Generative approaches to modelling synthetic populations

Nic Geard

School of Computing and Information Systems
Melbourne Data Analytics Platform
The University of Melbourne

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Vale of Rasselas, Tasmania

Overview

- How do we represent populations when modelling disease spread?

- Why it matters
- A generative approach to modelling populations
- Examples and applications
- Challenges and opportunities

Upper Howqua Valley, Victoria

Decisions about representation matter

Modelling an infectious disease outbreak

Susceptible people are healthy, but can get infected

Infectious people can infect susceptible people

Recovered people are protected against getting infected

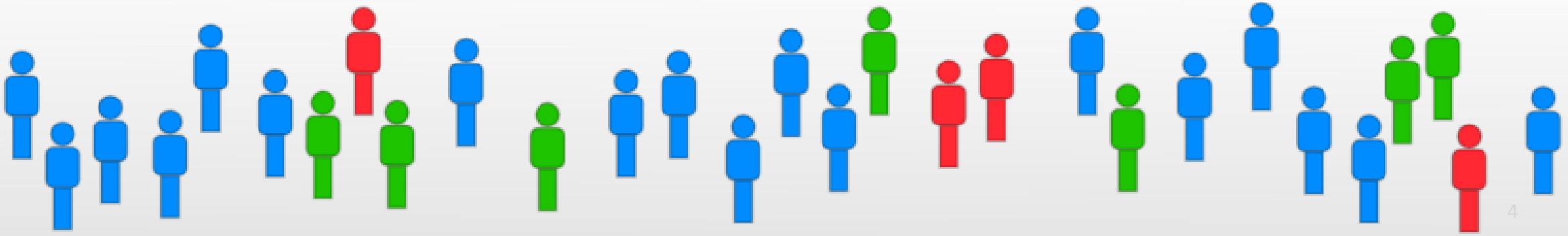
Infection (β):

Recovery (γ):

$$S' = S - \beta SI$$

$$I' = I + \beta SI - \gamma I$$

$$R' = R + \gamma I$$



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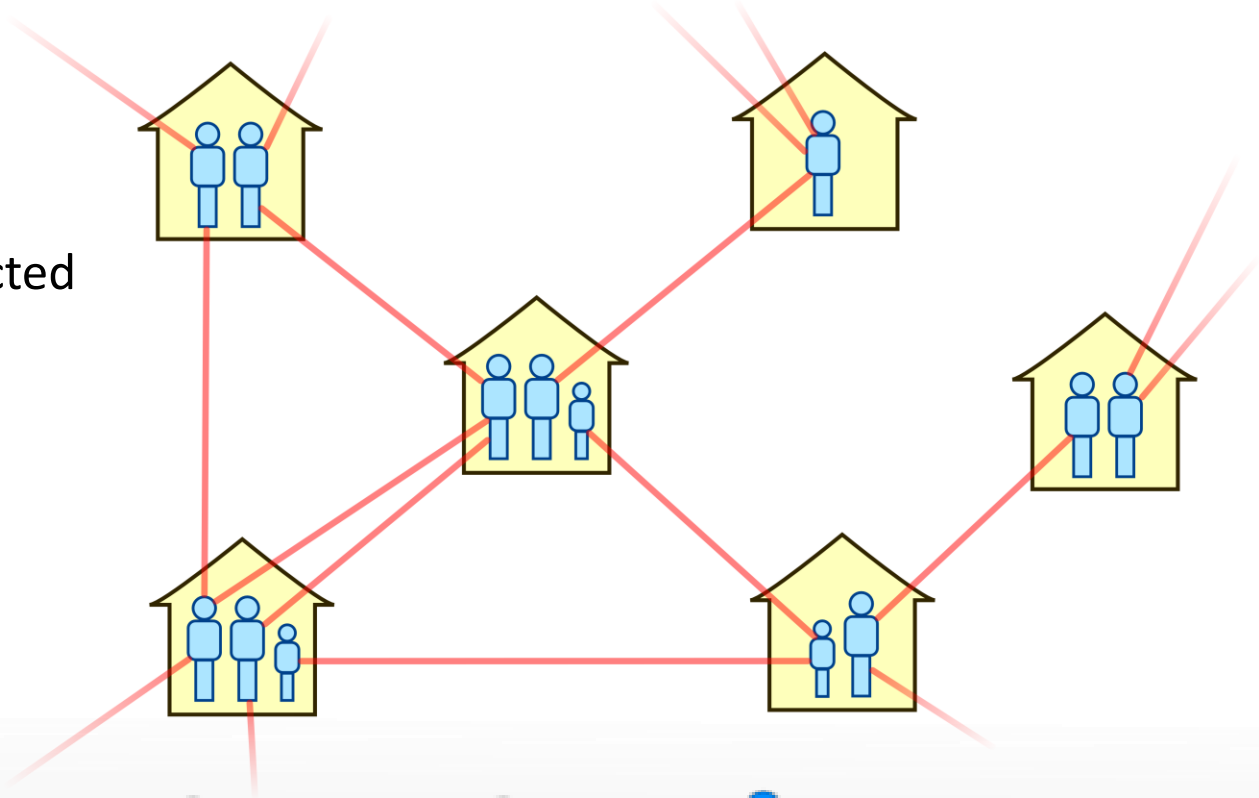
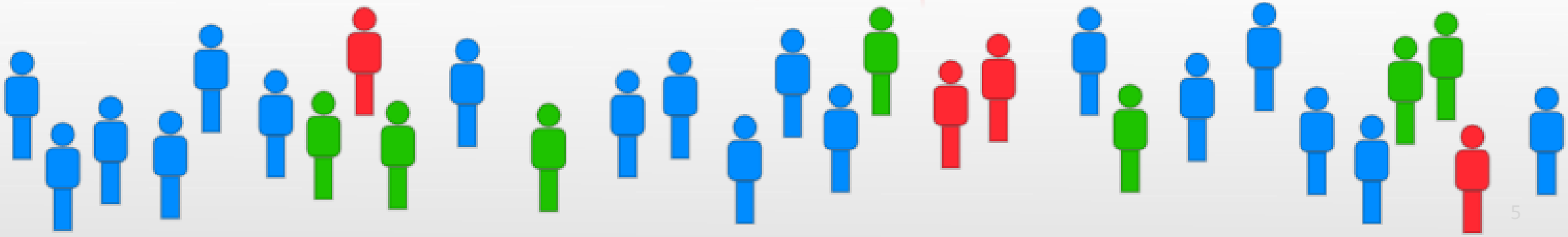
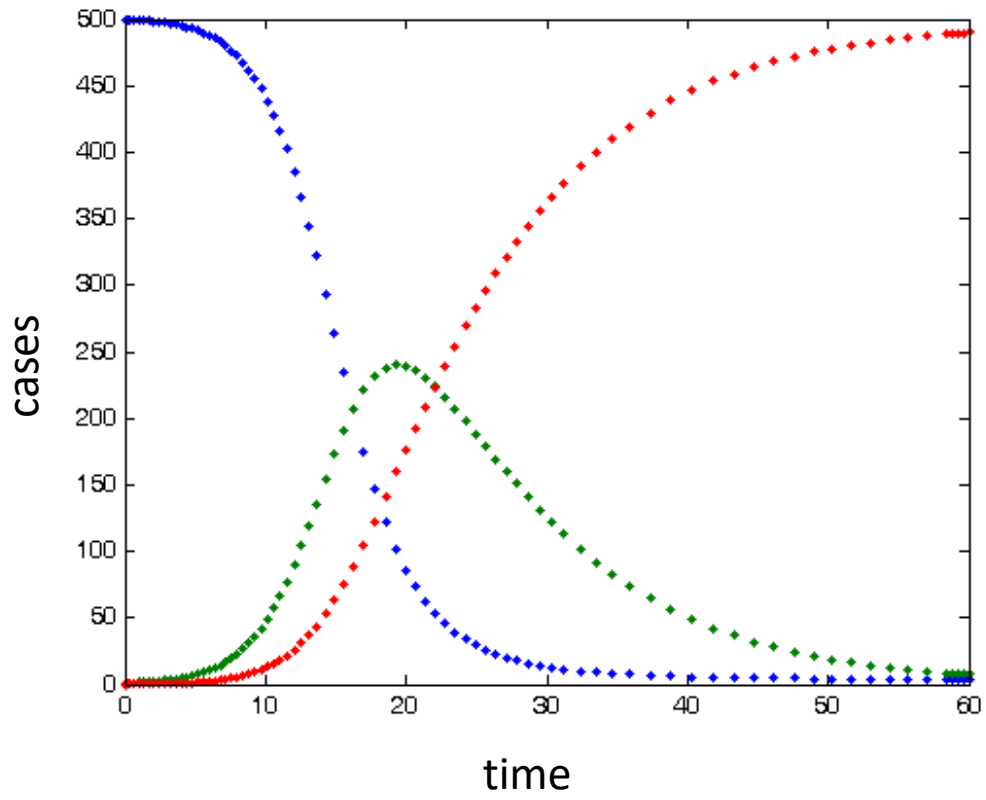




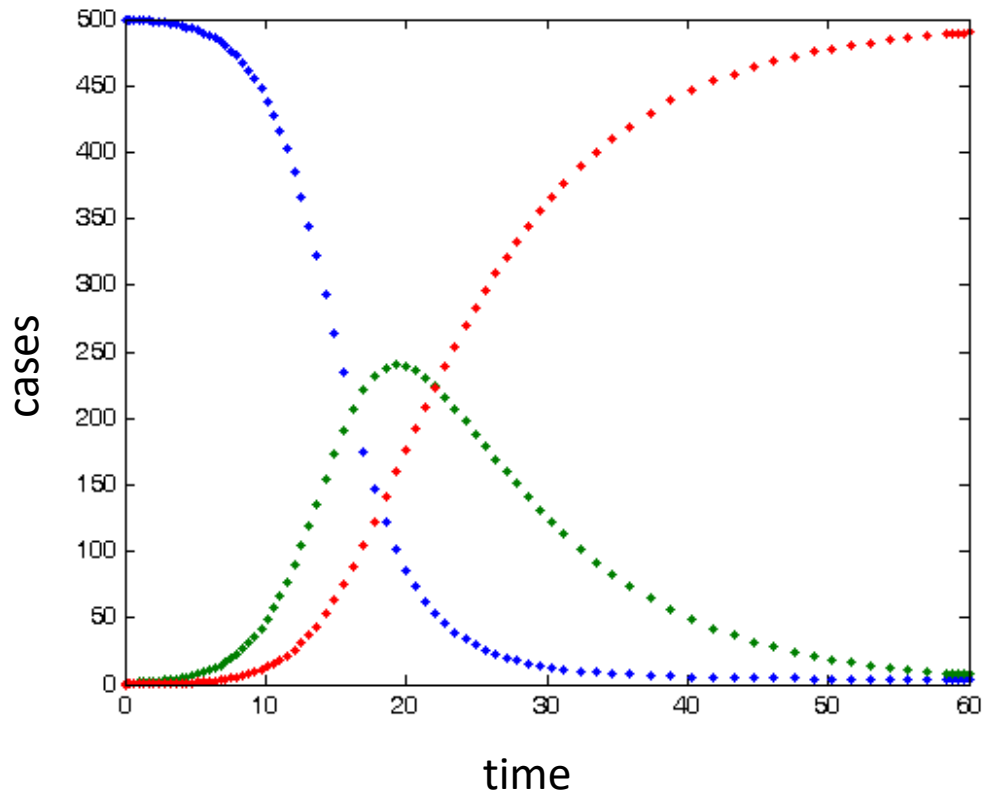
A typical modelling approach

- Start with a heterogeneous population…
- Create a simplified representation by collapsing that heterogeneity…
- Simulate a disease outbreak in our simplified population…
- Obtain an estimate of the fraction of the population who were infected by the end of the outbreak.



What if we want to know about a subgroup?

- e.g., what fraction of children aged under 3 years were infected by the end of the outbreak?



Modelling populations

- Mathematical models: age-structured compartmental models.
- Agent-based models: population structure derived from statistical data:
  - Sampling microdata on populations.
  - Iterative proportional fitting to match marginal distributions.
- Contact patterns derived from surveys of contact behaviour:
  - e.g., the POLYMOD study
  - Increasingly, statistical extrapolations of a relatively small number of empirical studies to a much wider range of demographic settings.

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A generative approach to modelling populations

Eddystone Point, Tasmania

Generating populations

- What do we mean by “generative”?

  able to produce or create something
  (Cambridge Dictionary)

- Early work by Stephen Eubank et al. (2004) Modelling disease outbreaks in realistic urban social networks. *Nature*

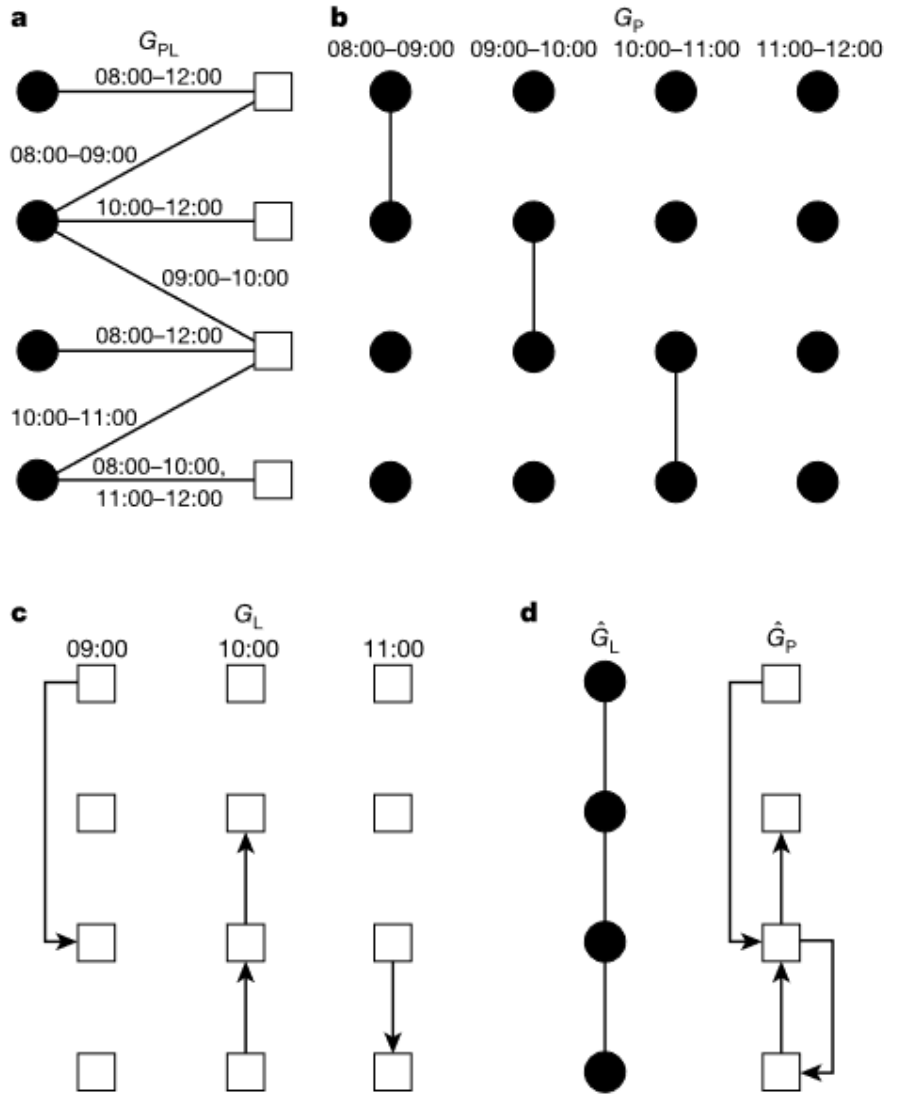
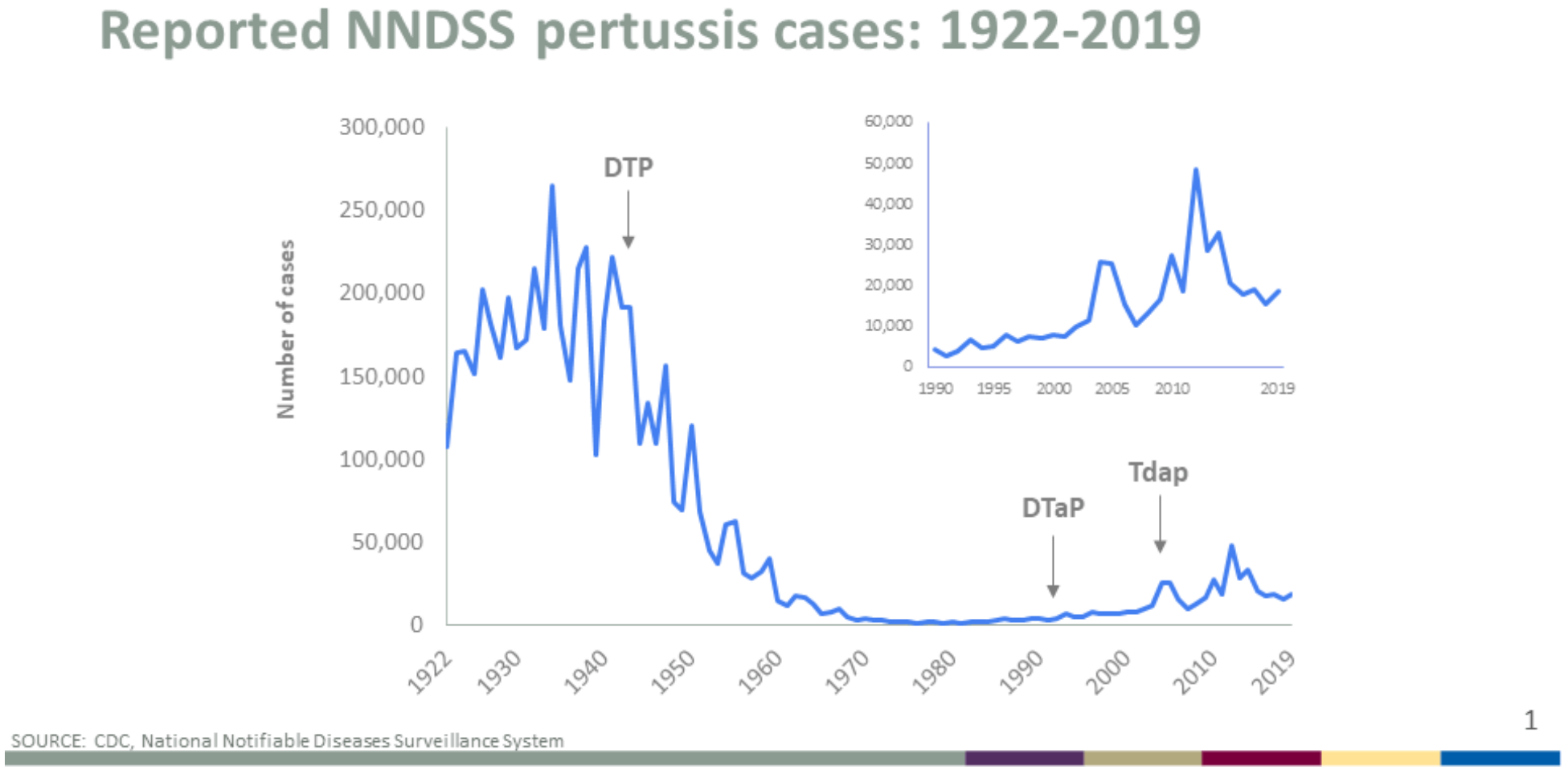


Figure 1 An example of a small social contact network. **a**, A bipartite graph G_{PL} with two types of vertex representing four people (P) and four locations (L). If person p visited location l, there is an edge in this graph between p and l. Vertices are labelled with appropriate demographic or geographic information, edges with arrival and departure times. **b**, **c**, The two disconnected graphs G_P and G_L induced by connecting vertices that were separated by exactly two edges in G_{PL}. **d**, The static projections $\hat{G}_P$ and $\hat{G}_L$ resulting from ignoring time labels in G_P and G_L. People (such as 24-year-old male) are represented by filled circles, and locations (such as 34 Elm Street) by open squares.

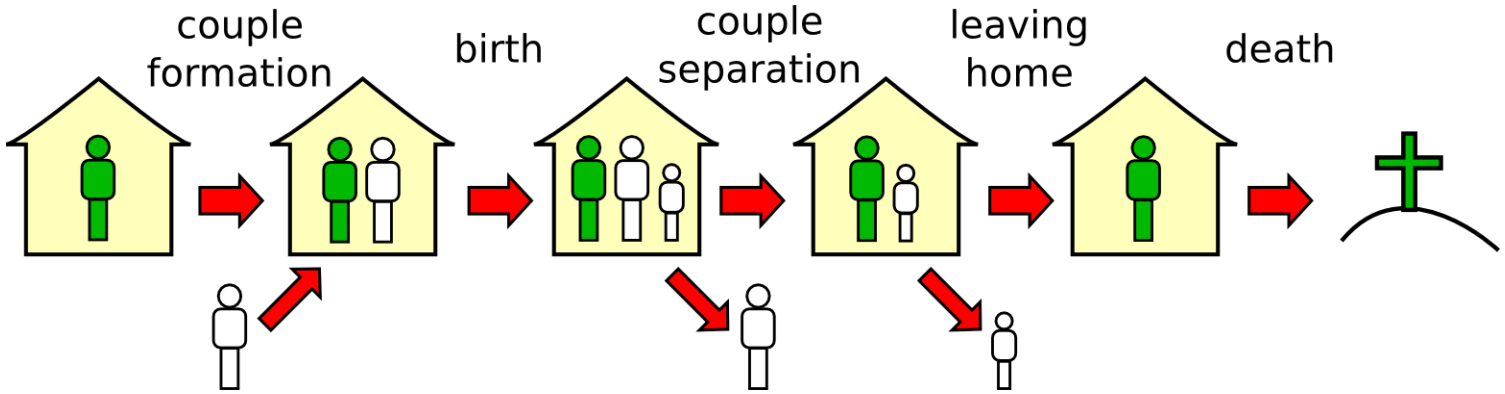
Pertussis (whooping cough) in Australia



With Jodie McVernon, James McCaw, Katie Glass, Emma McBryde, and others.

Households

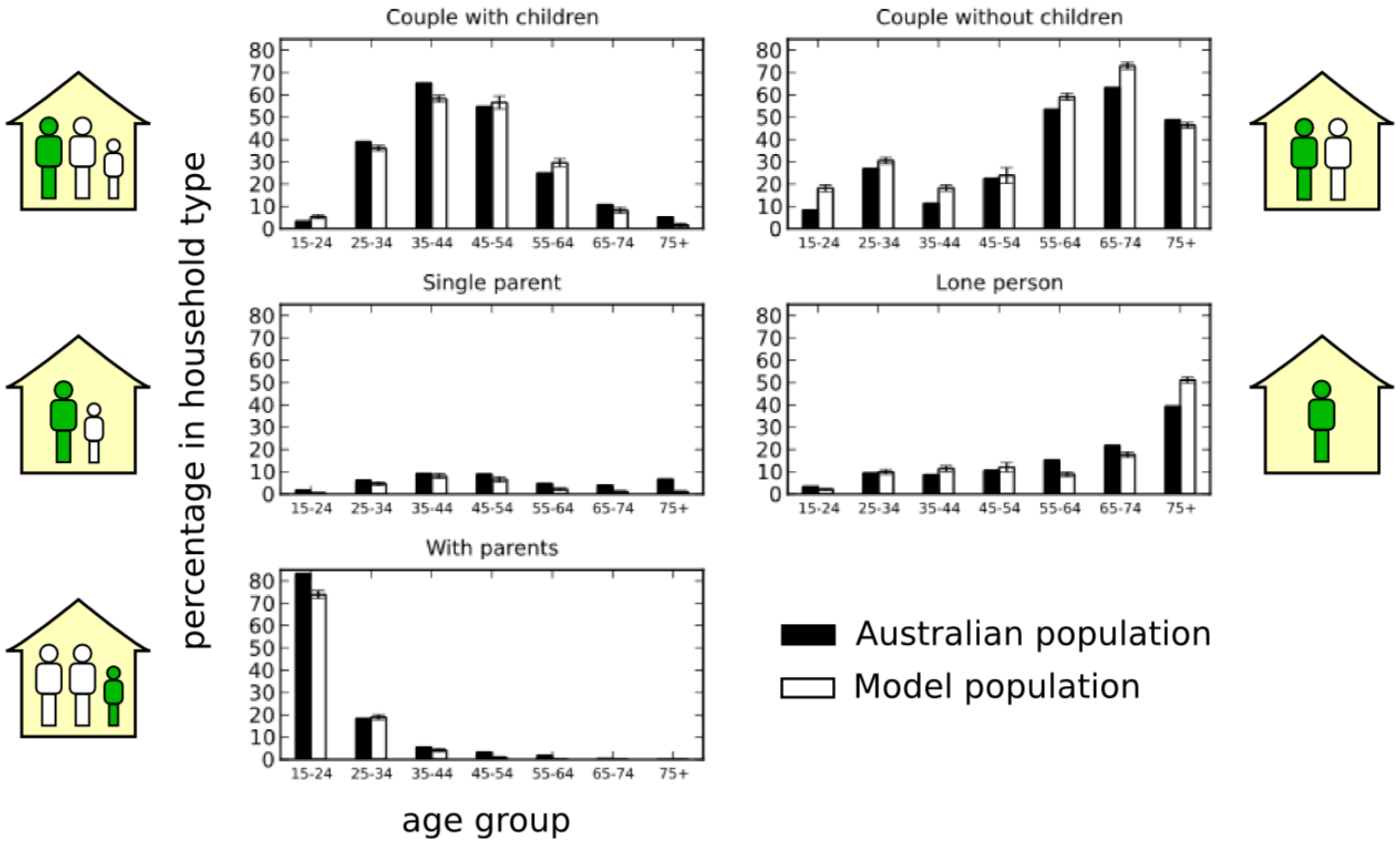
A generative model of households



Parameterised using:

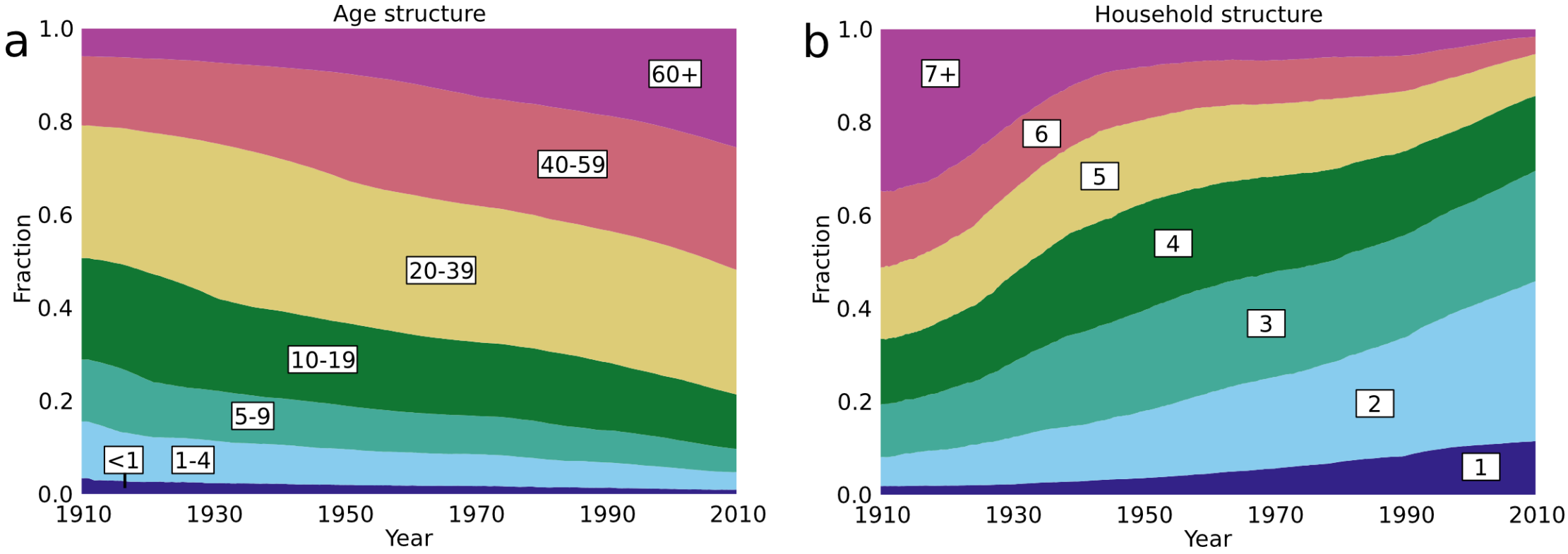
- fertility and mortality data (ABS)
- household formation and dissolution data (HILDA and AIFS).
- Python: https://bitbucket.org/ngeard/simodd-pop

Calibrating the demographic model



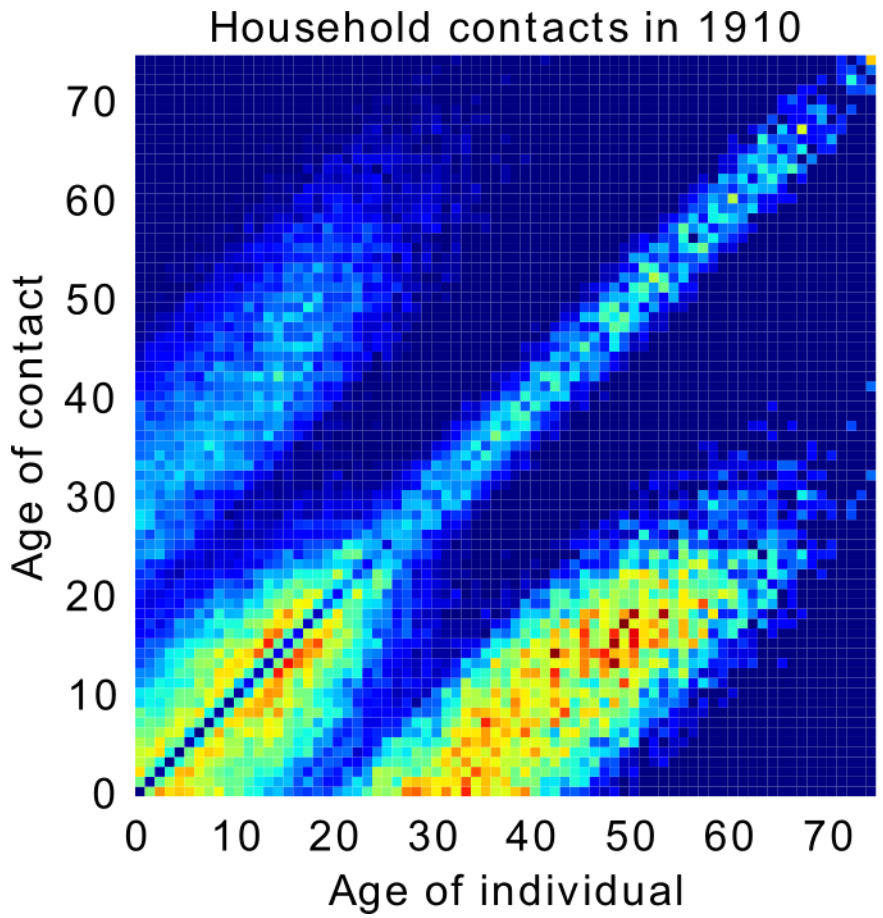
Geard et al. (2013) Synthetic population dynamics: a model of household demography. *JASSS*

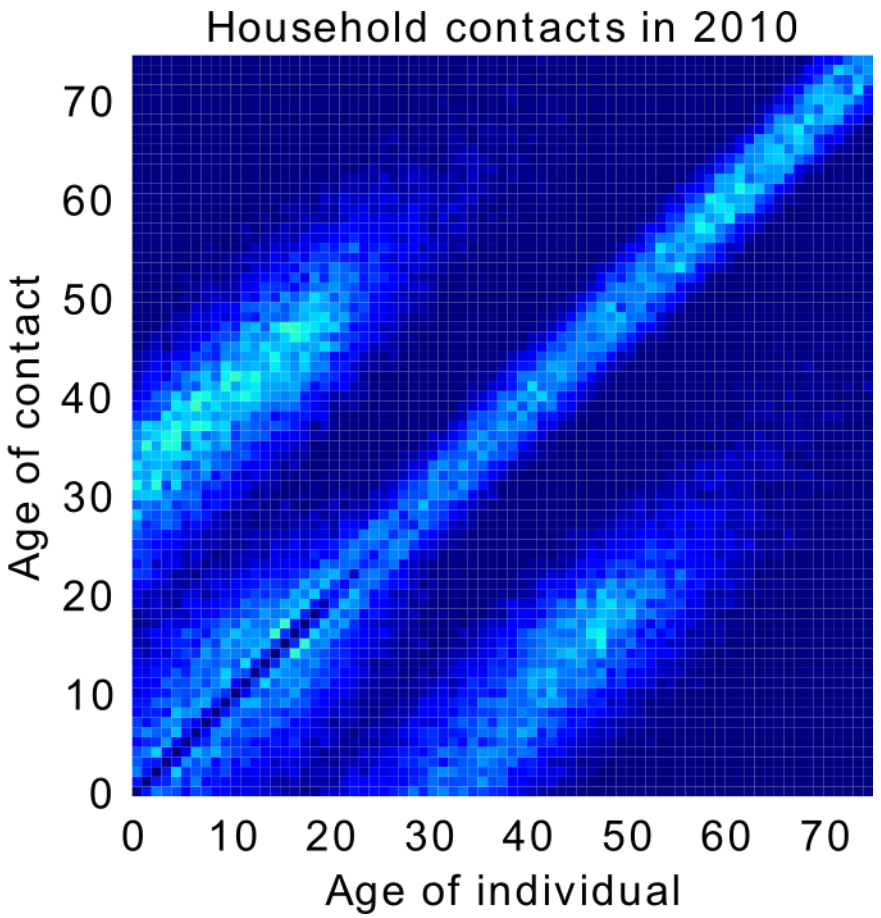
Modelling demographic change



Geard et al (2015) The effects of demographic change on disease transmission and vaccine impact in a household structured population. *Epidemics*

Emergent household contact patterns



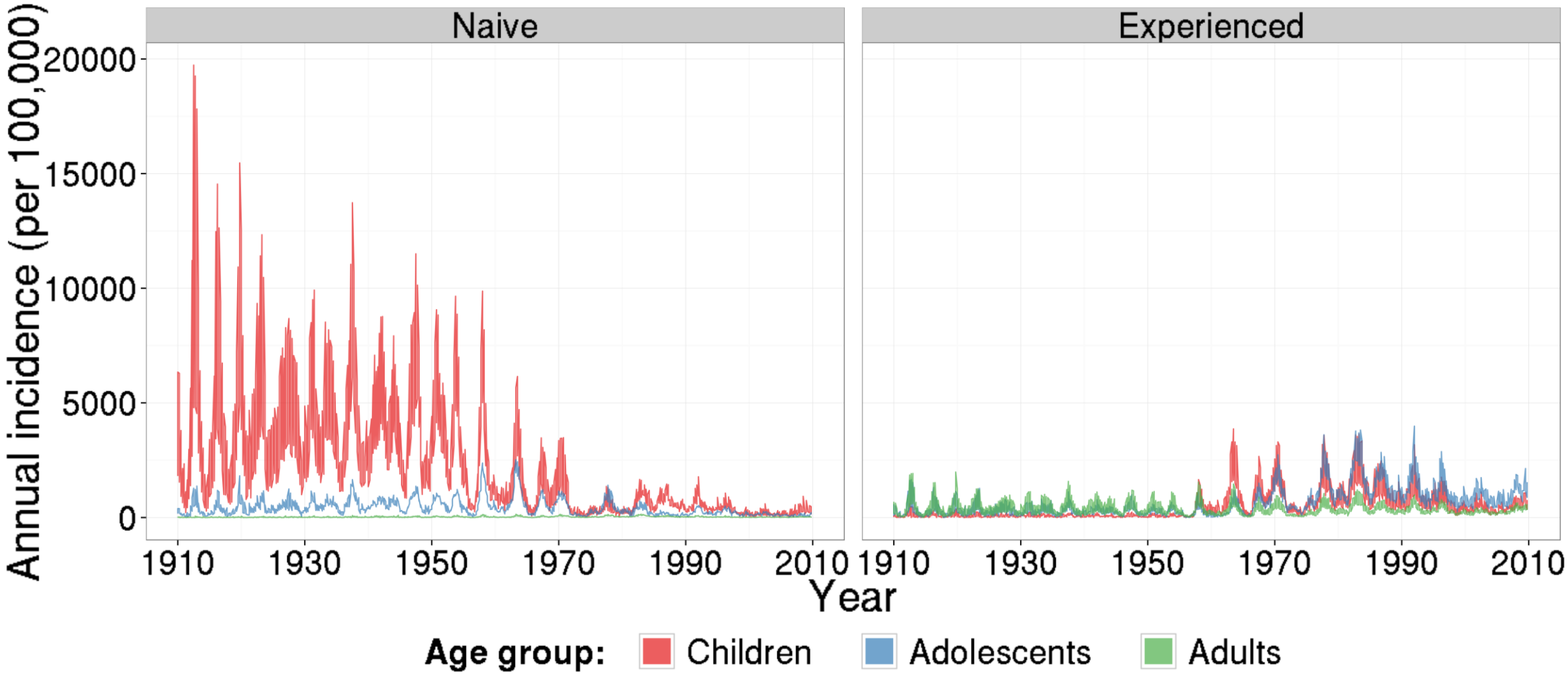


Geard et al. (2015) The effects of demographic change on disease transmission and vaccine impact in a household structured population. *Epidemics.*

Lake Rhona, Tasmania

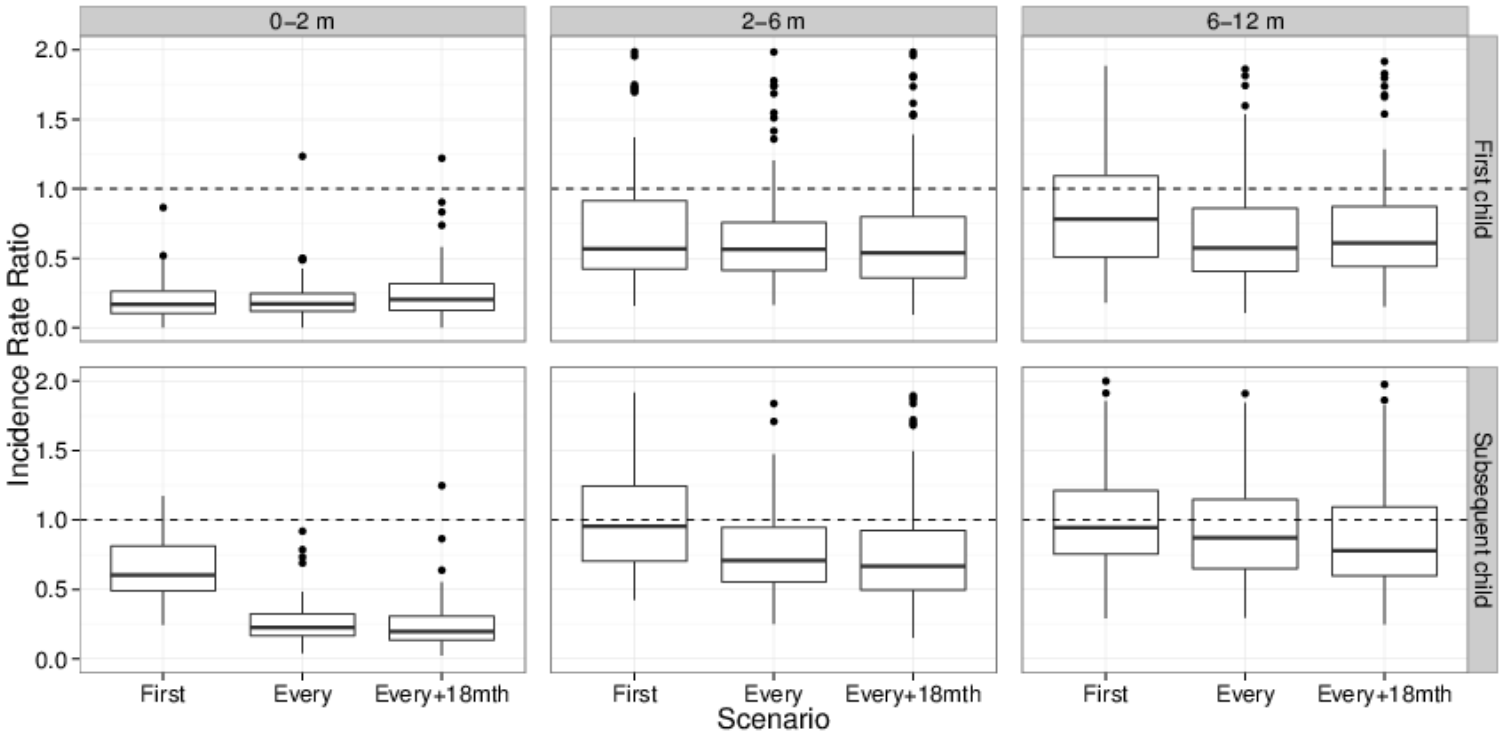
Example applications

Pertussis (whooping cough) in Australia



Exploring antenatal vaccination

Age group (infants <1 year)

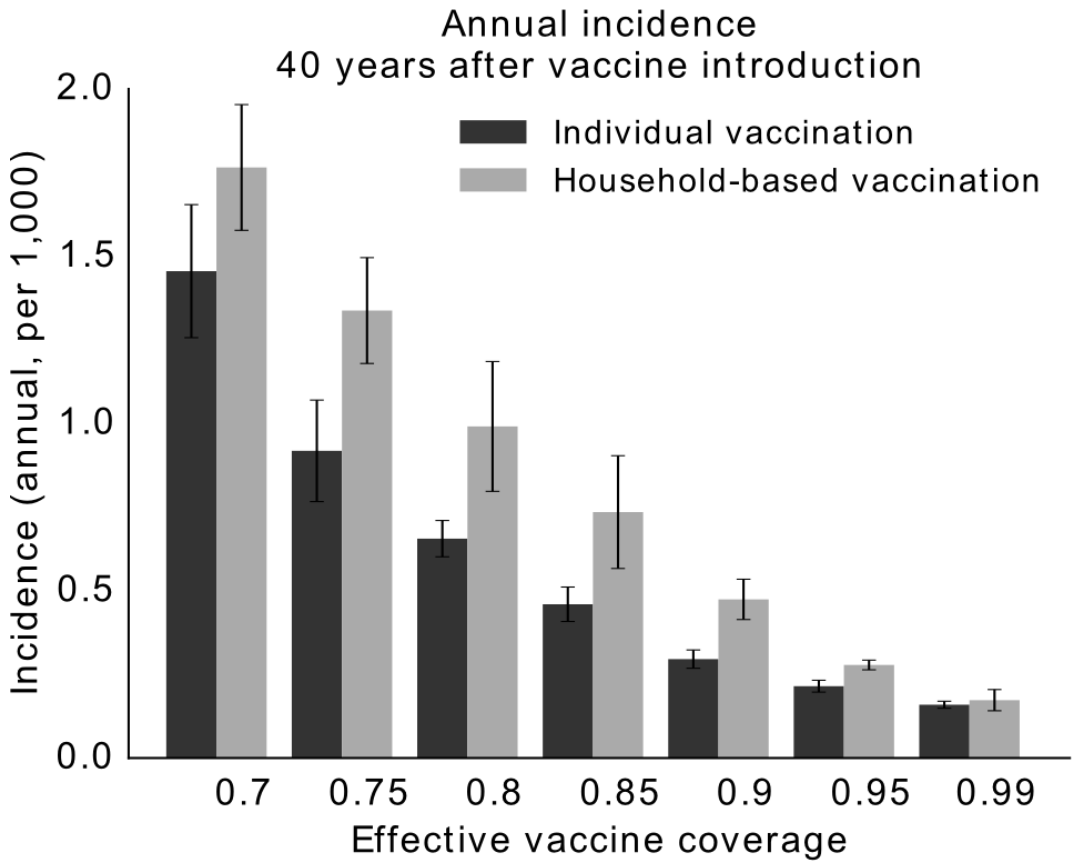


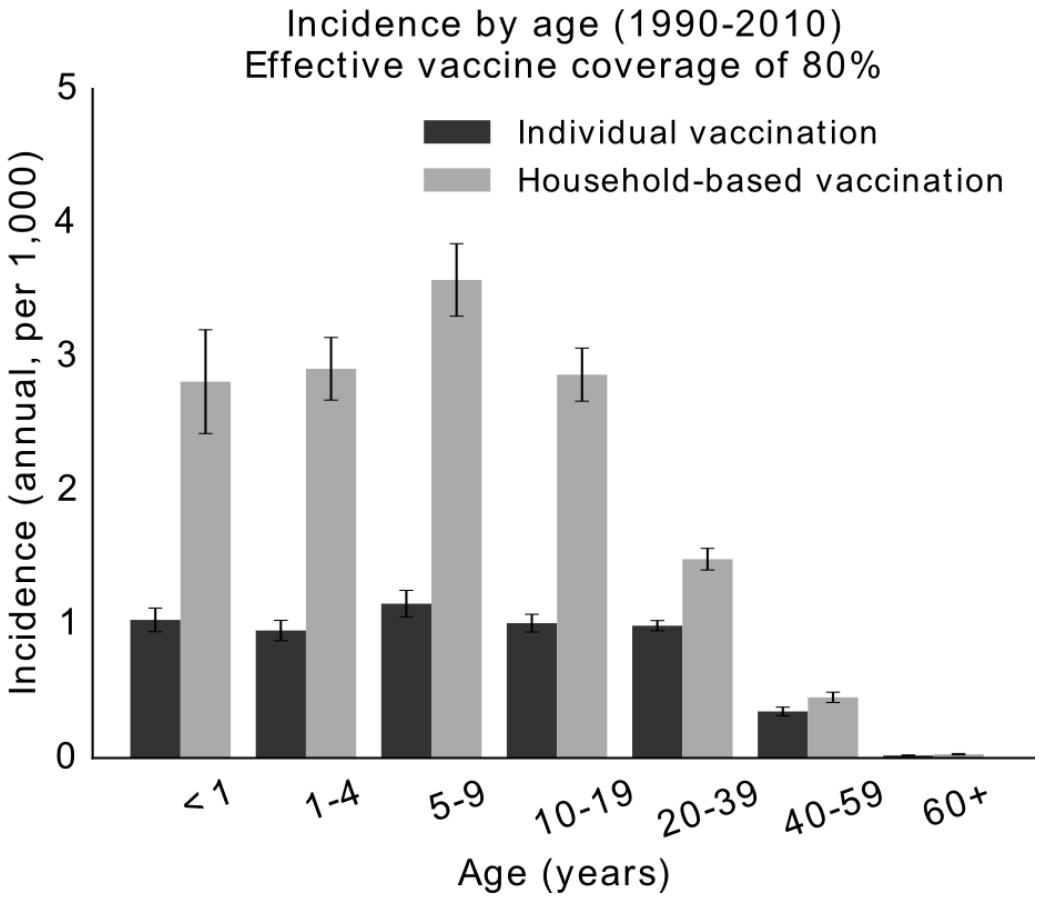
With Trish Campbell, Jodie McVernon and others.

Campbell et al. (2017) Determining best strategies for maternally-targeted pertussis vaccination using an individual based model. *American Journal of Epidemiology*

Campbell et al. (2016) Influence of population demography and immunization history on the impact of an antenatal pertussis program. *Clinical Infectious Diseases*

Omitting households can result in an overestimate of vaccine impact



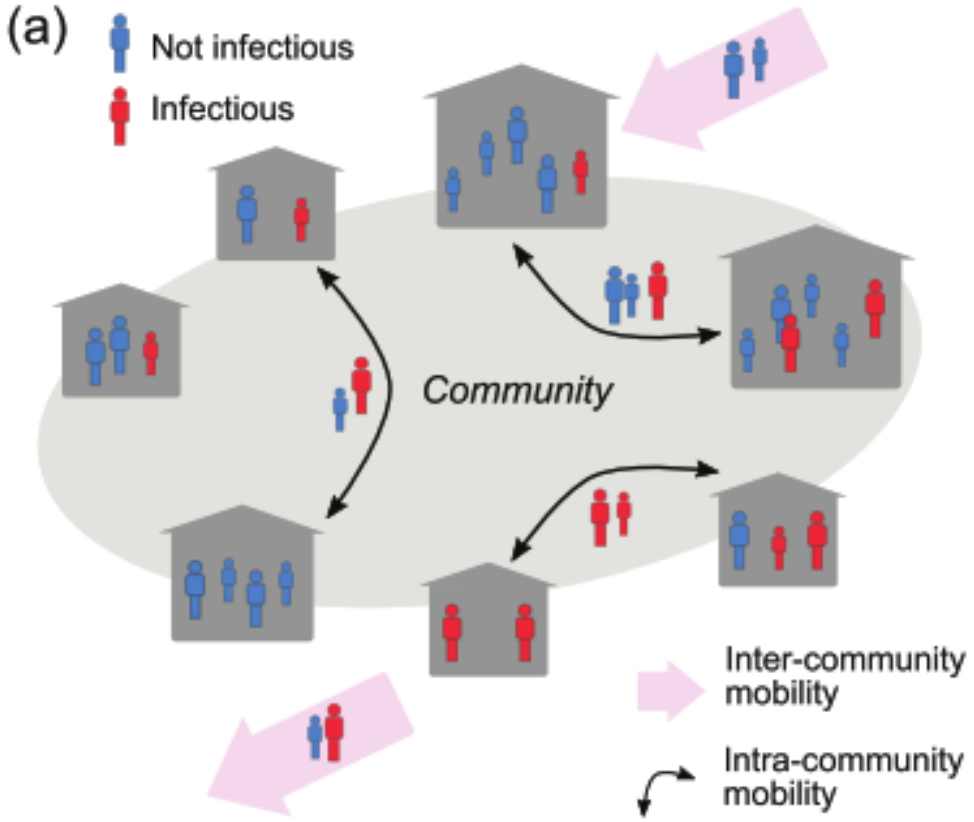


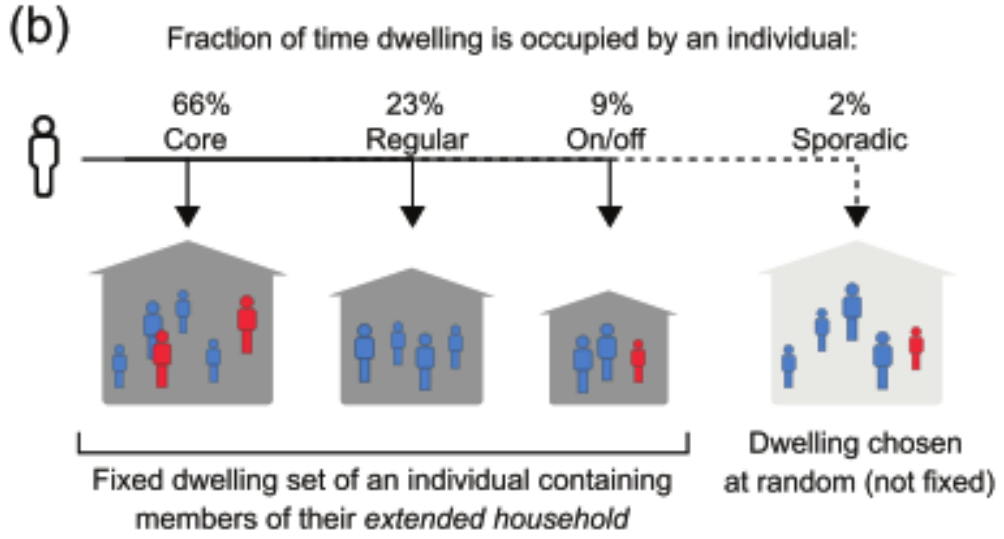
Geard et al. (2015) The effects of demographic change on disease transmission and vaccine impact in a household structured population. *Epidemics*

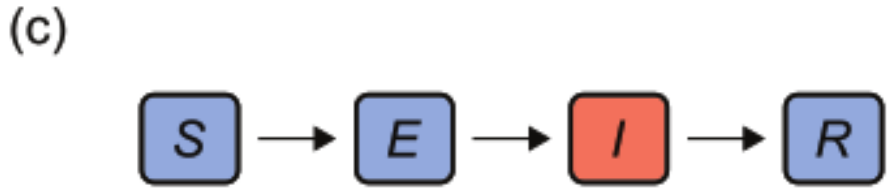
Other pathogens

- Lymphatic filarisis (with Sting Xu, Colleen Lau, Archie Clements, Katie Glass):
  - What are the long-term dynamics of transmission in American Samoa?
  - Xu et al. (2019) *Epidemics*
- Tuberculosis (with Romain Ragonet, James Trauer, Emma McBryde):
  - Which age group is the primary drivers of TB in high-incidence settings?
  - Ragonnet et al. (2019) *BMC Medicine*
- Respiratory Syncytial Virus (RSV) (with Alexandra Hogan, Trish Campbell):
  - What is the likely impact of a (hypothetical) antenatal RSV vaccine?
  - Campbell et al. (2020) *BMC Medicine*
- Rotavirus (with Julie Bines, Richard Bradhurst, Vicka Octaria, Amanda Handley):
  - What is the likely impact of a neonatal schedule over the medium term?
  - Geard et al. (2022) *Human Vaccines & Immunotherapeutics*
- Scabies (with Nefel Tellioglu, Michael Marks, Rebecca Chisholm):
  - What is the likely effectiveness of the WHO's recommended strategies for mass drug administration?
  - Tellioglu et al. (2023) *Epidemiology & Infection*

Indigenous households





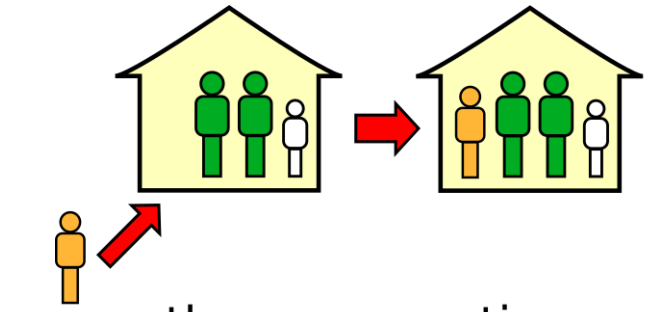


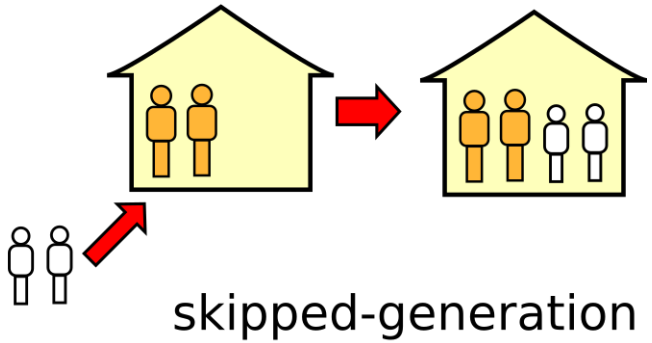
With Rebecca Chisholm, Ben Hui, David Regan, Jodie McVernon and others.

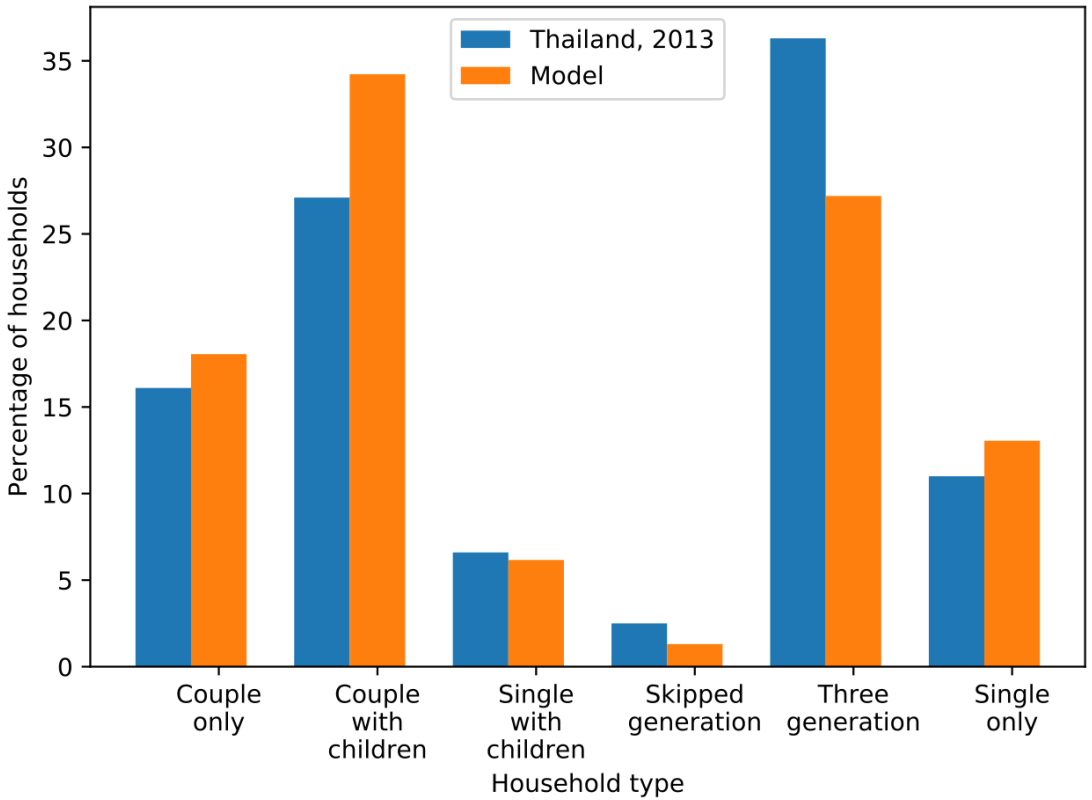
Chisholm et al. (2020) The effects of demographic change on disease transmission and vaccine impact in a household structured population. *Epidemics*

Hui et al. (2021) Modelling testing and response strategies for COVID-19 outbreaks in remote Australian Aboriginal communities. *BMC Infectious Diseases*

Adapting to Thai household demography







(ongoing: in collaboration with Wirichada Pan-Ngum & Wiriya Mahikul, Mahidol University, Thailand)

Mount Buffalo, Victoria

Challenges and opportunities

Current and future work

- Contact patterns in enclosed settings: generating synthetic hospital contact networks by simulating work schedules of nurses and other healthcare staff.
- Lots more work to do adapting these approaches to other demographic settings: LMICs, marginalised populations, etc.
- Other population attributes – can we use generative approaches to overlay socioeconomic, employment, and related characteristics on our synthetic populations?
- Theoretical work around what matters, and how we make decisions about representation of populations.

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Thank you

Nic Geard

ngeard@unimelb.edu.au

https://sites.google.com/site/nicgeard

Mount Buffalo, Victoria