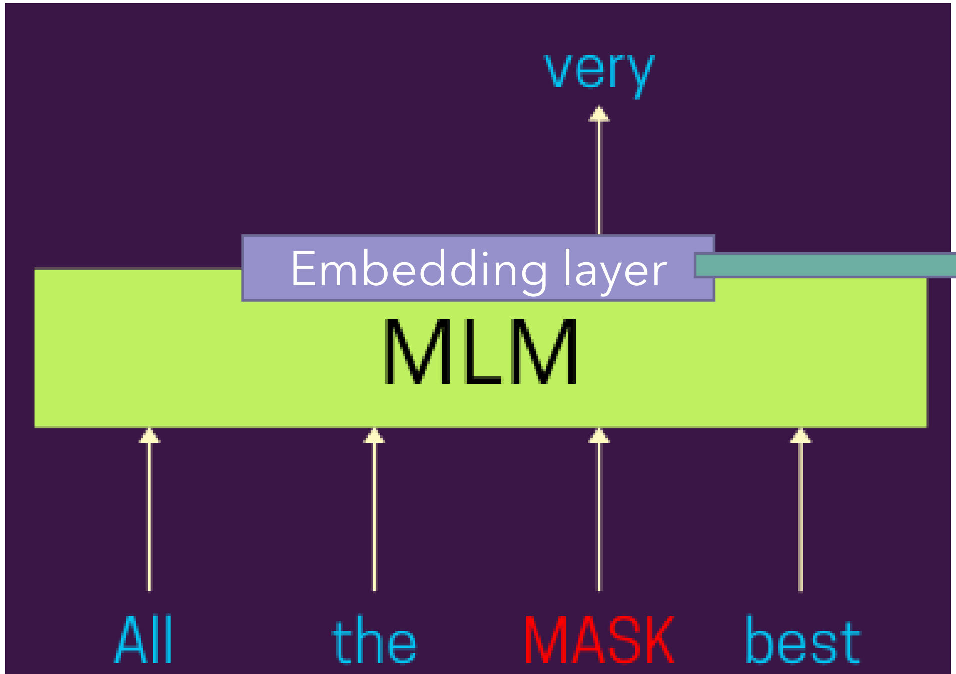
$$\text{I love chocolate.} \leftrightarrow \underbrace{\begin{matrix} 0.3 & -0.2 & 0.9 \\ 0.4 & 1.3 & -1.2 \\ 0.2 & 3.5 & -0.6 \\ 1.1 & -1.2 & 0.8 \end{matrix}}_{\text{\# of words}}$$

Embedding dimension

Not just networks: text embeddings

Language Modeling (LM) is a very popular way to embed text using neural networks (specifically *attention-based transformers*)

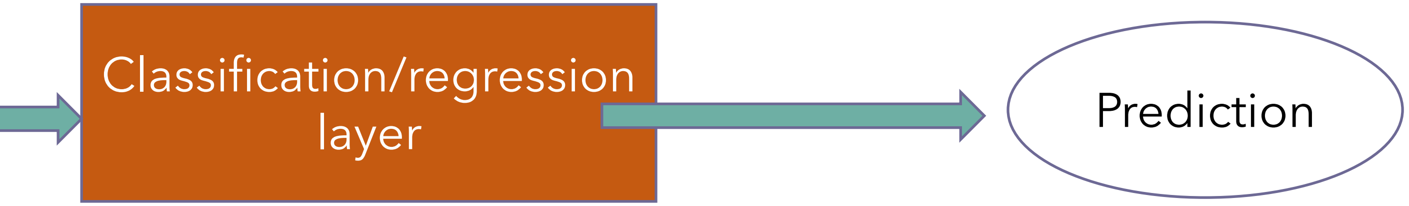
1) **Pre-training** as Language Model: model predicting missing/masked words in a sentence (self-supervised on large corpora, e.g. www, Wikipedia, Twitter) -> to predict the masked word, all the sentence is encoded in its embedding layer



2) Task-specific **fine-tuning**: final classification/regression layer for the final task (supervised regression/classification on labelled data)

With Step1, the models “learns the language” in general and with Step2, it learns how to deal with specific tasks

You can extract sentence-embeddings as the second-last layer (the one before masked-token prediction)



Vaswani A, *Attention is all you need*, 2017

https://huggingface.co/blog/getting-started-with-embeddings

Example: Twitter retweet network on «vaccination»

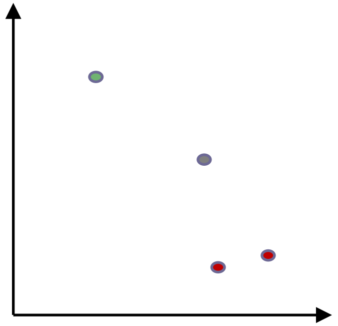
ProVax and AntiVax classification through network and text fetaures

- **Embedding of Tweets text** into a N-dimensional

Text	Label	User ID
Odio i vaccini	AntiVax	1
Non vaccinatevi mai	AntiVax	1
Oggi partono le vaccinazioni.	Neutral	2
Vaccino fatto	ProVax	2

Gori D, *Mis-tweeting communication: a Vaccine Hesitancy analysis among twitter users in Italy*, Acta Biomedica, 2021

Text embeddings



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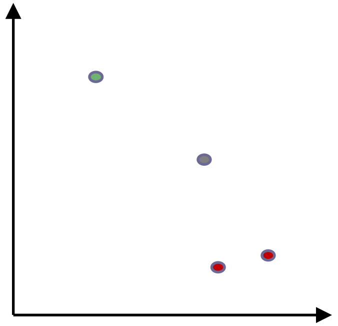
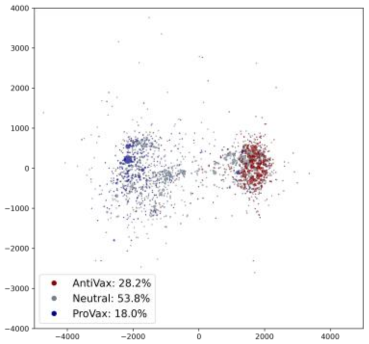


Network 2d layout



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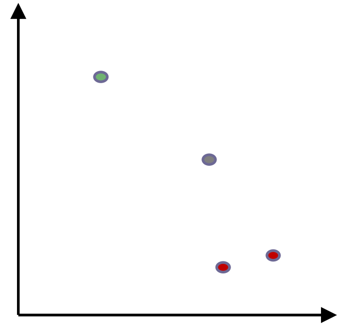

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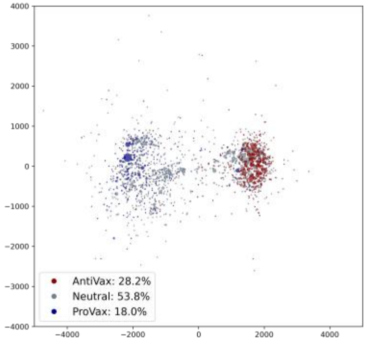
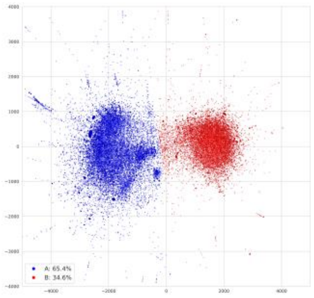


Predictions



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ProVax and AntiVax classification through network and text fetaures

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- Merge text and network features to classify users (Deep learning or simpler)
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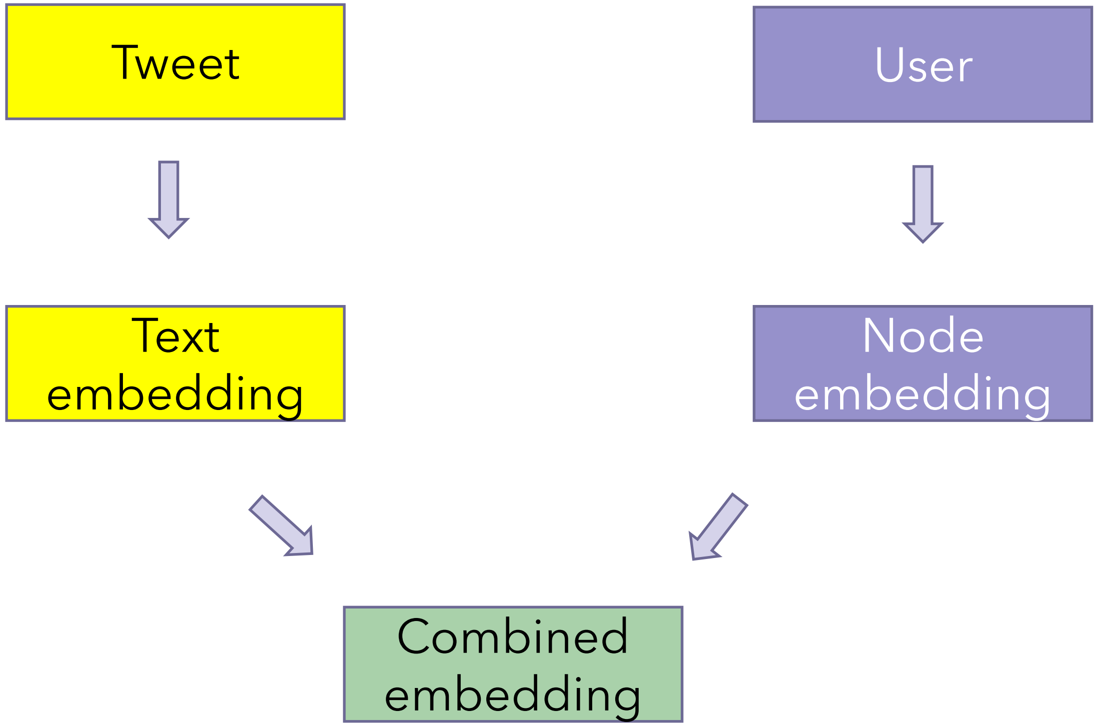


Scientific literature automated search and analysis

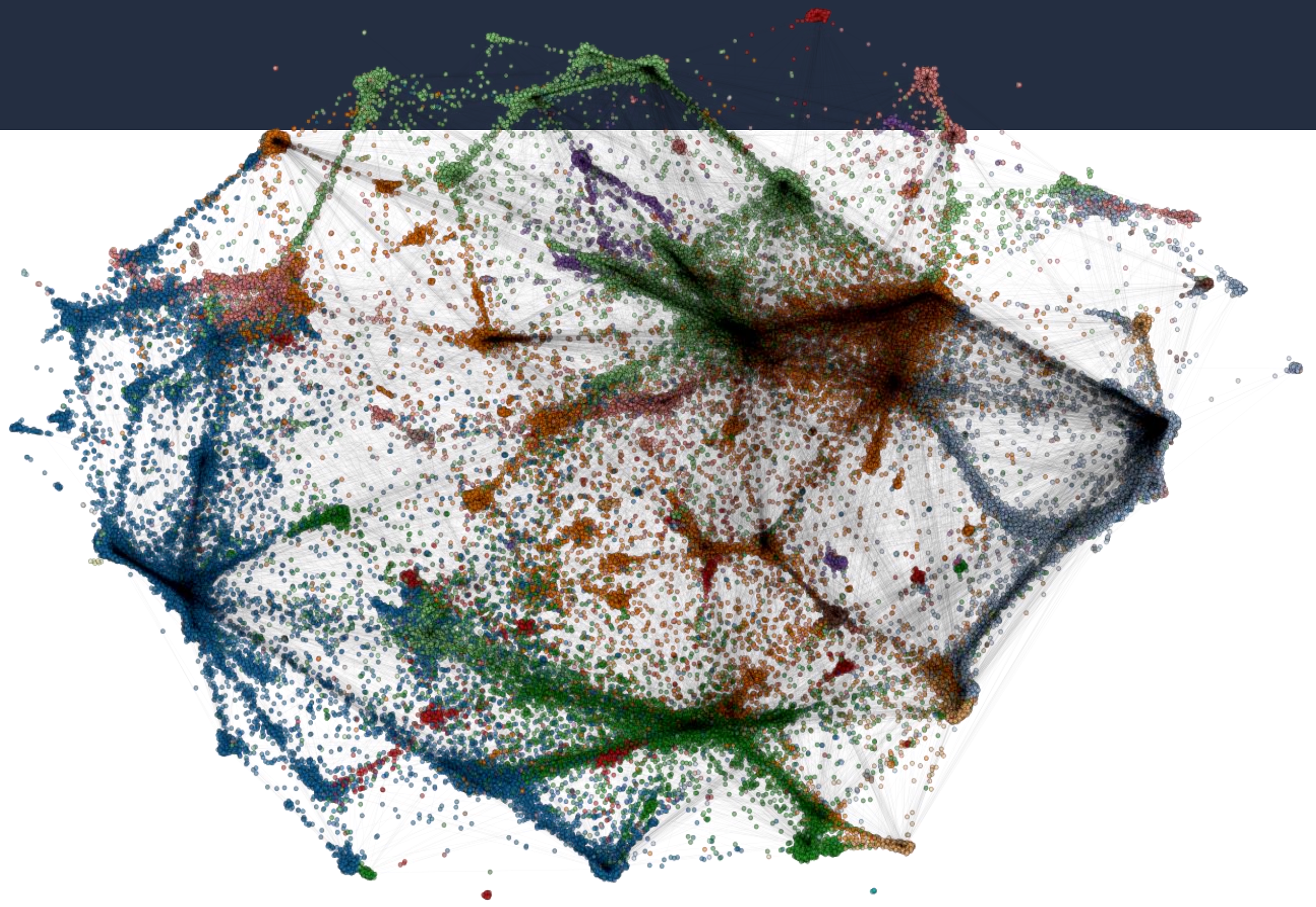
We collected the whole Pubmed archive

Choose topics of interest: e.g. COVID-19

Citation network

Topic modelling: transform abstracts into vectors and clusterize them to extract the different topics

Natural Language Processing and Regular Expressions to extract information: values, keywords, results



Scientific literature automated search and analysis

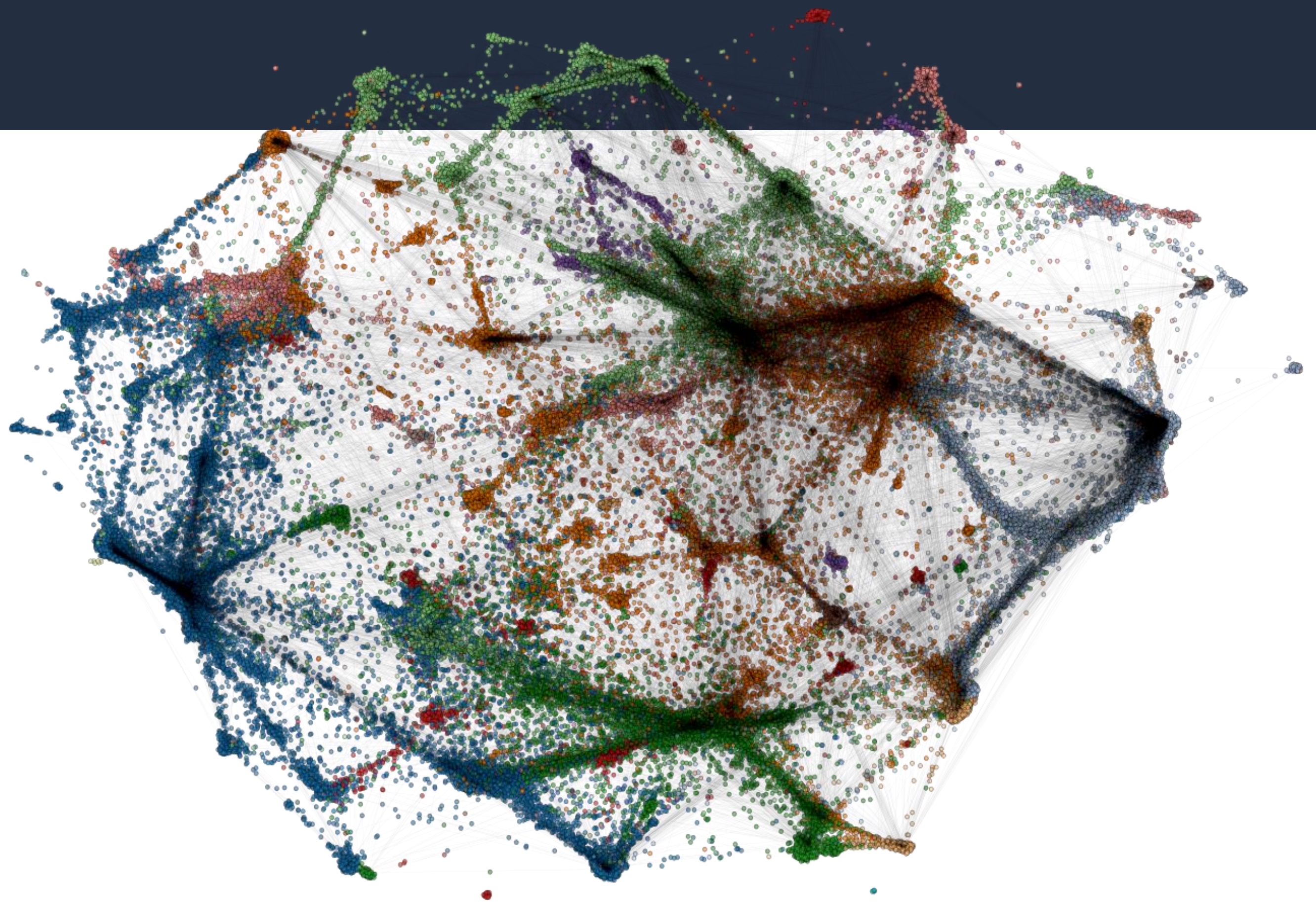
Early detection of relevant papers

Automated approach to:

- Measure citation growth speed

- Build autor-level features

- Explore the relationship between groundbreaking papers and network structure: "hub" authors & papers



Success is driven by connections?
https://bigthink.com/the-well/the-science-of-success/

Citations are indicators of good quality?

https://link.springer.com/article/10.1007/s11192-023-04735-0

Environmental traces

Epidemiological monitoring at urban level

Clinical and mobility data integrated to wastewater sequencing

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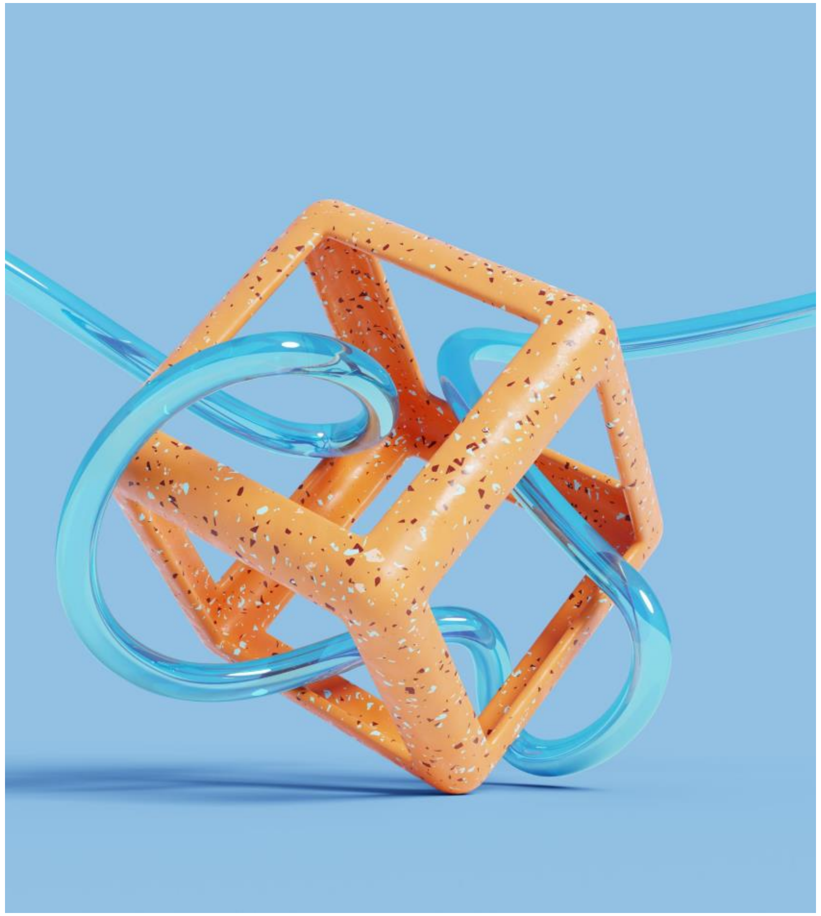

Epidemic entanglement

Difficult to disentangle single contributions of epidemic drivers

Example: at now, the number of COVID-19-infected individuals is way lower than during the pandemic peaks of 2020-2021. This is due to:

a) lower transmissibility of the virus?
b) increased vaccination coverage?
c) mutated social habits? (distancing, facial masks)
d) different climatic conditions?
e) less testing

3-year monitoring of COVID-19 in Bologna metropolitan area

- Epidemiological mathematical model adjusted on clinical data
- RNA sequencing on urban sewage
- Emergence of SARS-CoV-2 lineages over time through genomic data
- Road traffic time series
- Vaccination coverage of the population

HERA

RNA sequencing of wastewater

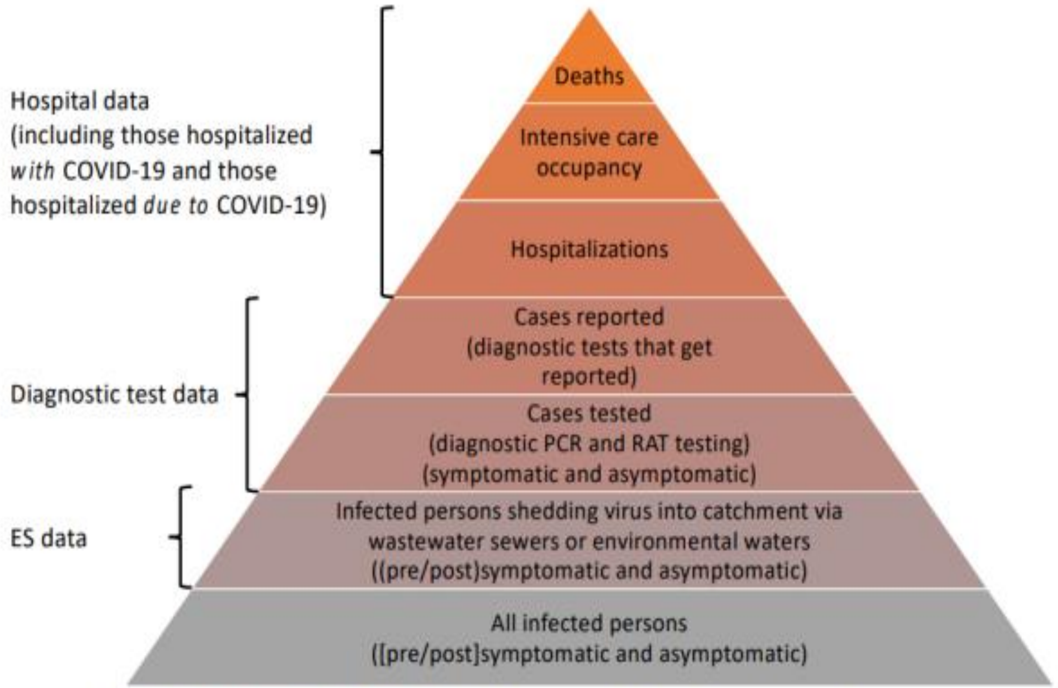

Figure 1. Illustration of the role of SARS-COV-2 environmental surveillance as a source of data on COVID-19 and SARS-CoV-2 in communities via a defined wastewater catchment[5].

[5] World Health Organisation (WHO) Environmental surveillance for SARS-COV-2 to complement public health surveillance, 14 April 2022. WHO-HEP-ECH-WSH-2022.1-eng.pdf. Environmental surveillance for SARS-COV-2 to complement public health surveillance – Interim Guidance (who.int)

- Martin, J.; Klapsa, D.; Wilton, T.; Zambon, M.; Bentley, E.; Bujaki, E.; Fritzsche, M.; Mate, R.; Majumdar, M. **Tracking SARS-CoV-2 in Sewage: Evidence of Changes in Virus Variant Predominance during COVID-19 Pandemic**. *Viruses* 2020, *12*, 1144. doi: 10.3390/v12101144
- Izquierdo-Lara R, Elsinga G, Heijnen L, Munnink BBO, Schapendonk CME, Nieuwenhuijse D, Kon M, Lu L, Aarestrup FM, Lycett S, Medema G, Koopmans MPG, de Graaf M. **Monitoring SARS-CoV-2 Circulation and Diversity through Community Wastewater Sequencing, the Netherlands and Belgium.** *Emerg Infect Dis.* 2021 May;27(5):1405-1415. doi: 10.3201/eid2705.204410.
- Nattino G, Castiglioni S, Cereda D, et al. **Association Between SARS-CoV-2 Viral Load in Wastewater and Reported Cases, Hospitalizations, and Vaccinations in Milan**, March 2020 to November 2021. *JAMA.* 2022;327(19):1922–1924. doi:10.1001/jama.2022.4908

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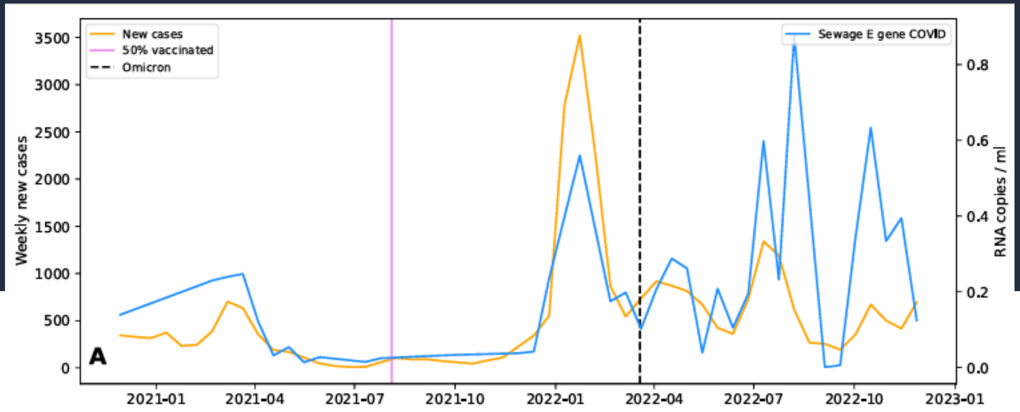

Methods

- Sampling twice per month (November 2020 – November 2022)
- RNA extraction and real-time PCR on SARS-CoV-2 E-gene
- Viral load estimation from serial dilutions

Results

- Correlation between sewage viral load and number of cases: positive test ratio (r=0.73)
- Hospitalizations decline but viral load increase

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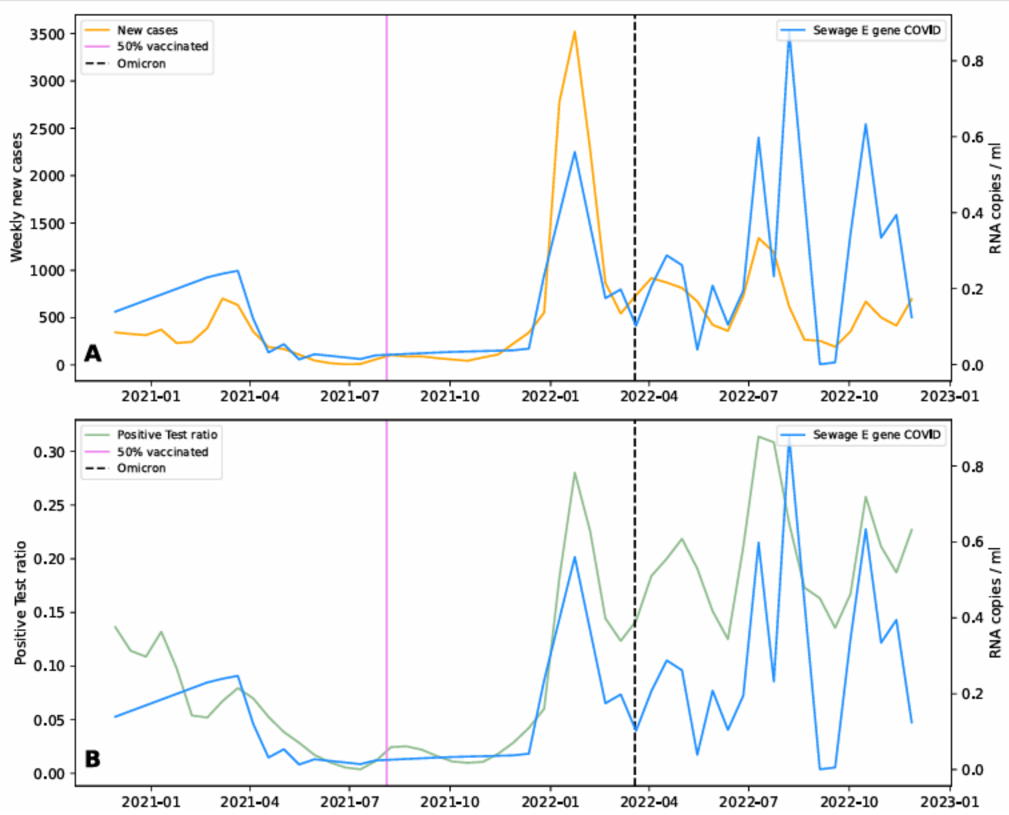

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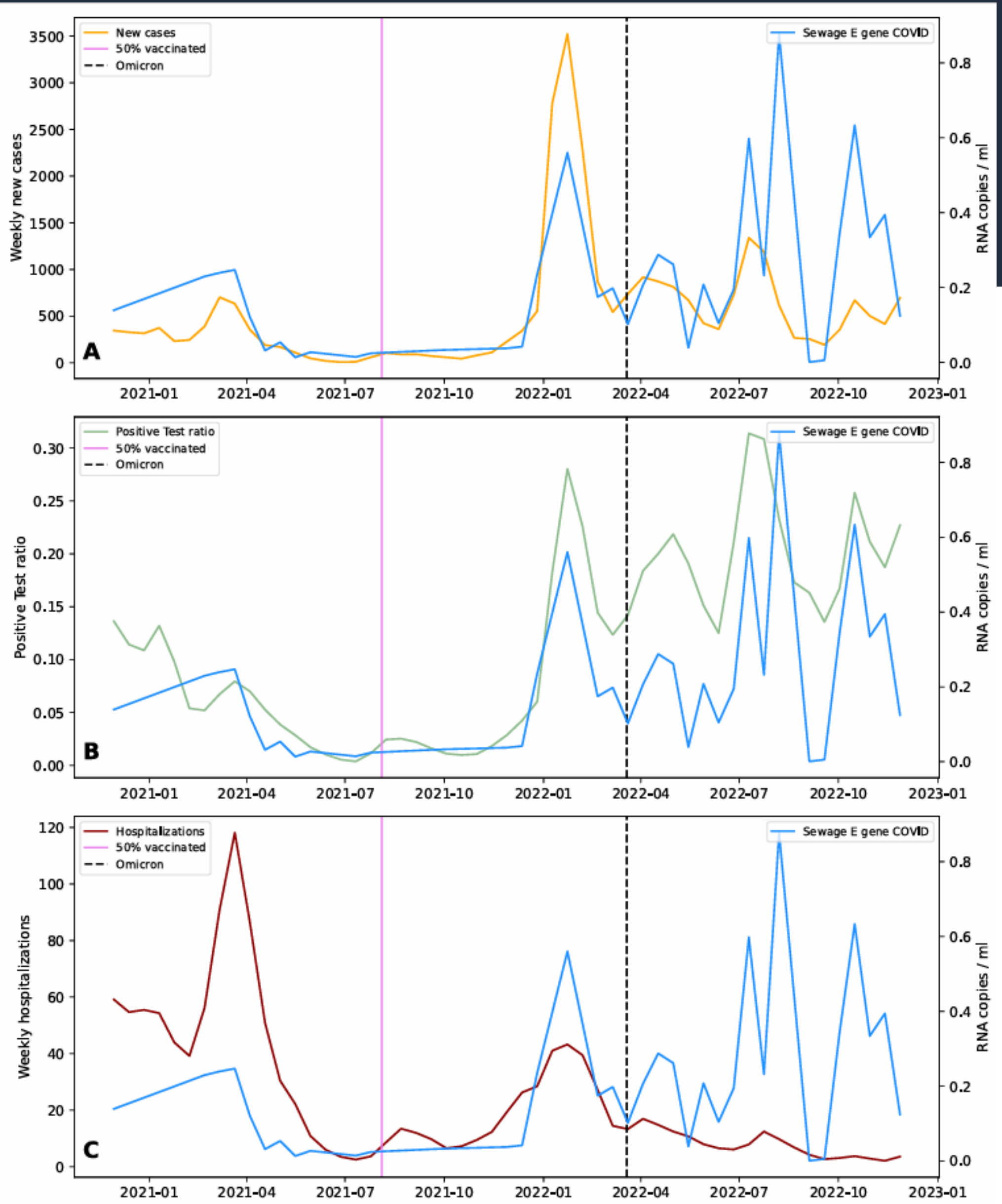

Sociability and mobility

Sociability: amount of social activity, estimated from the number of infections through an epidemiological model

Mobility: measured from road traffic in Bologna

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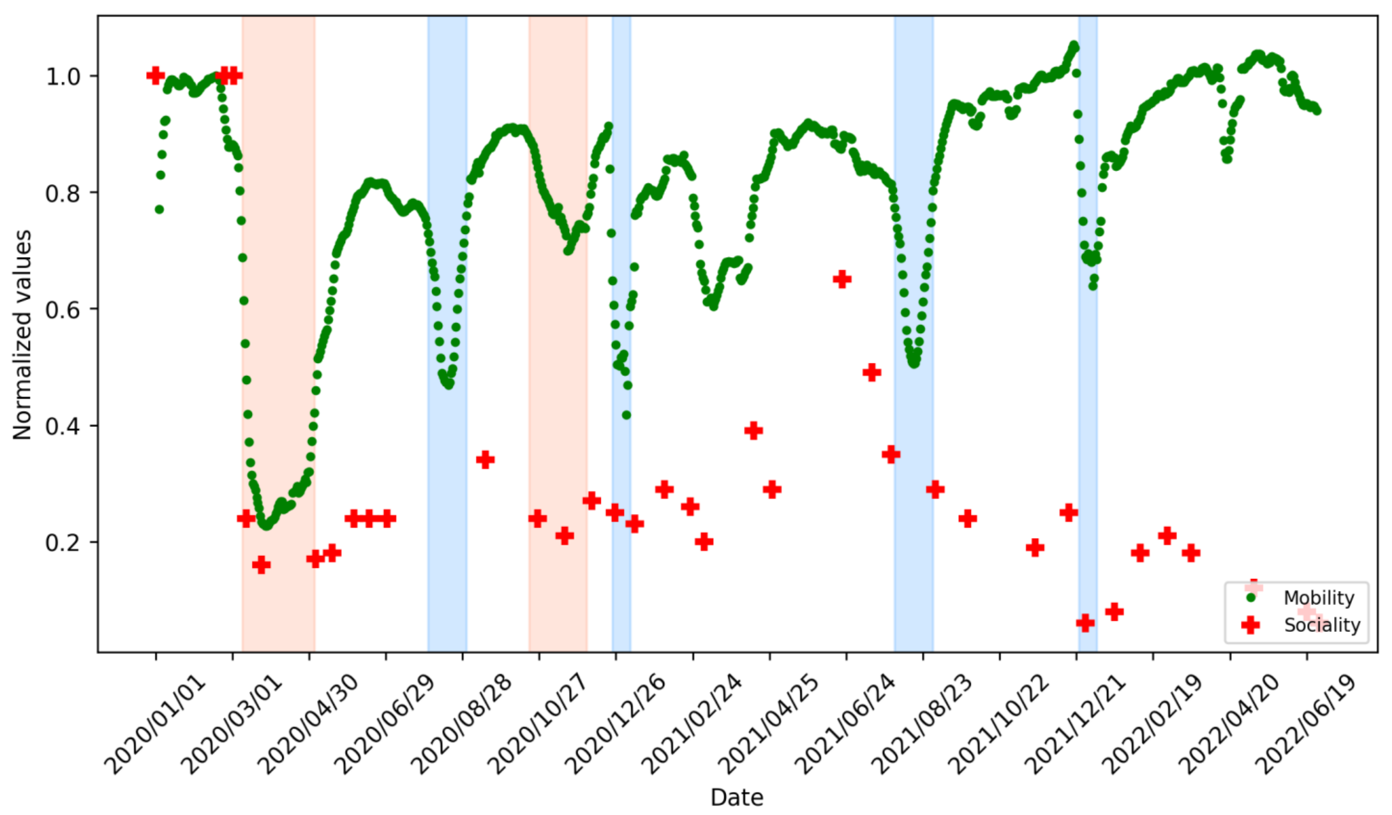
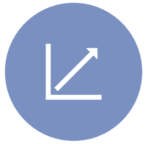
- **Blue areas**: holidays





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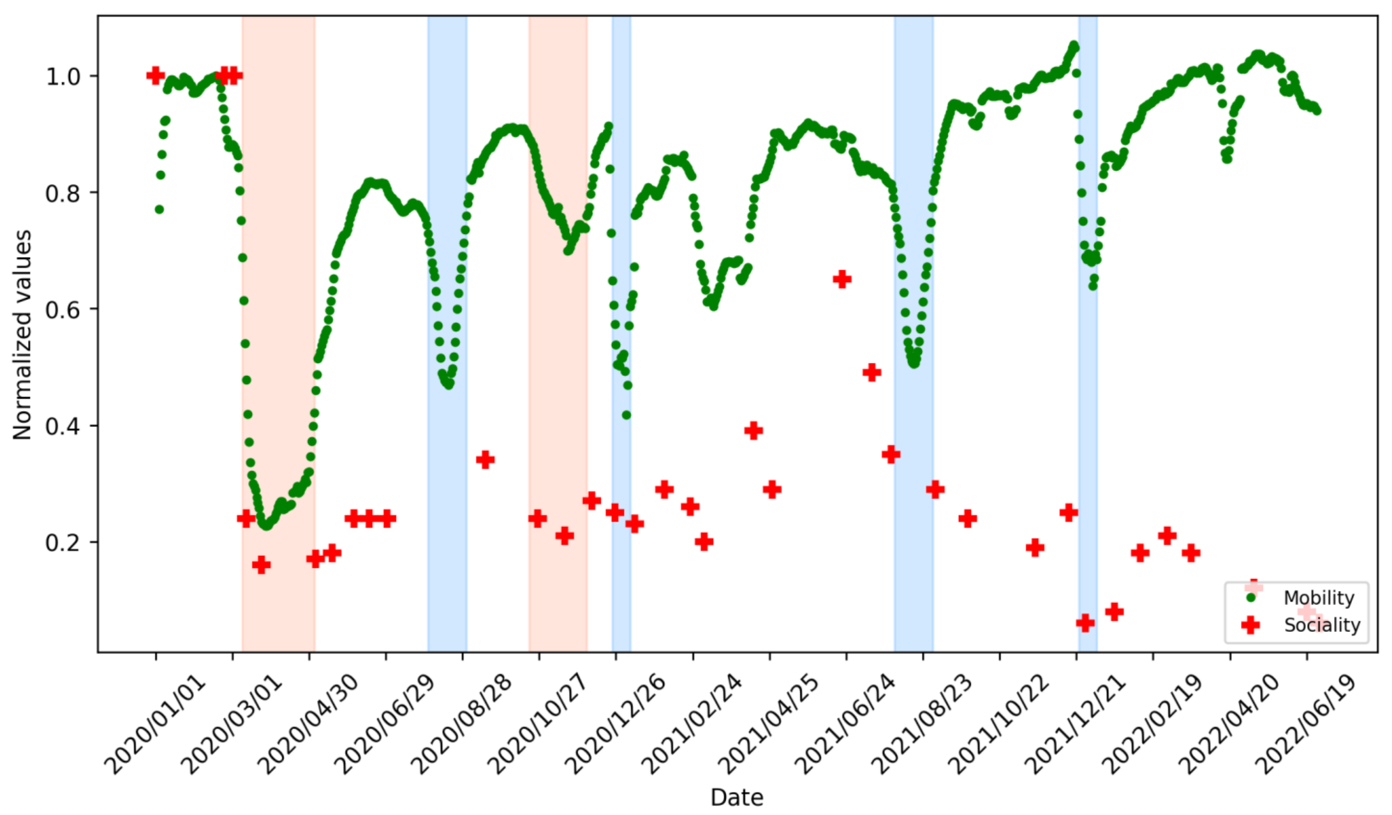


- **Mobility** is critically impacted at the first lockdown (February 2020)
- **Mobility** slowly recovers to pre-pandemic values, with down-ward peaks at holidays and closures

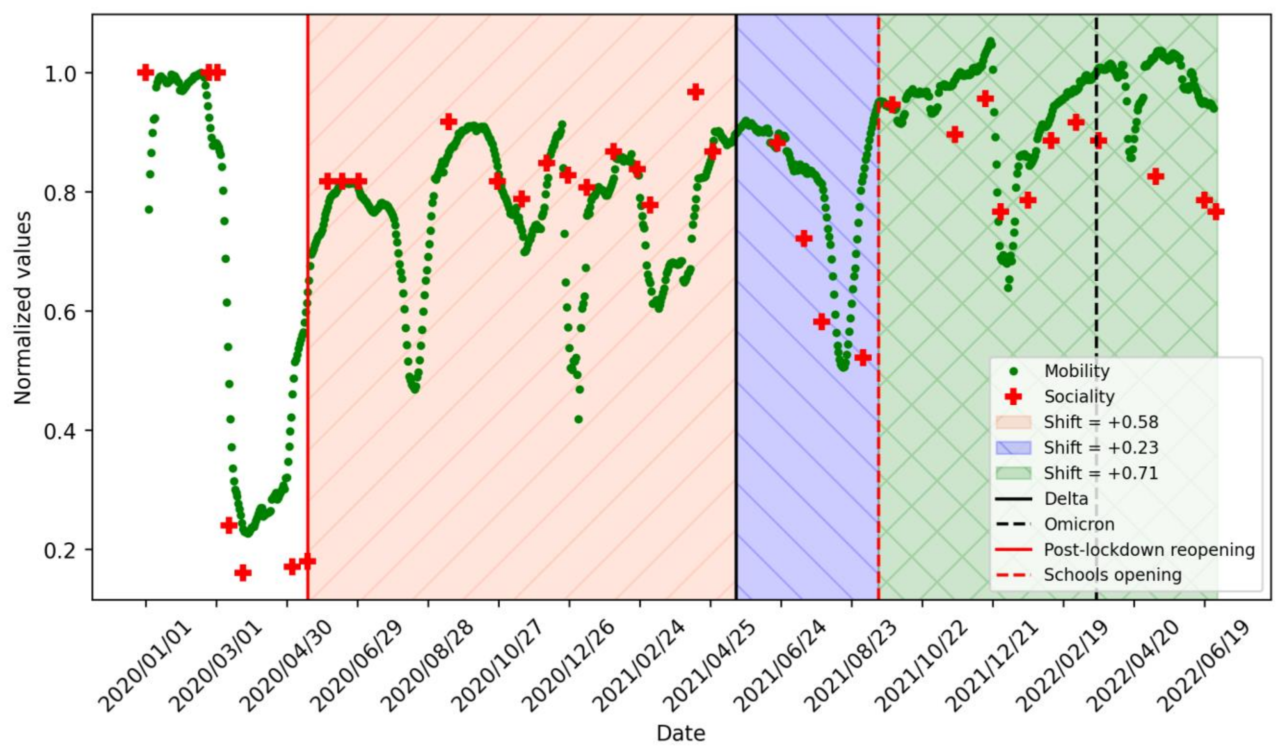
- **Sociability** impacted at the first lockdown (same as mobility), but remains generally low -> contacts are now protected and viruses are weaker

Sociability and mobility

3 breakpoints: shift to re-normalize mobility and sociability (on the first value)

Day	Event	Shift
18/05/2020	Activities reopening (bar, restaurants)	0.58
17/05/2021	Delta variant in Emilia Romagna	0.23
15/09/2021	Schools reopening	0.71

- High correlation (r=0.76)
- **Mobility can be used as a proxy to parametrize sociability** in the model for *short* periods (3 months at least)



- **Shifts ~ gap between protected and unprotected contacts**
- Small shift at outbreak (still not much protection) and summer 2021
- Larger shifts during periods of increased sensitivity to control measures (distancing, facial masks)

Conclusions

We live in an era where many traces are available:

to big tech corporates: surveillance capitalism ☹

to «investigative» scientists: reveal unexpected associations and hidden correlations ☻

For a physicist, new areas emerge in which laws can be proposed and their validity verified through measurements and experiments

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