Physics of Life Data Epidemiology

Lect 1: Introduction

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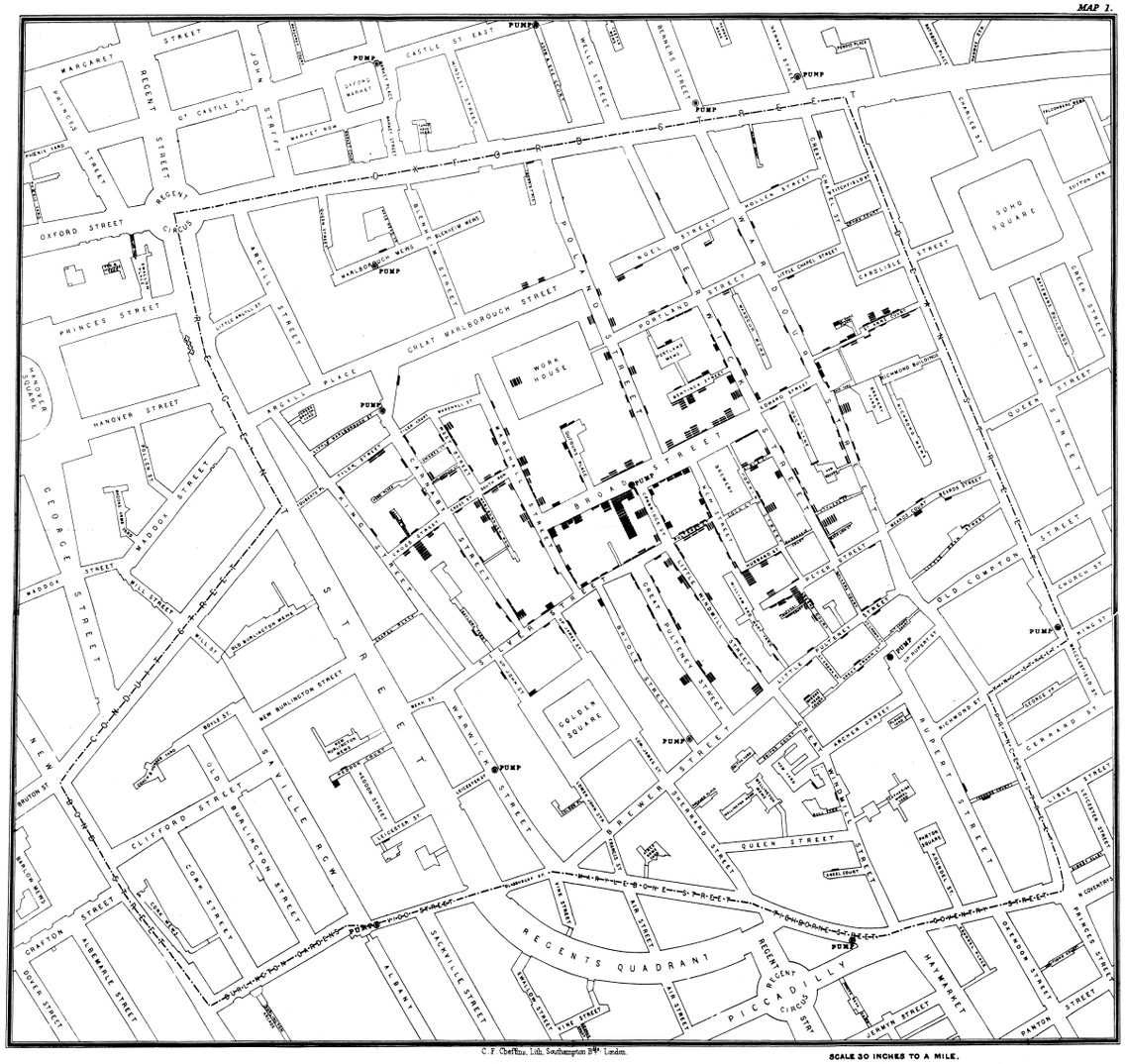
outbreak analytics



Cholera: understand the drivers of propagation

The Broad Street cholera outbreak, occurred in 1854 near Broad Street in the Soho district of London, England. It killed 616 people

Based on the spatial pattern of illness among residents, John Snow hypothesised that cholera was spread by an agent in contaminated water and identified the transmission hotspot.

outbreak analytics

[The New Yorke Times, https://www.nytimes.com/interactive/2020/03/22/world/coronavirus-spread.html]

COVID-19: early warning

30 Dec 2019: WHO informed about an *urgent notice on the treatment of pneumonia of unknown cause* by Wuhan Municipal Health Committee

17 Jan 2020: China reports 41 cases + 1 deaths in Wuhan. **BUT:** Thailand reports 2 cases and Japan 1 case, all traveling by plane from Wuhan airport

outbreak analytics

COVID-19: early warning

Wuhan airport, passenger per day, w= 3301

Wuhan airport, catchment population, N = 19 millions

daily probability of travelling out of Wuhan $p_{\text{daily}} = \frac{w}{N}$

$p_{\text{travel}} = p_{\text{daily}}\, T_d$

time to detect a case, T_d=incubation period + time to hospitalisation. Incubation period 5-6 days; time to hospitalisation 4-5 days (from SARS)

$I_{\text{trav}} = I_{\text{Wuhan}}\, p_{\text{travel}}$

[Report num 1 Imperial College, https://www.imperial.ac.uk/media/imperial-college/medicine/mrc-gida/2020-01-17-COVID19-Report-1.pdf]

outbreak analytics

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estimated cases 1,723 (95% CI: 427 – 4,471) (Epidemic assessment)

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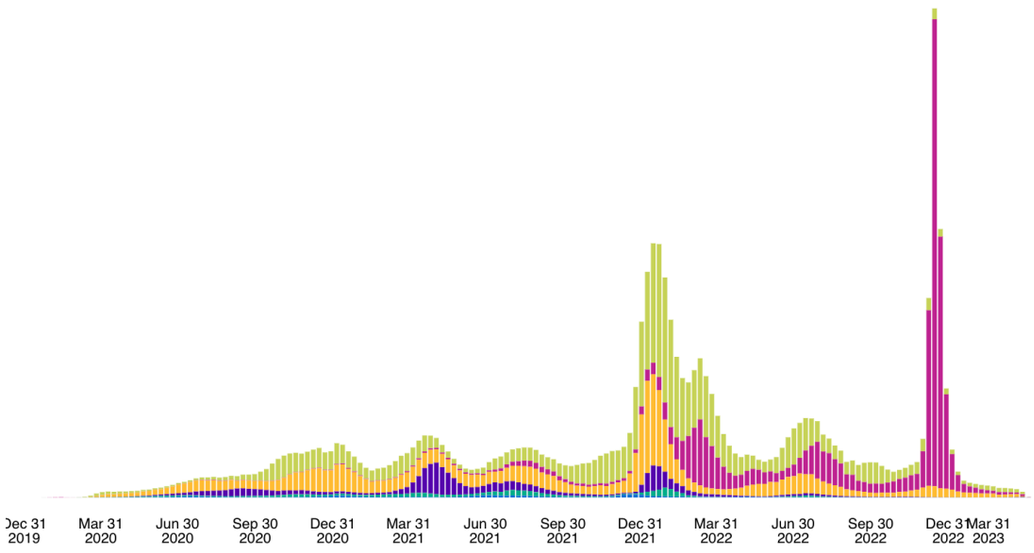
Epidemiology

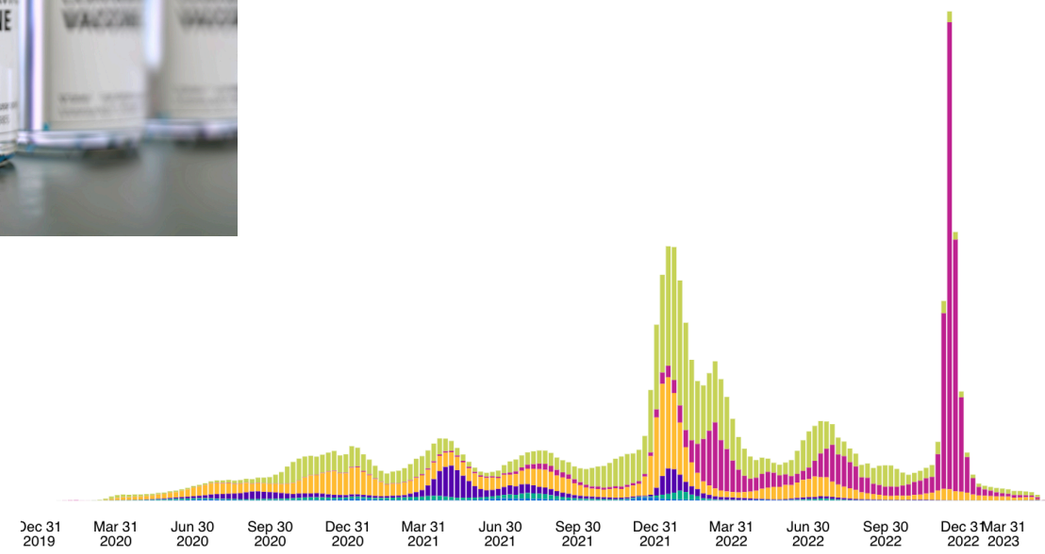


epidemiology

By definition, epidemiology is the **study** (**scientific, systematic, and data-driven**) of the **distribution** (frequency, pattern) and **determinants** (causes, risk factors) **of health-related states** and events (not just diseases) in specified populations (neighborhood, school, city, state, country, global). It is also the application of this study to the control of health problems

[Principles of Epidemiology in Public Health Practice, CDC]

Fighting infectious diseases

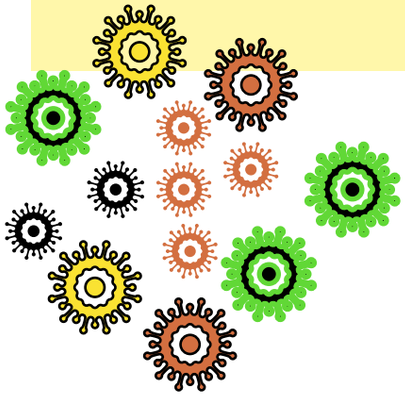


public health

medicine

epidemiology

microbiology



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Epidemiology

mechanistic modelling
modelling epidemics with a physics approach
—> contagion

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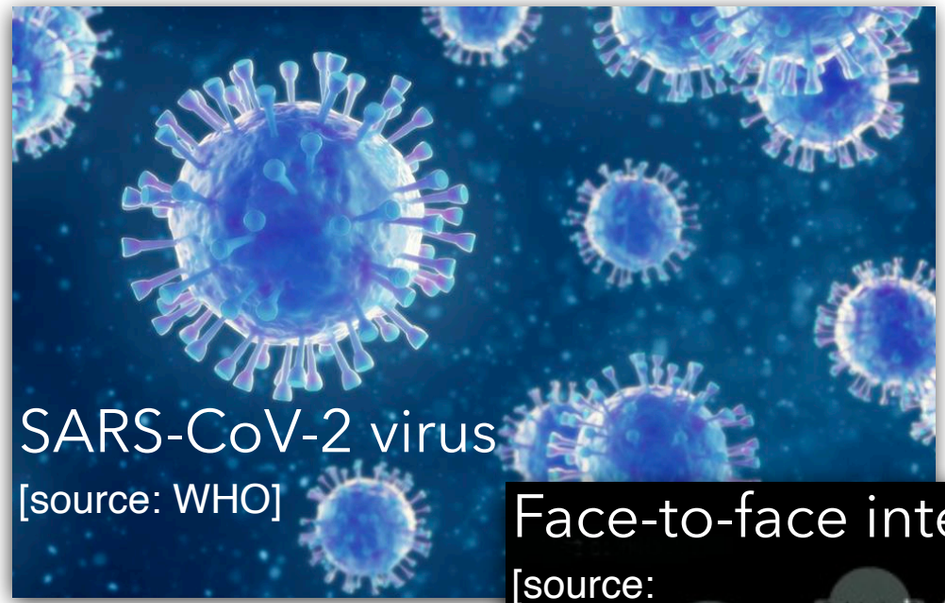
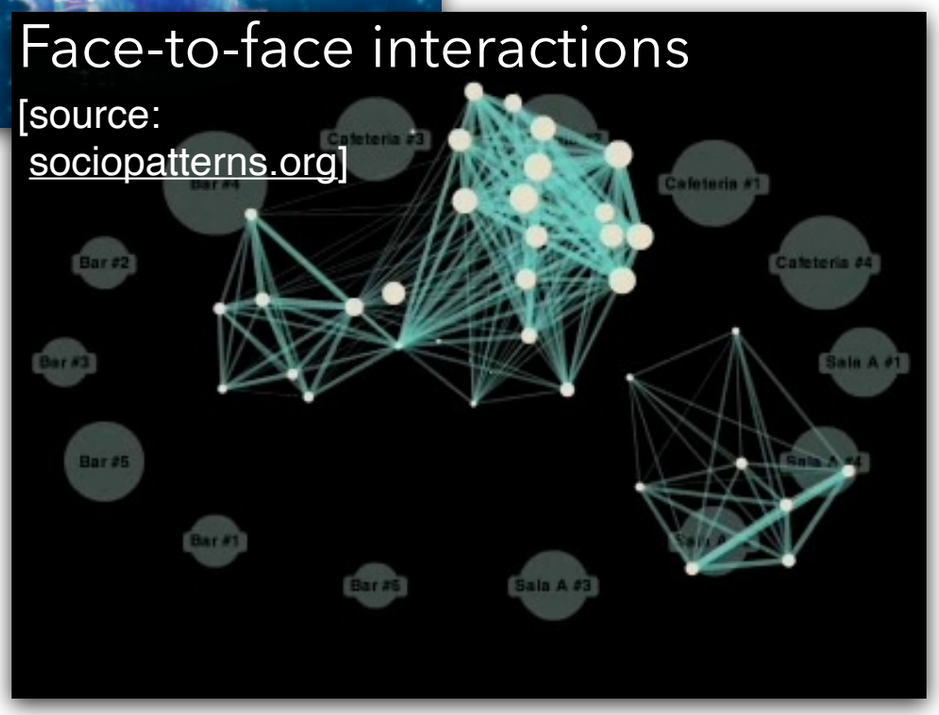


SARS-CoV-2 virus

[source: WHO]

Face-to-face interactions

[source: sociopatterns.org]



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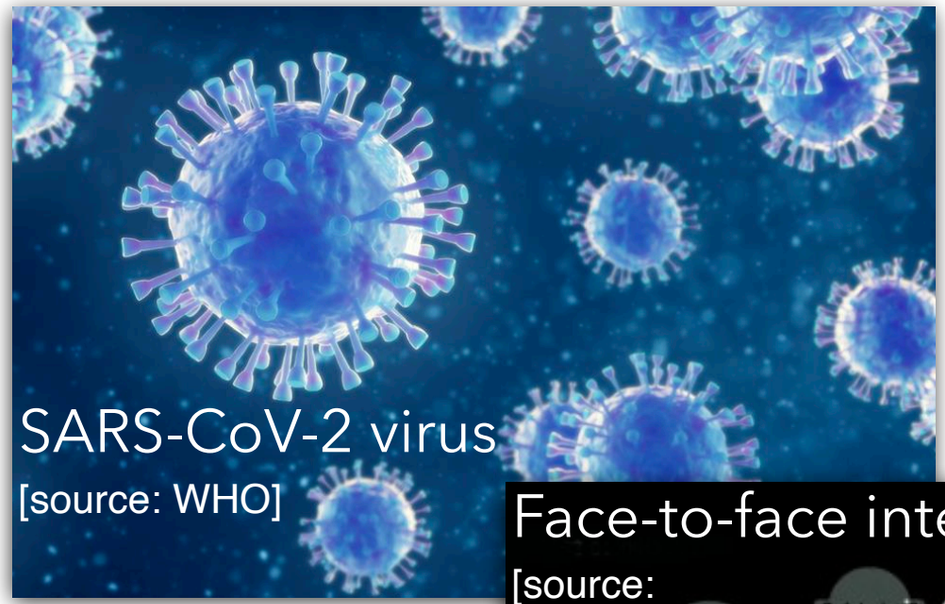

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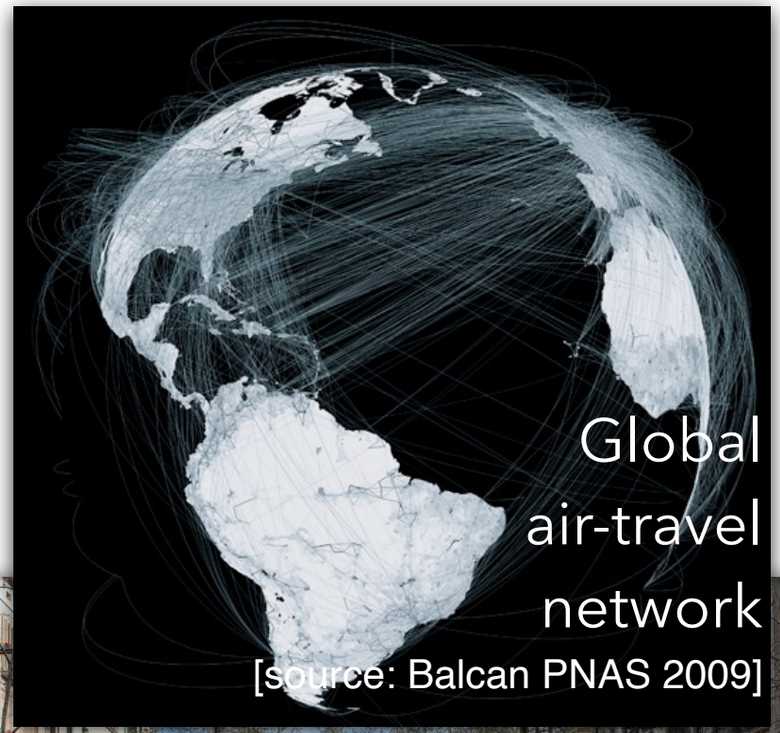

Global air-travel network

[source: Balcan PNAS 2009]

Face-to-face interactions

[source: sociopatterns.org]

Lockdown in Barcellona, Mar 2020

[source: New York Times]

Physics modelling of epidemics

Modelling grounded in complex systems physics

- non-linear dynamics
- stochastic processes
- spreading on networks
- coarse-graining techniques
- mean field approximations

Formulating theory

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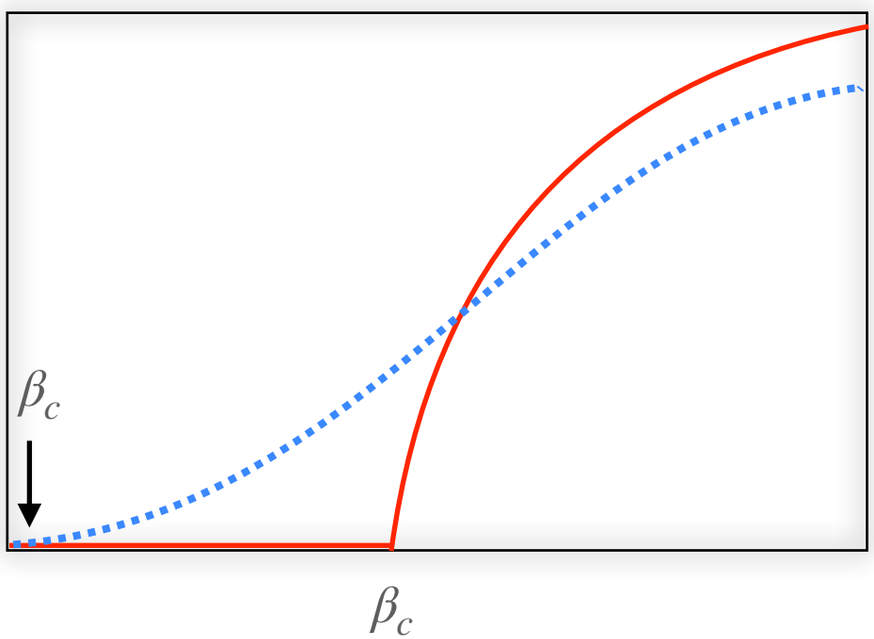

phase transition epidemic extinction/ epidemic invasion

factors that turn a disease to a pandemic

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Formulating theory

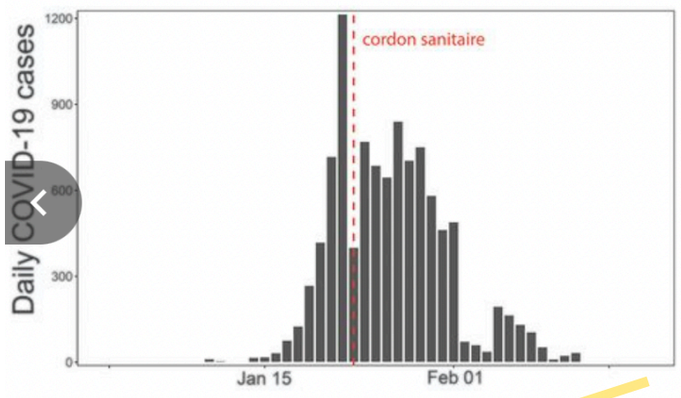
Confronting models with data

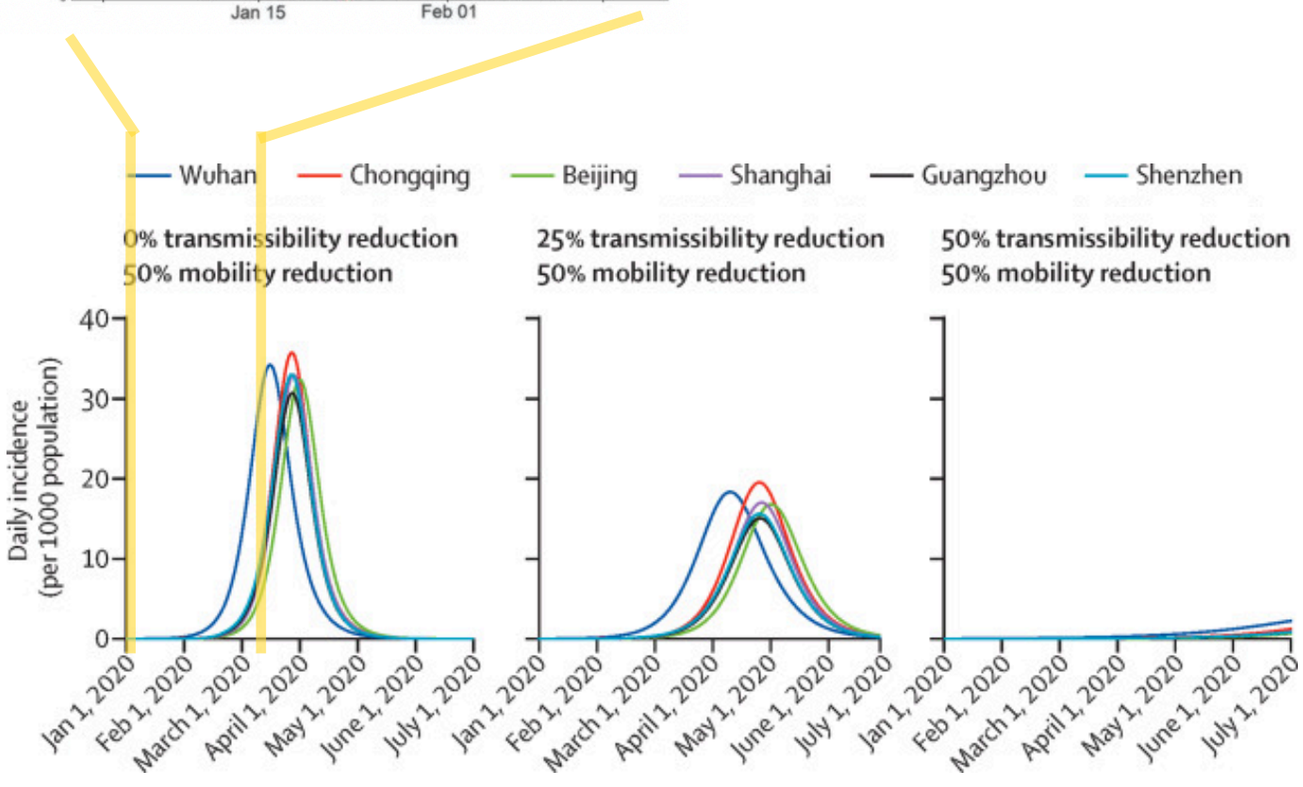
- Data aggregation
- Data filtering
- Design of appropriate null-models
- Statistical estimates of outbreak risk indicators
- Data assimilation techniques
- Bayesian inference

Validating models&theories (retrospective analysis) real-time outbreak analysis

outbreak analytics

[Kraemer et al Science 2020]





[Wu et al The Lancet 2020]

COVID-19: first forecasting analysis

population dynamics modelling

+

air-travel, large-scale database of within-China mobility

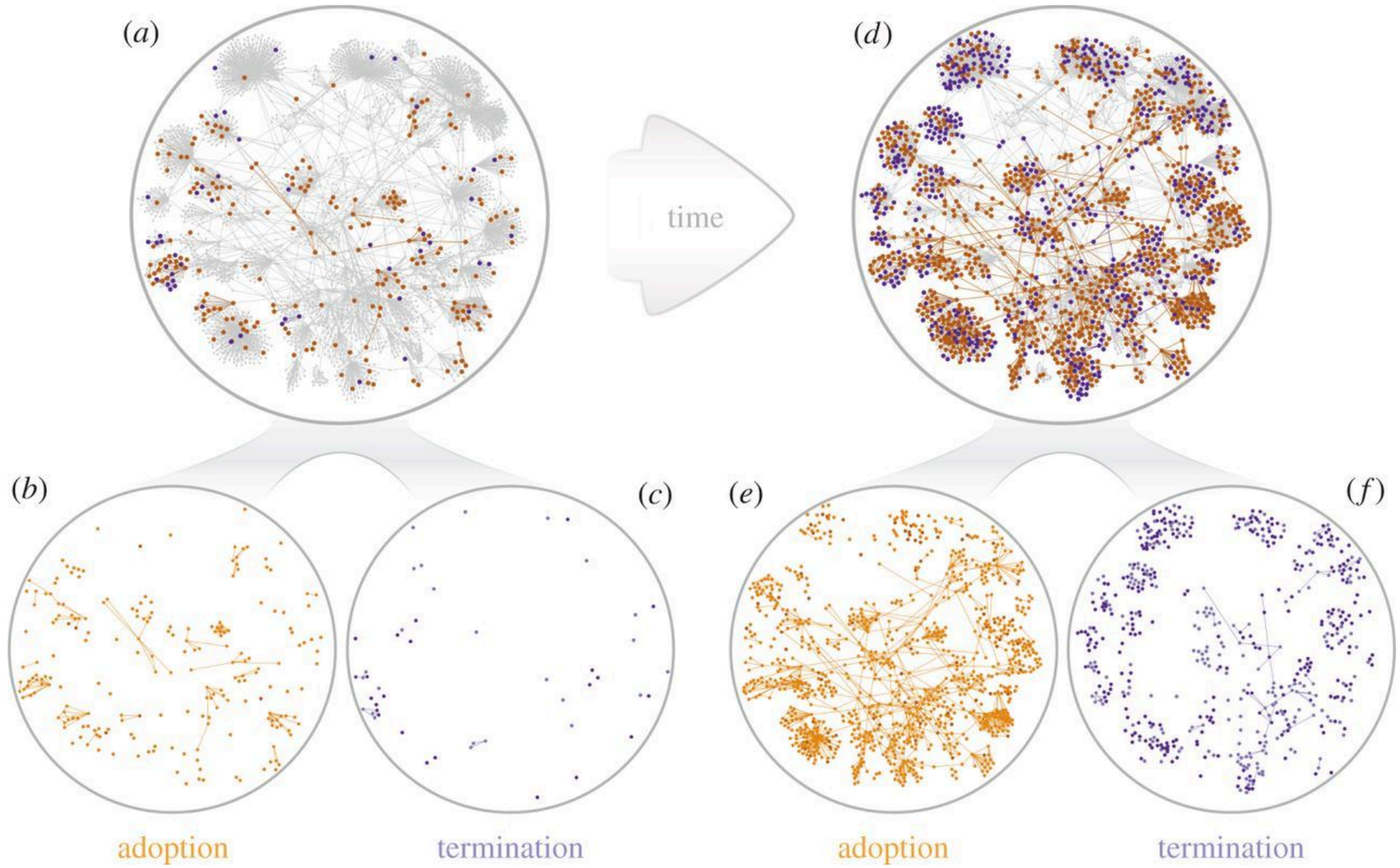
+

Markov Chain Montecarlo Maximum likelihood

1) Independent self-sustaining outbreaks in major cities globally could become inevitable

2) Preparedness plans and mitigation interventions should be readied for quick deployment globally

contagion beyond infectious diseases: spread of innovation



analysis of a dataset recording the spreading of Skype service to empirically support the assumptions behind models of social contagion. The probability of adoption via social influence is linearly proportional to the fraction of adopting neighbours.

[Karsai et al J R Soc Interface 2014]

Syllabus

- Population dynamics in epidemiology
- Outbreak analysis
- Interplay between human behavior and epidemics
- Human mobility and spatial epidemic spread
- Contagion in non-communicable diseases
- Labs

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- **Course Organization:**

~15 lectures + ~ 6 labs + 2 projects days + Exam

- **Course Schedule: see Moodle**

Timetable

- Monday, 12.30pm-2pm, Lab P104 (Complesso Paolotti)
- Wednesday, 2.30pm-4pm, P1C (Complesso Paolotti)

Labs

- Python/Jupiter Notebooks
- Modeling + Data Analysis

Exam: two parts

- Written test
- To have the projects evaluated it is mandatory to pass the written test
- Projects performed by a group of 1-3 people
- Final grade: more weight to the project

- Official exam dates for this semester:
  to be communicated

Prerequisites

- Theory:
  - Differential equations
  - Probability theory
  - (preferred) Graph Theory, Complex Networks
- Computational:
  - (preferred) Basic Python with Jupiter

Refs.

- Books
  - Keeling, Matt J.; Rohani, Pejman, Modeling infectious diseases in humans and animals.
    Princeton University Press, 2008.
  - Kiss, István Z., Miller, Joel, Simon, Péter L., Mathematics of Epidemics on Networks.
    Springer, 2017.
- Scientific Papers:
  - R. Pastor-Satorras, C. Castellano, P. Van Mieghem and A. Vespignani. Epidemic processes in complex networks.
    Rev. Mod. Phys. 87, 925 (2015) (https://arxiv.org/abs/1408.2701)
  - + papers cited in the slides