Complex Symptoms: Understanding epidemics from the perspective of complexity science

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ExAMPLER Workshop

29-04-24

My central claim

- Epidemics have always been with us and **always will be with us**.
- The spread of disease is influenced by human **behaviours**, **movements**, and **knowledge**.
- Resources are **scarce** and interventions are **expensive**, especially in the communities most likely to be impacted.

We need a framework and we need it yesterday

→It must be accessible to non-simulators.

→It must be designed to be responsive.

→We cannot rely on responsive simulation results.

→We need a huge amount of compute power to support this.

We need to build the community to support this

Disease is here to stay, but it’s hard to predict what it’ll do

(holy anthromorphisation, Batman!)

A connected world means greater exposure to disease

Smallpox – High-fatality smallpox come to Europe in the 17th century

- Indigenous Americans experienced case fatality rates up to 90% upon contact.
- Smallpox mutates in the 17th century, with massively increased rates of fatalities even in Old World.
- Movement through trade/military networks (awkward: mobility traditionally cited as example of empire's benefit to the governed).

Cholera – Cholera wracks Europe, and researchers argue about what causes it

- Rising international network of epidemiological researchers
- Cholera arrives in Europe in 1817; resurgences in 1832 and 1854
- British strongly oppose quarantines or travel blockages between Britain and India or Hong Kong

Plague – Russian-born Waldemar Haffkine develops and delivers vaccines in the 19th century.

- Work reflects importance of collaboration, buy-in, and trust of the governed

Foreign Bodies: Pandemics, Vaccines and the Health of Nations. Simon Schama, 2023.

Ebola – rising problem as travel becomes easier

- Smaller outbreaks recorded since the 1970s; new clusters every year since 2016
- 2014-16 outbreak kills over 11k
- Improved transportation networks for development/commerce → ???

gosh I can't think of any more recent examples… 🤔🤔🤔

What makes it so hard to predict or respond?

- Behaviours and Norms
  - **Economics**: both situates and limits response.
    - "after famine comes the fever”
    - huge economic cost of destroyed stock during sanitation regime
    - if you’re living hand to mouth, eating already-dead chimpanzees or going to work contagious is rational
    - new pushes into mining and forestry bring people into contact with Ebola, again and again
  - **Gender roles**:
    - women confined to homes got more plague (from continuous close contact);
    - those doing caring tend to die of Ebola – while those doing mining, forestry tend to contract Ebola
  - **Religion**:
    - Jains won't kill animals - this includes fleas and rats.
    - Caste & purdah relevant for treatment.
    - Superspreader events – singing in a group?

- Movement
  - **Where?:** which things are close? Which things look close, but don’t actually interact?
  - **How?:** how do things move through an environment?
  - **Multiple dimensions**: eg homes on higher floors of buildings are safer from rats
  - **Space** is **hard** and **expensive** to include in simulations

- Knowledge
  - **Alternative treatments**: folk practices/medicine re-emerge (with plague, Ebola, etc)
  - **Decision-Making and Uncertainty**:
    - If you think your family member will die in quarantine and then you won’t be able to bury them properly, why hand them over?
    - If you think you MIGHT not be infectious, and they want to put you in a ward with people who definitely have Ebola…?

Humans are only the beginning!

Zoonosis: “an infection or infectious disease **transmissible** under natural conditions **from vertebrate animals to humans**.”

Porta, Miquel ed. (2008). Dictionary of Epidemiology.

- Bubonic plague – from fleas
- Influenza (all flavours) – from birds, sometimes stopping over in pigs
- Monkeypox – squirrels, ironically
- Bovine tuberculosis – (guess)
- Lyme disease – from ticks
- Marburg – bats and pigs, we think?
- Rabies – various mammal friends
- Hantavirus – from rodents
- Nipah – bats, we think

“60% of all infectious diseases currently known either cross routinely or have recently crossed between other animals and us”

Ebola: The natural and human history, David Quammen.
Excerpt from his longer book *Spillover*, 2014.

Dirk Brockmann and Dirk Helbing (2013) The hidden geometry of complex, network-driven contagion phenomena. Science 342 (6164), 1337-1342.

To review

What I've described here is a set of systems which are

- Profoundly spatial
- Non-linear
- Motivated by interaction among different populations
- …which are all mobile
- …and characterised by contextualised, often social or economic, behaviours

Complexity scientist bait, tbh

Using my current research project as a motivating example

Our project

- Create a spatially-informed agent-based simulation for modelling multinational, multimodal risk of the spread of disease **as a function of human behaviours**.

- Make use of open data and information to **estimate population, connectivity, movement, and modes of transit** in **historically underserved areas**.

- Use the model to explore the **universe of possible epidemics**, contributing to larger conversations about policy and the practice of health interventions in crisis situations.

https://github.com/dime-worldbank/Disease-Modelling-SSA/

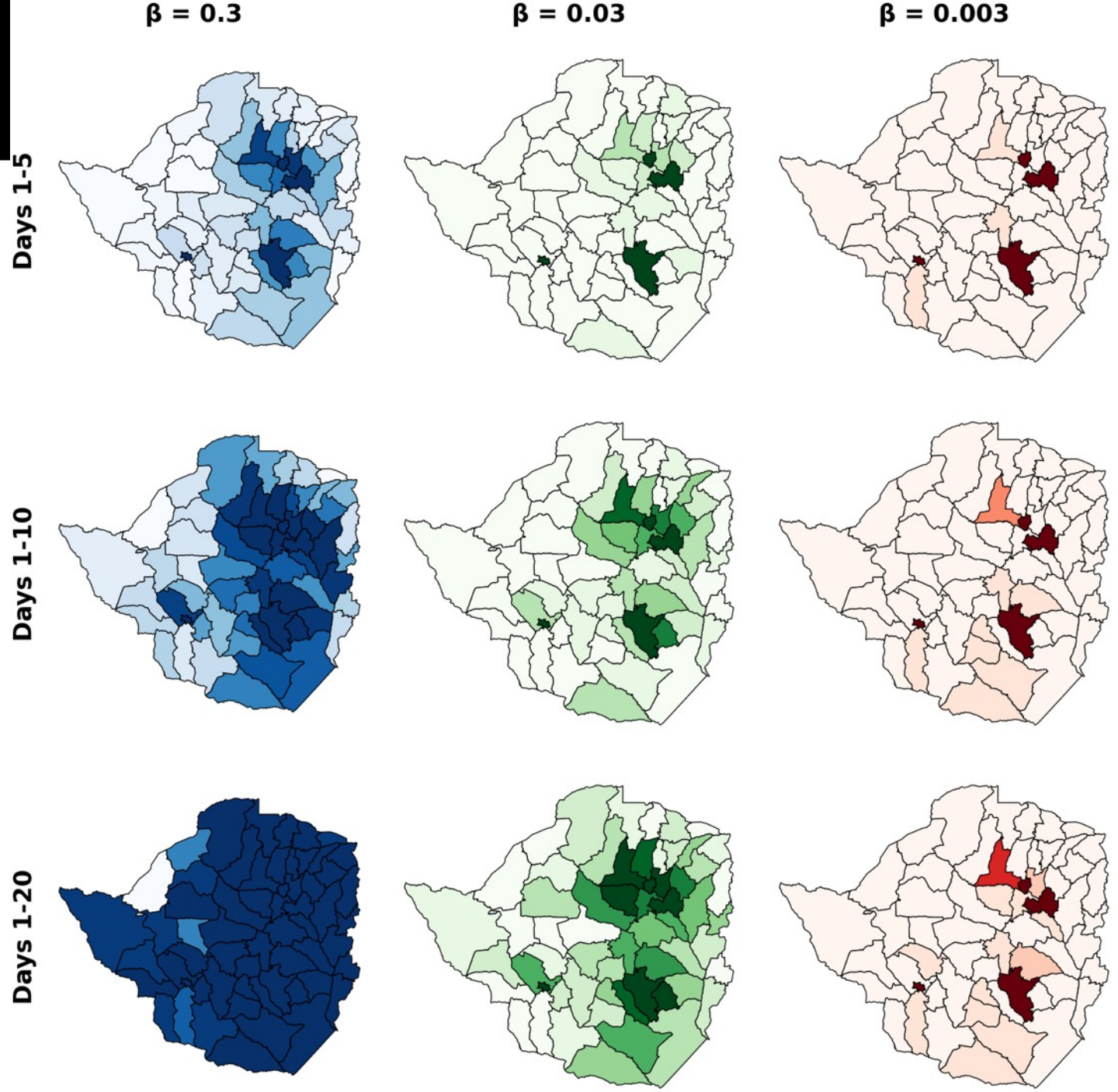
With probability from OD mobile phone data, individuals may choose to visit another district (based on their employment and the day of the week)

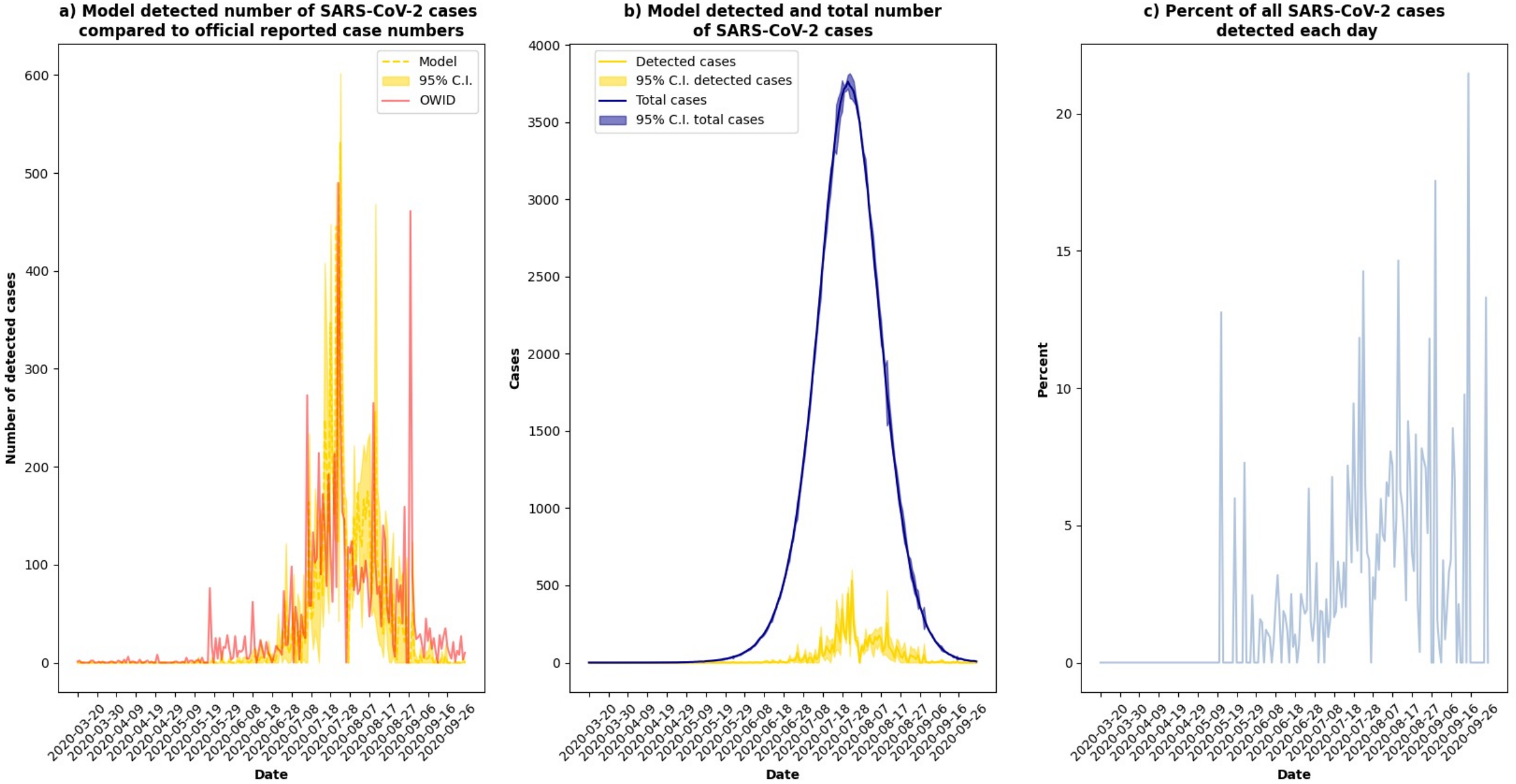
individual people move between their homes and community, interacting with others based on their own employment/status type

transmission occurs based on interaction, beta value, and age-specific susceptibility rates

symptomatic and asymptomatic cases - as well as hospitalisations, critical care cases, and deaths - are tracked by district-day

50% Sample




a) Model detected number of SARS-CoV-2 cases compared to official reported case numbers
Model
95% C.I.
OWID
Number of detected cases
Date
b) Model detected and total number of SARS-CoV-2 cases
Detected cases
95% C.I. detected cases
Total cases
95% C.I. total cases
Cases
Date
c) Percent of all SARS-CoV-2 cases detected each day
Percent
Date

Major challenges

- Cases versus testing: statistical treatments of **uncertainty**.
- We need access to **HPC** to run simulations (currently using UCL's Research Computing Services, specifically Myriad@UCL)
- **Data access permissions** compound this ^^^
- Steep **learning curve**
  - Using remote servers via command line (Everyone Loves VIM™)
  - Rolling our own documentation as we go along
  - Data transfer woes
- Project partners don't want to hear about it unless it's already **operationally useful**

What’s the vision?

“I got a lot of problems with [the current state of play with regard to simulation of, in particular, neglected tropical diseases] and now you're gonna hear about it.”

– *modified traditional introduction to a Festivus-season Airing of Grievances*

A series of provocations

Disease prevention may be the great question of our (and every other?) era

- Where is the funding, post-pandemic?
- Where are the large communities?
- How are we going to ensure the long-term usability of our models?

A series of provocations framed as suggestions

- You can't parachute people in at the last moment: **trust** has to be earned through **long-term partnerships**.
- We need an **established community** – the epidemiological equivalent of MatSim.
- Hardware and HPC is going to be key to this effort…so we've got to be sure we're **training people** accordingly.

A lot of "technical work" is actually soft-skill **community building**, as the ExASCALE team is currently doing.

Thank you!

Dr Robbie Manning Smith

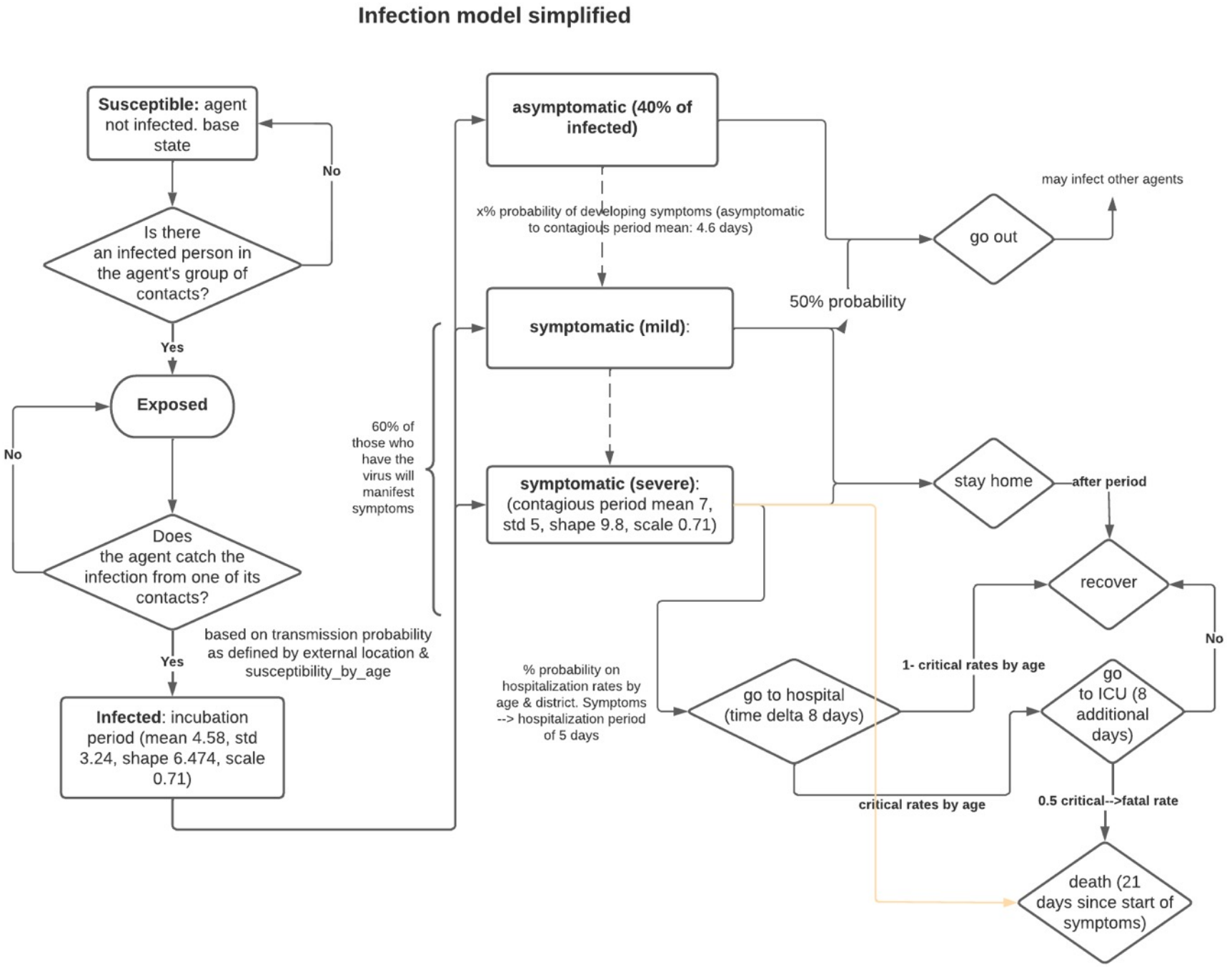
Sophie Ayling

HUGE thank you to **Dr Sveta Milusheva** of the World Bank for her support and guidance

We acknowledge the use of the UCL Myriad High Performance Computing Facility (Myriad@UCL)

Thank you to UKRI FLF for funding Grant # MR/T02075X/1

Questions or complaints? s.wise@ucl.ac.uk


Infection model simplified
Susceptible: agent not infected. base state
No
Is there an infected person in the agent's group of contacts?
Yes
Exposed
No
Does the agent catch the infection from one of its contacts?
Yes
based on transmission probability as defined by external location & susceptibility_by_age
Infected: incubation period (mean 4.58, std 3.24, shape 6.474, scale 0.71)
60% of those who have the virus will manifest symptoms
asymptomatic (40% of infected)
x% probability of developing symptoms (asymptomatic to contagious period mean: 4.6 days)
symptomatic (mild):
symptomatic (severe): (contagious period mean 7, std 5, shape 9.8, scale 0.71)
50% probability
go out
may infect other agents
stay home
after period
recover
No
% probability on hospitalization rates by age & district. Symptoms --> hospitalization period of 5 days
go to hospital (time delta 8 days)
1- critical rates by age
go to ICU (8 additional days)
critical rates by age
0.5 critical-->fatal rate
death (21 days since start of symptoms)