Efficient methods for infectious disease transmission modelling

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Potential Collaborations: Machine Learning and Global Health Network (<https://mlgh.net>), UKHSA

The COVID-19 pandemic and global mpox transmission has shown us the important role infectious disease modelling can have in informing policy response in real time. By March 2023, nearly 150,000 papers about modelling COVID-19 had been indexed by Web of Science based upon a wide variety of methods including mechanistic (compartmental Susceptible-Infected-Recovered type models or individual based methods), semi-mechanistic (renewal or Hawkes Process models) or fully stochastic methods. Unsurprisingly, most of the methods used were purely temporal because these are quicker and easier to develop and run, with only 6% of the published research including any spatial component. With increasing globalisation and climate induced changes in where disease transmission is occurring, capturing space in disease transmission models is more important now than ever. New higher quality datasets, which have been collated during the pandemic, give us the unique opportunity to develop more accurate methods for disease spread and drive forward the need for improvements in efficiency so they can be run in real time.

A PhD project on this topic could focus on different aspects of efficient inference for infectious disease models, depending on the candidate’s interest:

1. Working on improving the efficiency of an existing spatial-temporal renewal model to estimate the time varying reproduction number built on the methodology in [1] and [2].
   1. This could look like changing the probabilistic programming language it is built on, work on paralysing the method where possible and explore possibilities of running on HPCs/ GPUs.
   2. Explore combining the renewal model with other types of models to improve efficiency.
2. Spatial temporal models are parameterised by information about where people move. Existing gravity and radiation models are ok but don’t capture within country nuances. This project could focus on building better models of how people move, perhaps focusing on low-to-middle income countries where there is less data.
3. Developing an R package & tools for policy makers that implements these types of models [3].
4. Explore if a Hawkes Process based spatial-temporal model could be used to recreate transmission chains. This will build on previous work to use Hawkes Processes to model infectious disease outbreaks [4].
5. Investigate if approximate Bayesian inference methods are appropriate to use for the types of models in [1, 2 & 4] and if they are efficient enough to be used in real-time modelling.
6. Investigate if using fluids mechanics models across a network could be appropriate for modelling diseases, such as sexually transmitted diseases, that a spread through particular population groups [5].

References:

[1] Seth Flaxman et al. Estimating the effects of non-pharmaceutical interventions on COVID-19 in Europe. *Nature*, 584(7820):257–261, 2020.

[2] H. Juliette T. Unwin et al. State-level tracking of COVID-19 in the United States. *Nature Communications*, 11(1):1–9, 2020.

[3] James A. Scott et al. epidemia: Modeling of epidemics using hierarchical bayesian models (https://imperialcollegelondon.github.io/epidemia/), 2020.

[4] H. J. T. Unwin et al. Using Hawkes Processes to model imported and local malaria cases in near-elimination settings, PLoS computational biology, 17, (4), e1008830, 2021.

[5] [Kunihiko Taira](https://www.sciencedirect.com/author/18042919100/kunihiko-taira). Network-based analysis of fluid flows: Progress and outlook, Progress in Aerospace Sciences, 131, 2022