Physics of Infection – modelling infection dynamics

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A bit about me

- B.A.Sc. Engineering Physics (U Toronto)
- Ph.D. Computational Physics (U Guelph)
- Have worked on infectious disease dynamics ever since
- Cross-appointed R(D)SVS/SoPA
- "Analytical magpie" simple models, simulations, networks
- Both data-driven and data-inspired
- Foot-and-mouth diseases, bovine Tuberculosis, Rift Valley Fever, COVID-19, Avian influenza, etc.

Where it all began ...



Where it all began ...





"Psychohistory"



Based on the premise that the properties of human history could be described by statistical mechanics, if the human population was big enough (40x10¹⁵)





https://punchlistzero.com/specific-heat-of-ice/

If we know the statistical properties of <u>human contact</u>, can we describe epidemics







From https://wwwnc.cdc.gov/eid/article/12/11/06-0255_article

Soft condensed matter physics



Lord May of Oxford Govt CSA 1996-2000 Pioneer of Chaos Theory and Disease Ecology



OXIONO SCIENCE PUBLICATIONS INFECTIOUS DISEASES OF HUMANS DYNAMICS AND CONTROL ROY M. ANDERSON AND KOBERT N. MAY

From soft condensed matter physics to infectious disease models

Roy H. Crosby Public School, Markham Ontario Canada

Jamie Lloyd-Smith, UCLA, Professor Disease Ecology

https://punchlistzero.com/specific-heat-of-ice/

The Science of Networks

How does information flow create **emergent behaviour**?



2001 Foot-and-Mouth Disease Epidemic

6+ million livestock slaughtered

£8+ billion to control



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Received 22 May 2003 Accepted 31 July 2003 Published online 30 October 2003

The impact of local heterogeneity on alternative control strategies for foot-and-mouth disease

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The role of mathematical modelling in the control of the 2001 FMD epidemic in the UK

Rowland R. Kao 🖂











Percolation describes the change in component structure as probability of (bond/site) occupation changes

At the **percolation threshold**,

the largest component spans the population



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Percolation describes the change in component structure as probability of (bond/site) occupation changes

> For the simplest systems, the percolation threshold occurs when the basic reproduction number $R_0 = 1$

Percolation Threshold in livestock movement networks



PROCEEDINGS OF THE ROYAL SOCIETY B

BIOLOGICAL SCIENCES

Demographic structure and pathogen dynamics on the network of livestock movements in Great Britain

R.R Kao 🖂, L Danon, D.M Green and I.Z Kiss

Published: 16 May 2006 https://doi.org/10.1098/rspb.2006.3505

Under the right (ergodic) conditions,

the growth of the static network components captures the dynamic characteristics of disease spread

Genetic sequencing reveals network patterns

~ £2,000,000,000 est. in 1997 (3.1bn base pairs) WANTED 20 Volunteers to participate in the Human Genome Project a very large international scientific research effort.

The goal is to decode the human hereditary information (human blueprint) that determines all individual traits inherited from parents. The outcome of the project will have tremendous impact on future progress of medical science and lead to improved diagnosis and treatment of hereditary diseases. Volunteers will receive information about the project from the Clinical Genetics Service at Roswell Park, and sign a consent form before participating. No personal information will be maintained or transferred. Volunteers will provide a one-time donation of a small blood specimen. A small monetary reimbursement will be provided to the participants for their time and effort.



~ £20 (as of 2021) SARS-CoV-2 for 29.9K base pairs



https://www.genome.gov/about-genomics/educationalresources/fact-sheets/human-genome-project Fingerprints of individual viruses allow us to track disease spread



Accumulated Local Effects (ALE) plot

Machine Learning Analysis of Tayside Health Board data:

Risk factors to explain pairwise genetic distance relationships





Using a simple likelihoodbased model to combine sequence data with life history and network data vastly increases the discriminatory power of the data even when the resolution of the sequence data is poor

Likelihoods normalised relative to highest likelihood pathway.

Wood et al., 2025

Networks, games and behaviour

Playing with percolation: How influencing works through everyone





A few bad apples spoil the barrel

How networks influence biosecurity behaviour

Memory

Value



Memory

Value



Memory

Value



Memory

Value





What happens if someone doesn't care?



What happens if someone doesn't care?



What happens if someone doesn't care?

Influencing works through indirect action





A Few Bad Apples: A Model of Disease Influenced Agent Behaviour in a Heterogeneous Contact Environment

Jessica Enright 🖾, Rowland R. Kao 🖾

Spontaneous divergence of disease status in an economic epidemiological game

Ewan Colman , Nick Hanley and Rowland R. Kao



Simulated farmers trading over a network



Where do physicists fit in?

Physics stands between mathematics and "intuition"

... if we have a way of knowing what should happen in given circumstances without actually solving the equations, then we "understand" the equations, as applied to these circumstances.

A physical understanding is a completely unmathematical, imprecise and inexact thing, but absolutely necessary for a physicist.

Richard Feynman, Introduction the Feynman Lectures, Vol. II



