Human mobility and strain dynamics

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CIRM Probability and Biological Evolution

Marseille, France

29 June 2018

QUEENS' COLLEGE CAMBRIDGE

UNIVERSITY OF CAMBRIDGE

Disease and Mobility: A Neglected Factor in Epidemiology*

R. MANSELL PROTHERO[1] INTERNATIONAL JOURNAL OF EPIDEMIOLOGY, 1977

(for example the spread of smallpox in the past by the movement of refugees; the risks of typhoid in crowded insanitary refugee camps).

3. Physical stress may result from movement:
   (i) lowering resistance and so increasing susceptibility to infection (for example movements over distance, especially when these are enforced as a result of natural hazard or political disruption);
   (ii) problems of under-nutrition and mal-nutrition occurring in new environments; the former through difficulties in making economic adjustments, with periods of unemployment and thus limited means of acquiring food; the latter through the difficulty of adjusting to new kinds of food (for example movement from cereal staple to root staple areas), and/or difficulties associated with the preparation of foods (such as movements which are sex selective so that men move without their wives to support them).
4. Psychological stress may result from movement because of sociocultural-economic pressures in adjusting to new environments (especially in rural/urban movements where there are marked differences between the personal contacts in small homogenous rural communities and the impersonal nature of large heterogenous urban communities). However adjustment mechanisms operate in urban communities to assist newcomers, and rural/urban/rural circulation allows the maintenance of contacts with places of origin which are socially and economically stabilizing.

CONCLUSION

In each cell of the typology it is possible to show an association between a particular group of people involved in that type of mobility and one or more of the health hazards. It is evident that in epidemiological studies where it is important to identify and classify different pathogens, and possibly different vectors, it is also necessary to recognize the variety of human factors involved with particular reference to mobility. The attention and expertise required for the understanding of human factors is comparable to that required for pathogens and vectors. The forms of mobility outlined have spatial and temporal dimensions which are susceptible to quantitative geographical analysis, comparable for example to the statistical analysis of parasite/vector relationships in malaria developed initially by Macdonald and extended by others (23, 24, 25). These analyses of mobility cannot be done in isolation but should be in association with medical and, if relevant, entomological analyses. All are parts of a complex whole which must be fully understood if satisfactory measures are to be devised for the alleviation, control and eradication of disease and the improvement of health.

On a macro-scale the association of disease and human mobility can only be neglected at considerable risk (26). This paper demonstrates the importance of the association on a greater variety of scales and in greater detail than have been recognized in the past.

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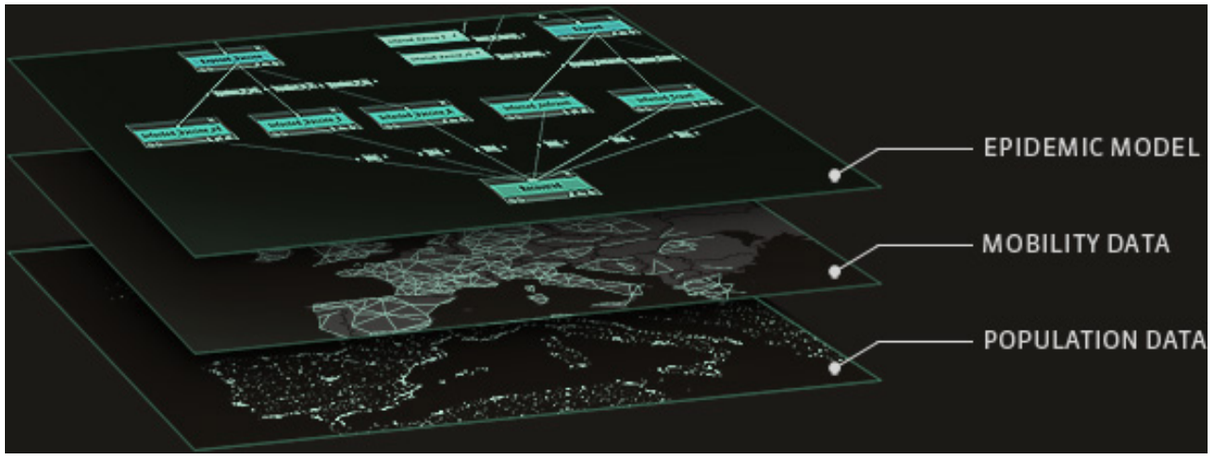
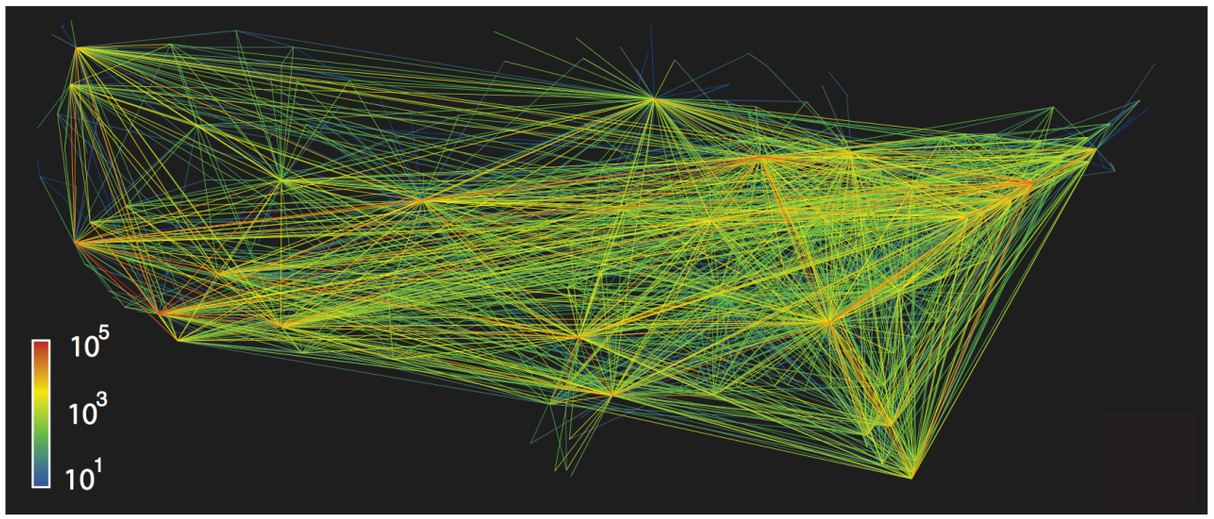
(15) Prothero, R M: Problems of public health among pastoralists in Africa: a case study. In N D McGlashan (ed.) *Medical Geography: techniques and field studies*. London, 105, 1972.

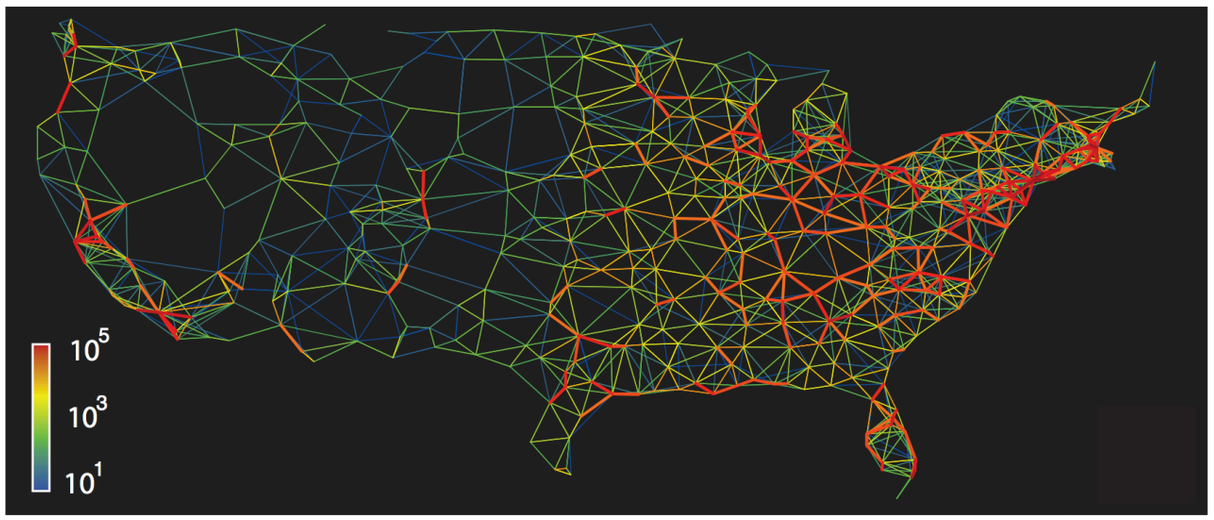
Human mobility affects how pathogens **spread**



gleamviz.org



Balcan *et al.*, PNAS (2009)



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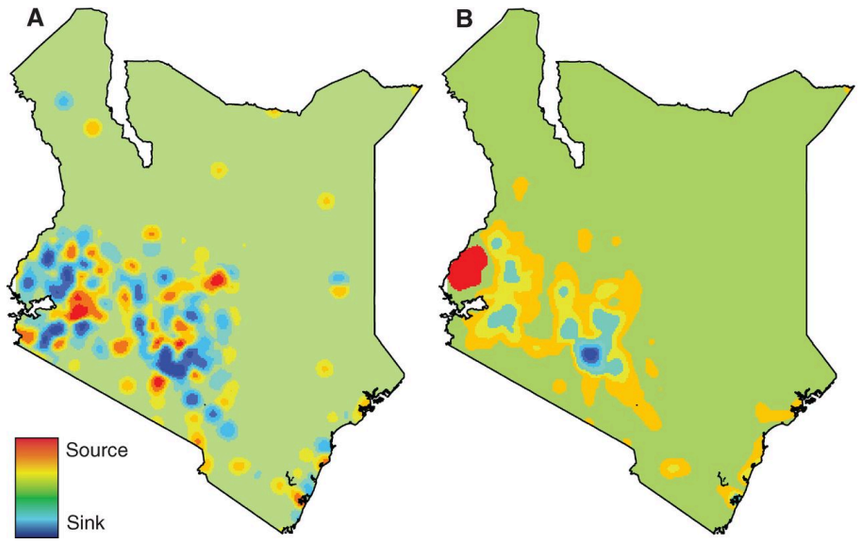
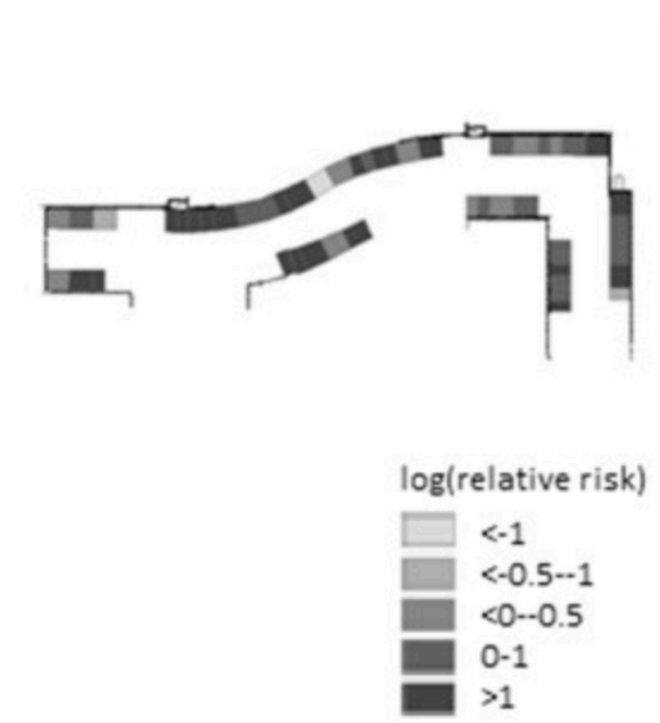


Wesolowski *et al.*, Science (2012)



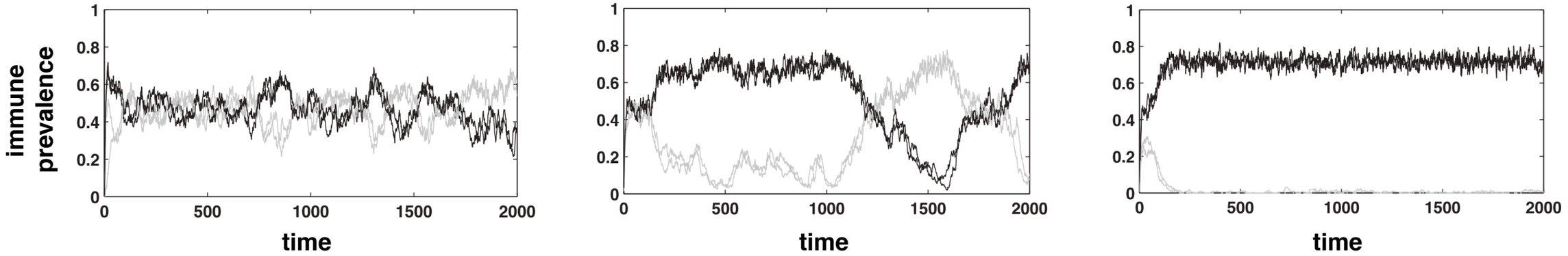
Kong *et al.*, BMC ID (2013)

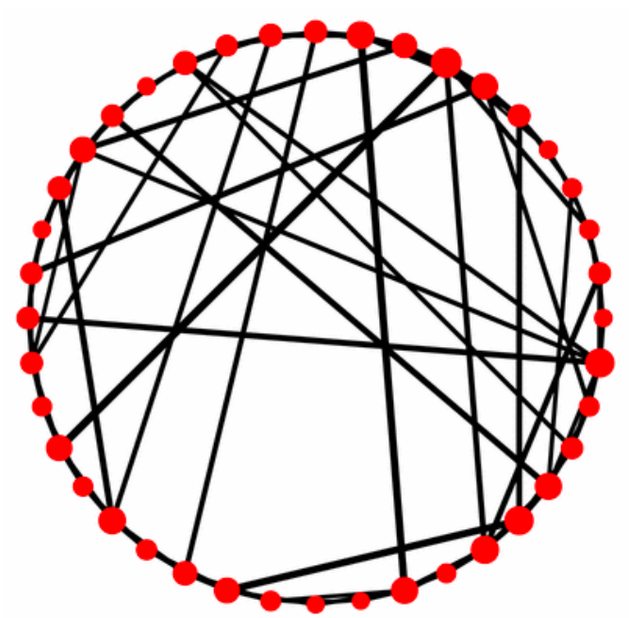
Human mobility affects how pathogens **evolve**

The effects of host contact network structure on pathogen diversity and strain structure

Caroline O'F. Buckee*†‡, Katia Koelle†§, Matthew J. Mustard†¶‖, and Sunetra Gupta*

cross-immunity →





introduction - *national study* - *haslemere study* - *strain dynamics*

But… how do humans move?

Bulk movement

The 'gravity model'

$$T_{i,j} = \frac{N_i^{\alpha} N_j^{\beta}}{f(d_{i,j})}$$

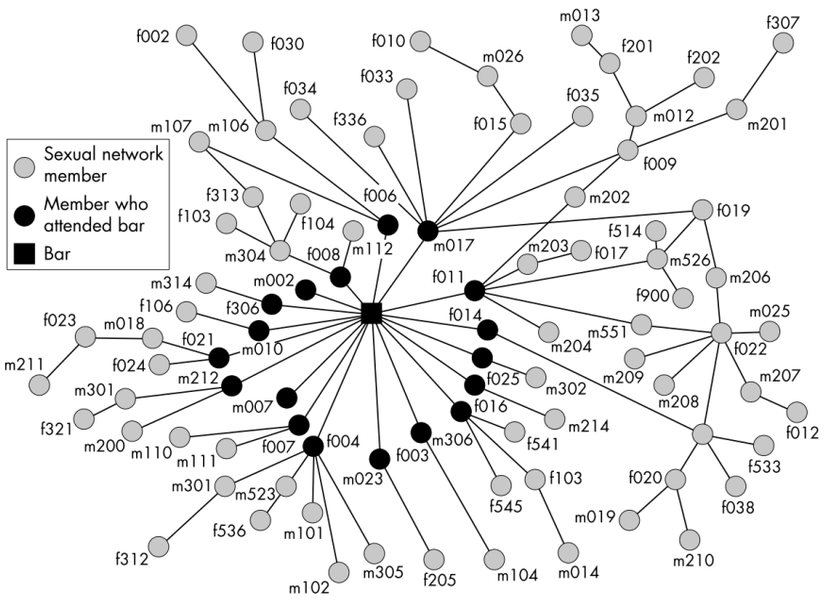
Zipf, Am Soc Rev (1946)

The 'radiation model'

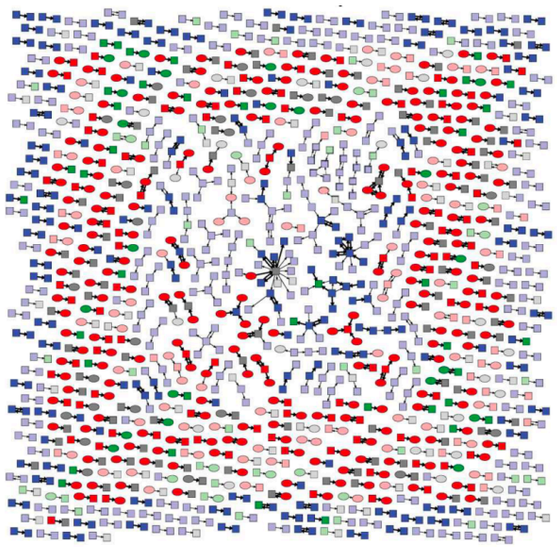
$$\langle T_{i,j} \rangle = T_i \frac{N_i N_j}{(N_i + s_{i,j})(N_i + N_j + s_{i,j})}$$

Simini *et al.,* Nature (2012)

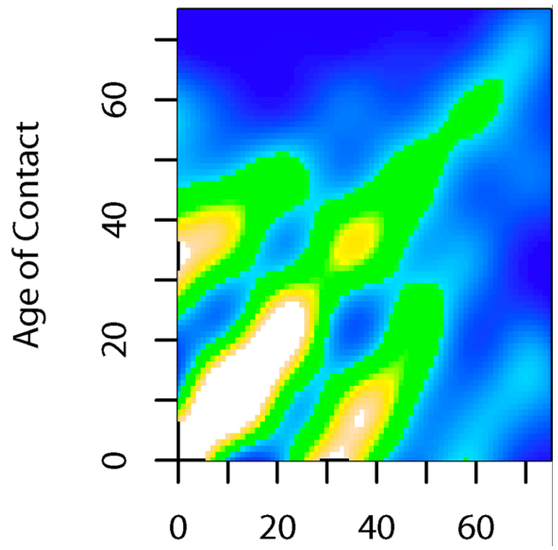
Interpersonal mixing



De *et al.,* STI (2004)



Wertheim *et al.,* PLoS Pathogens (2017)



Mossong *et al.,* PLoS Medicine (2008)

introduction - *national study* - *haslemere study* - *strain dynamics*

Contributors

Production team:

Maths team:

Julia Gog Maria Tang (me)

Petra Klepac

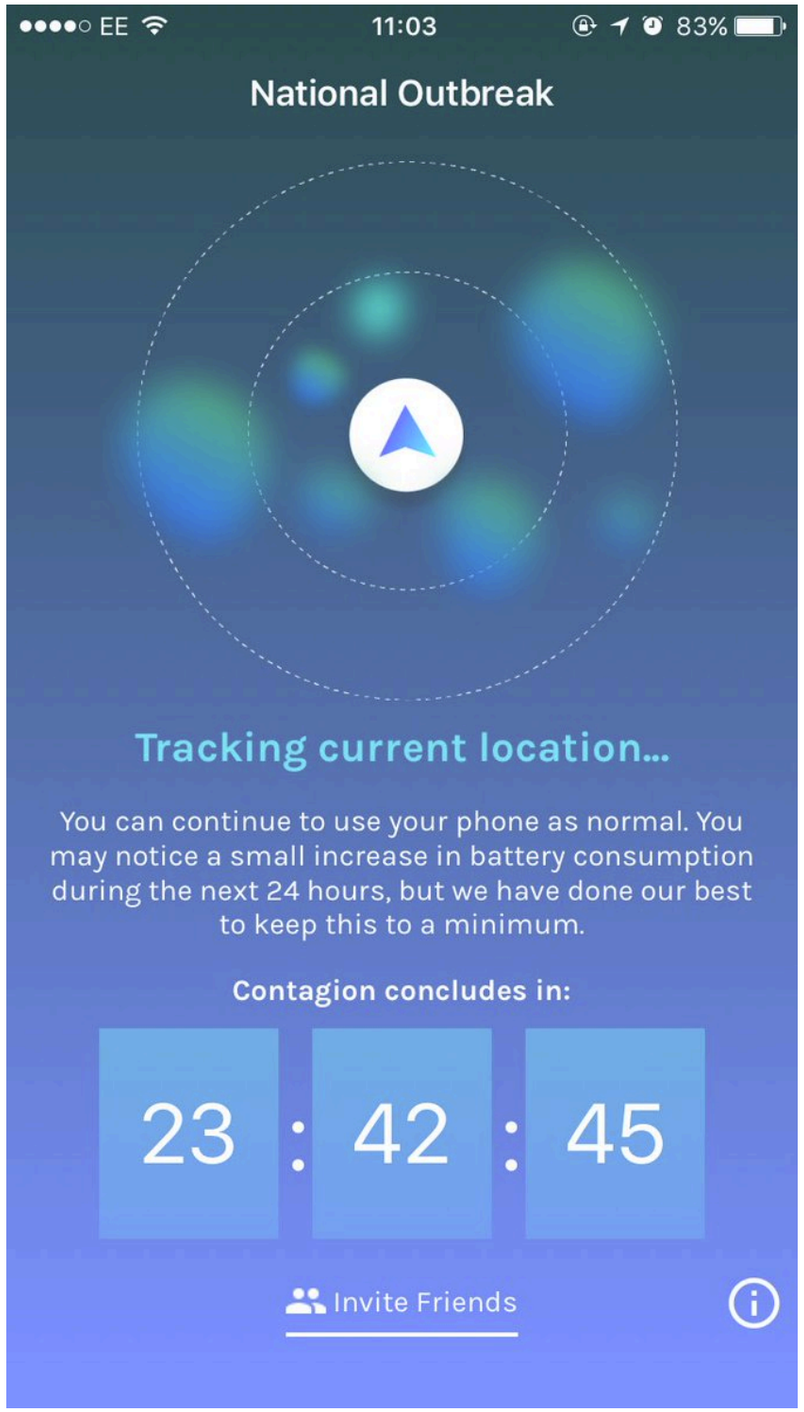
Andrew Conlan

Adam Kucharski

Hannah Fry

introduction - *national study* - *haslemere study* - *strain dynamics*

The BBC Pandemic app:



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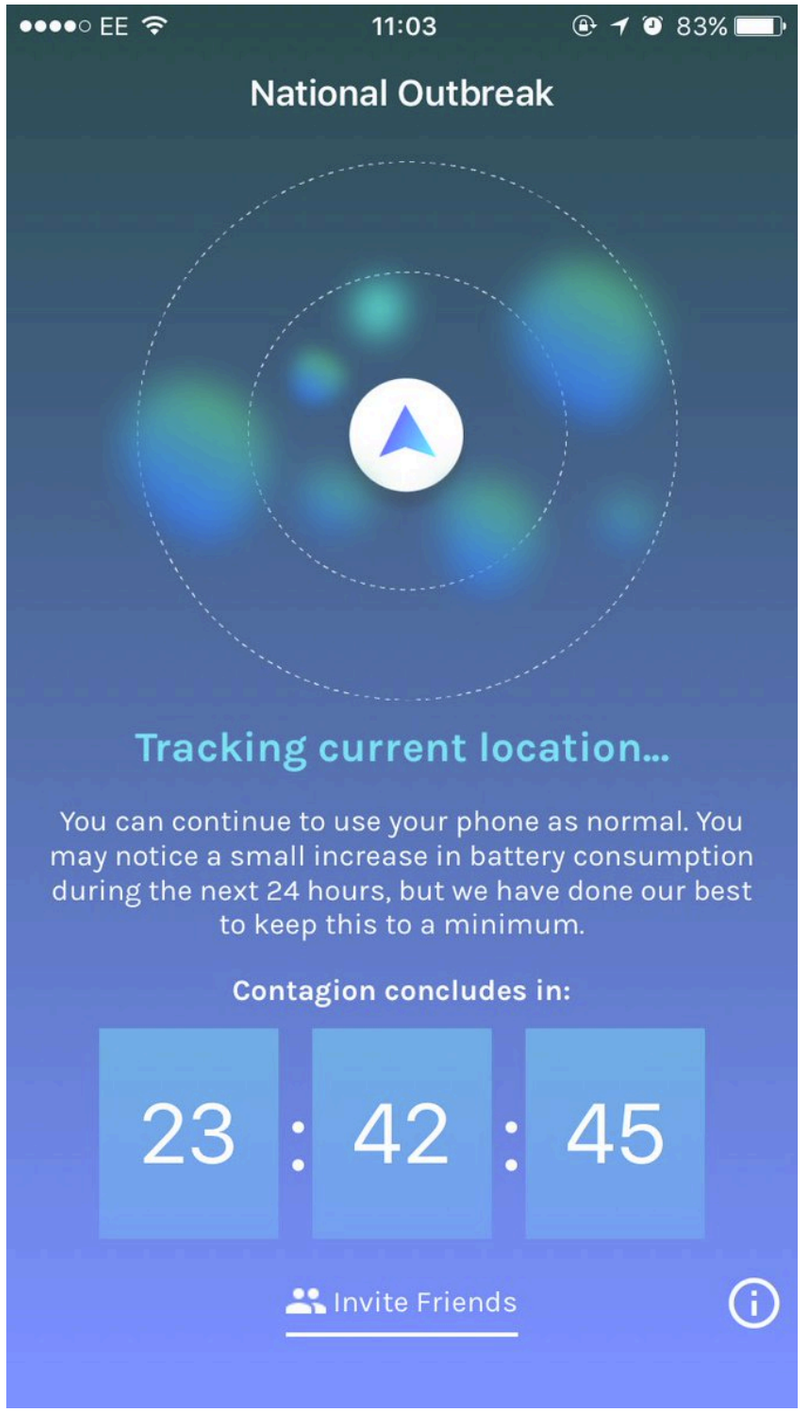
The BBC Pandemic app:

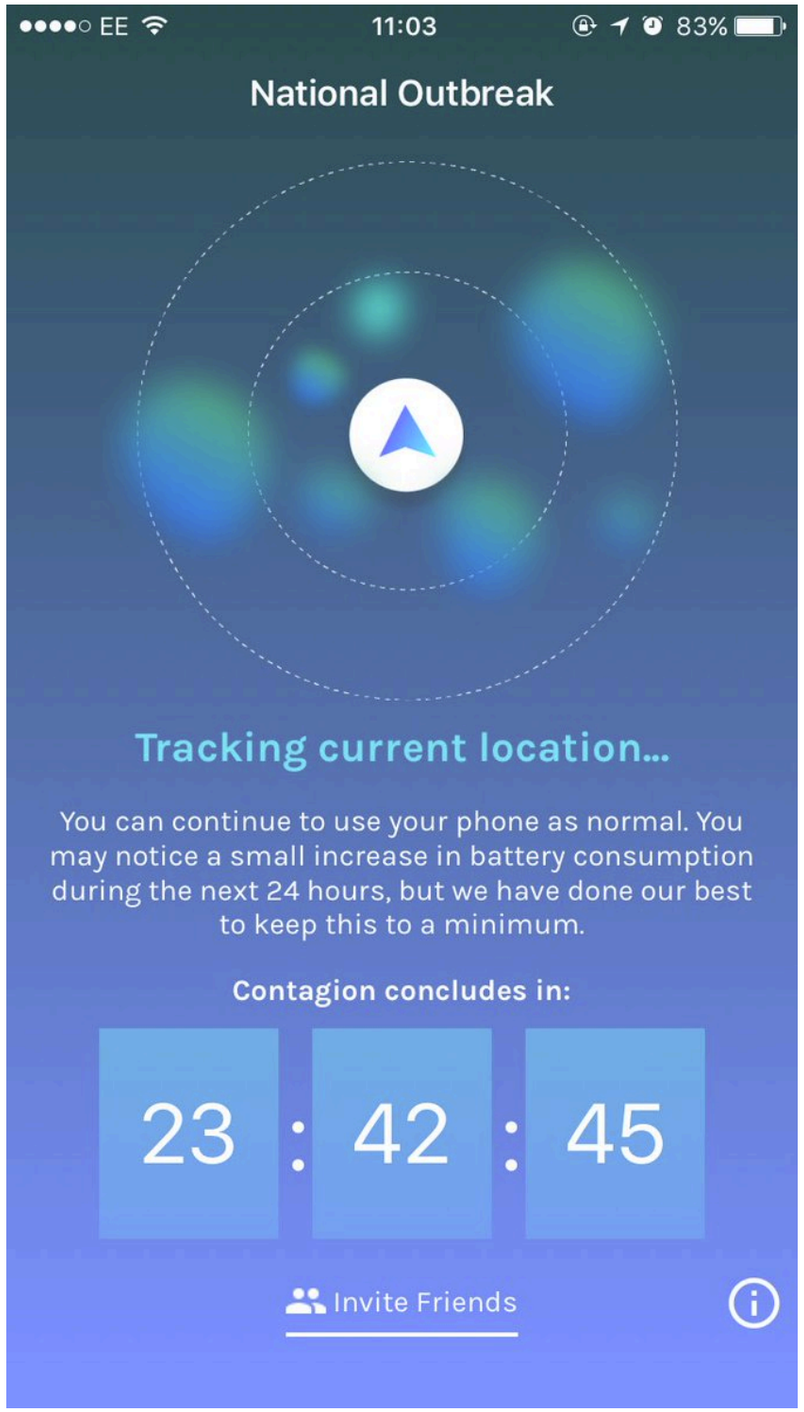
- Social contacts
- Geographic location (>1km)
- UK-wide



The BBC Pandemic app:

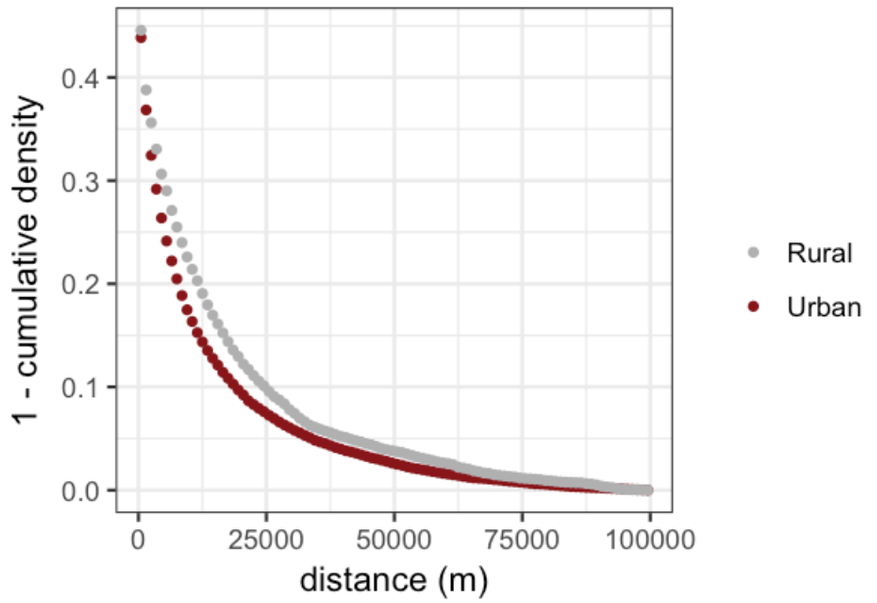
- Social contacts
- Geographic location (>1km)
- UK-wide

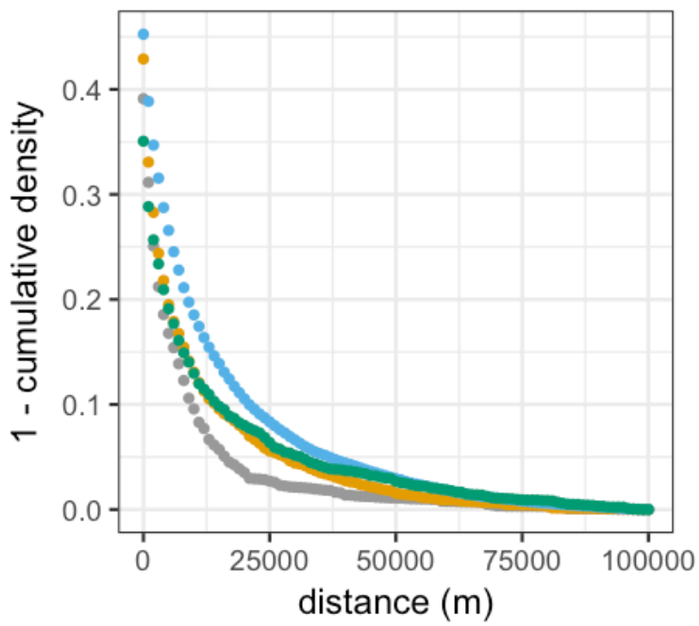
- Geographic location (>1m)
- Haslemere only

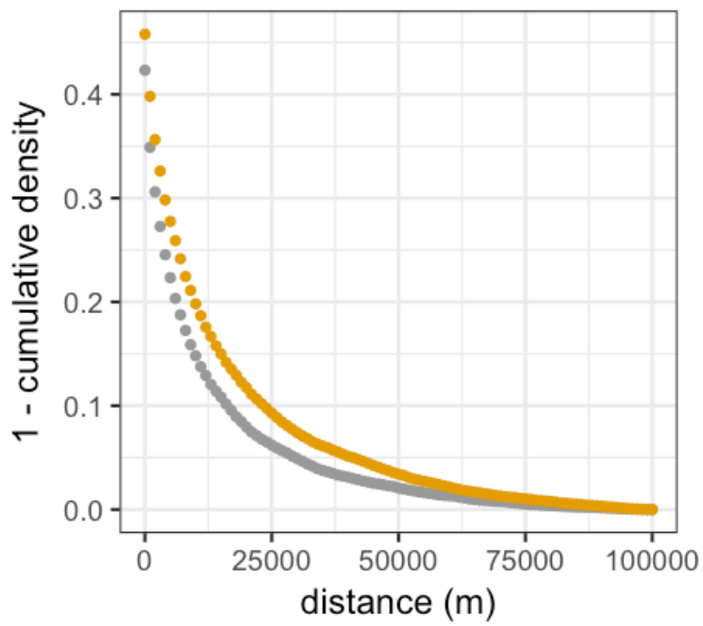


The National study

Probability of being more than ‘x’ meters away from the first recorded location



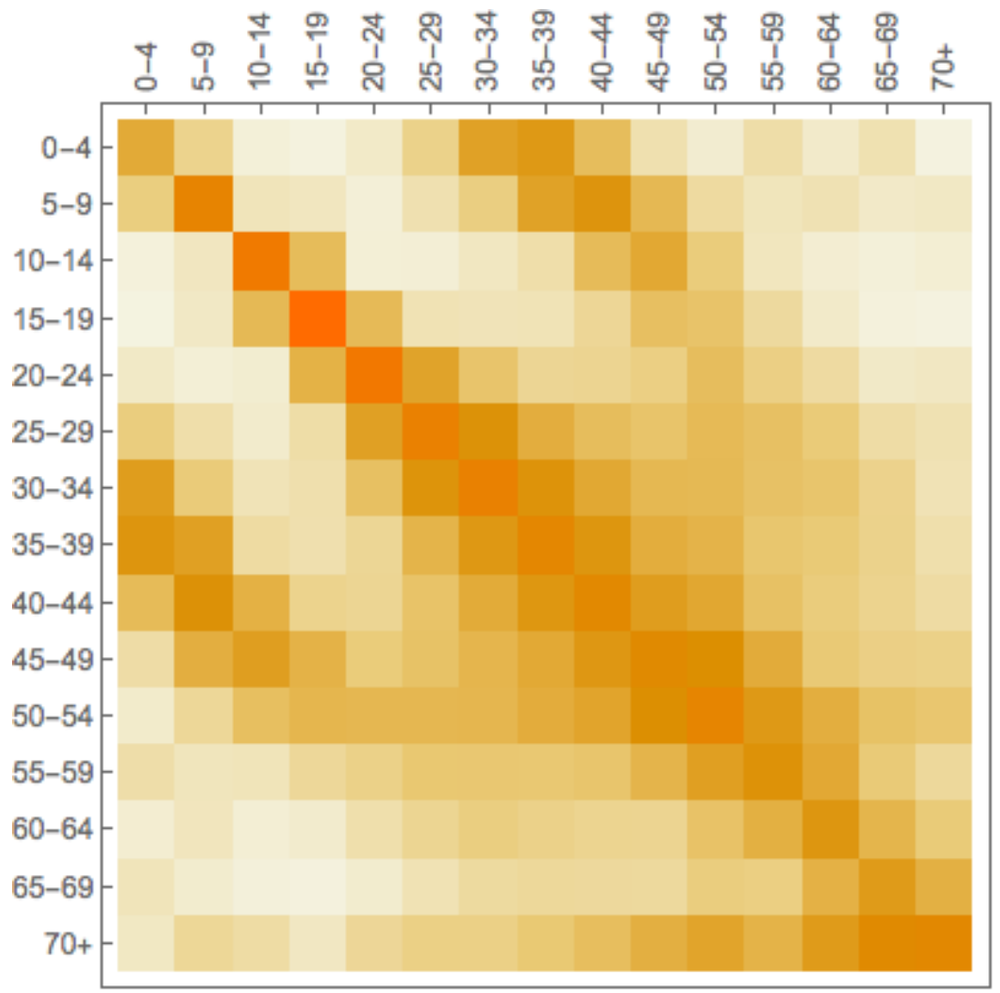




Klepac *et al.*, Epidemics (2018)

The National study

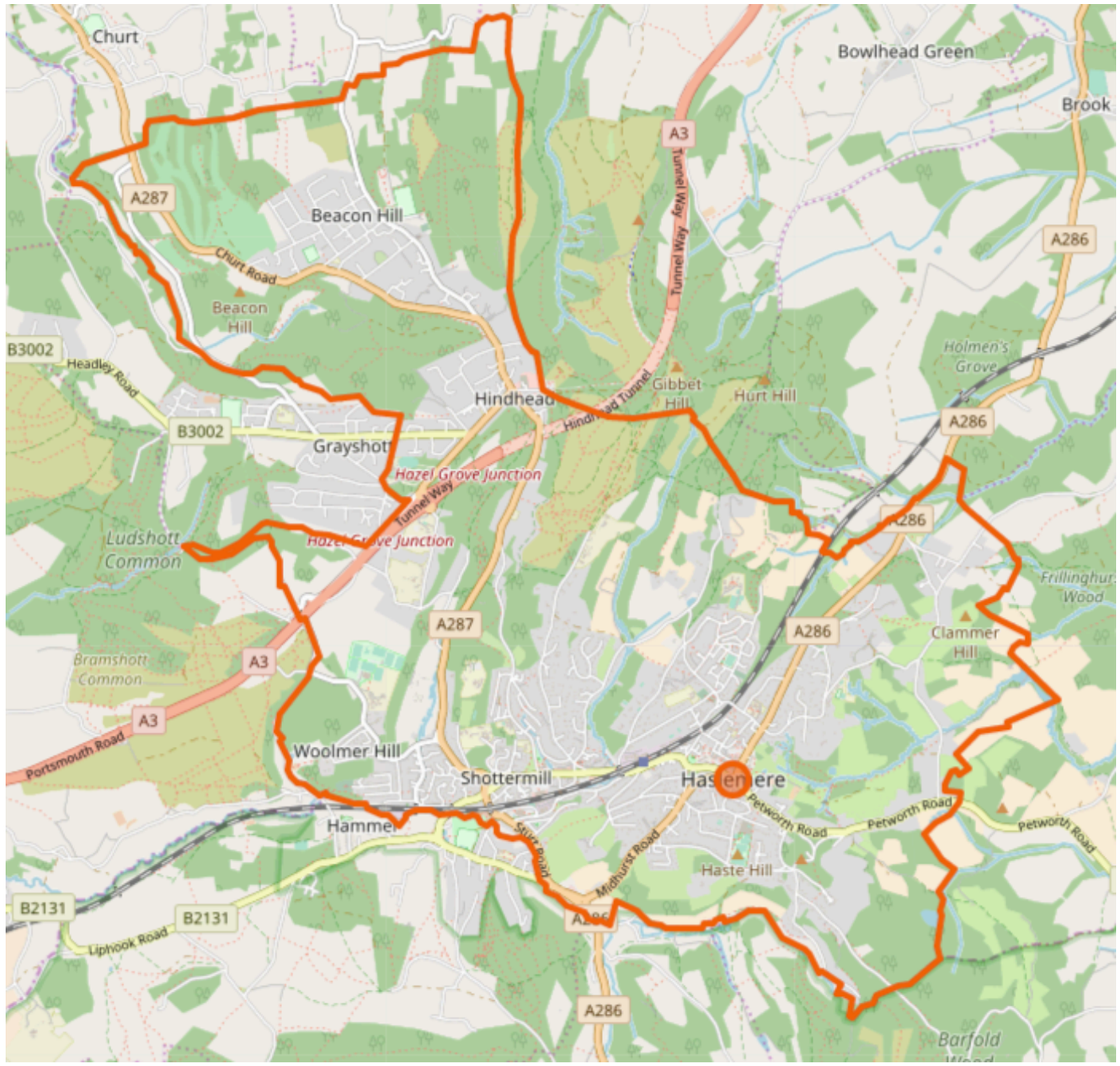
Age distribution of contacts



Klepac *et al.,* Epidemics (2018)

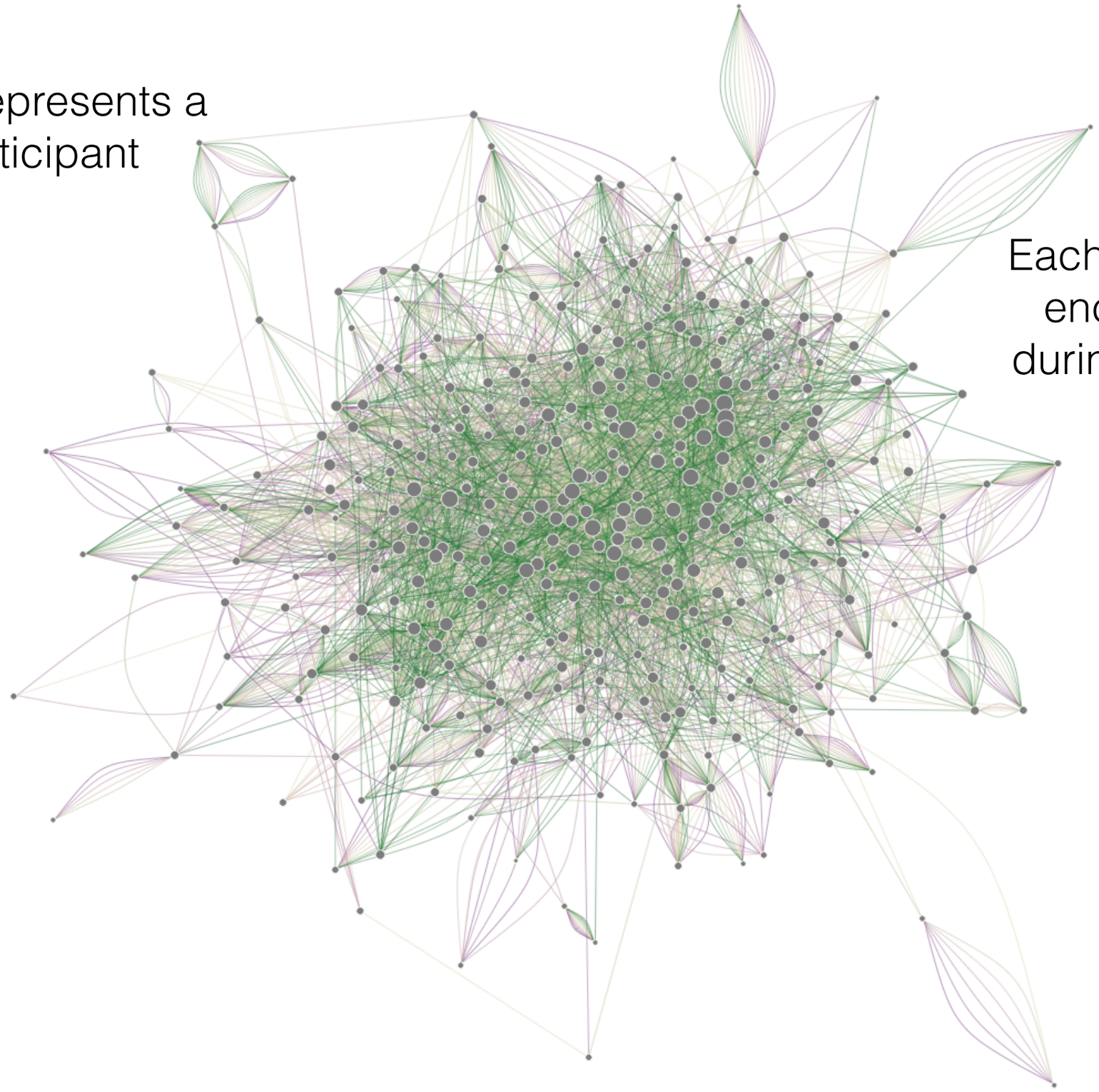
Movie credit: Julia Gog

The Haslemere study



The Haslemere study

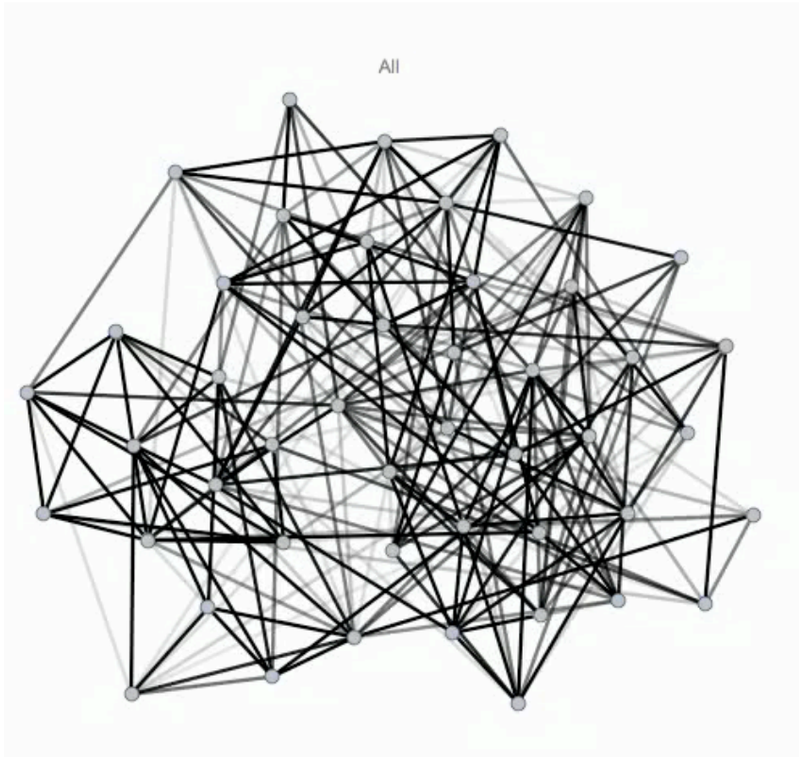
Each node represents a study participant



Each link represents an encounter w/in 20m during one quarter-day

Kissler *et al.,* coming soon

Host structure



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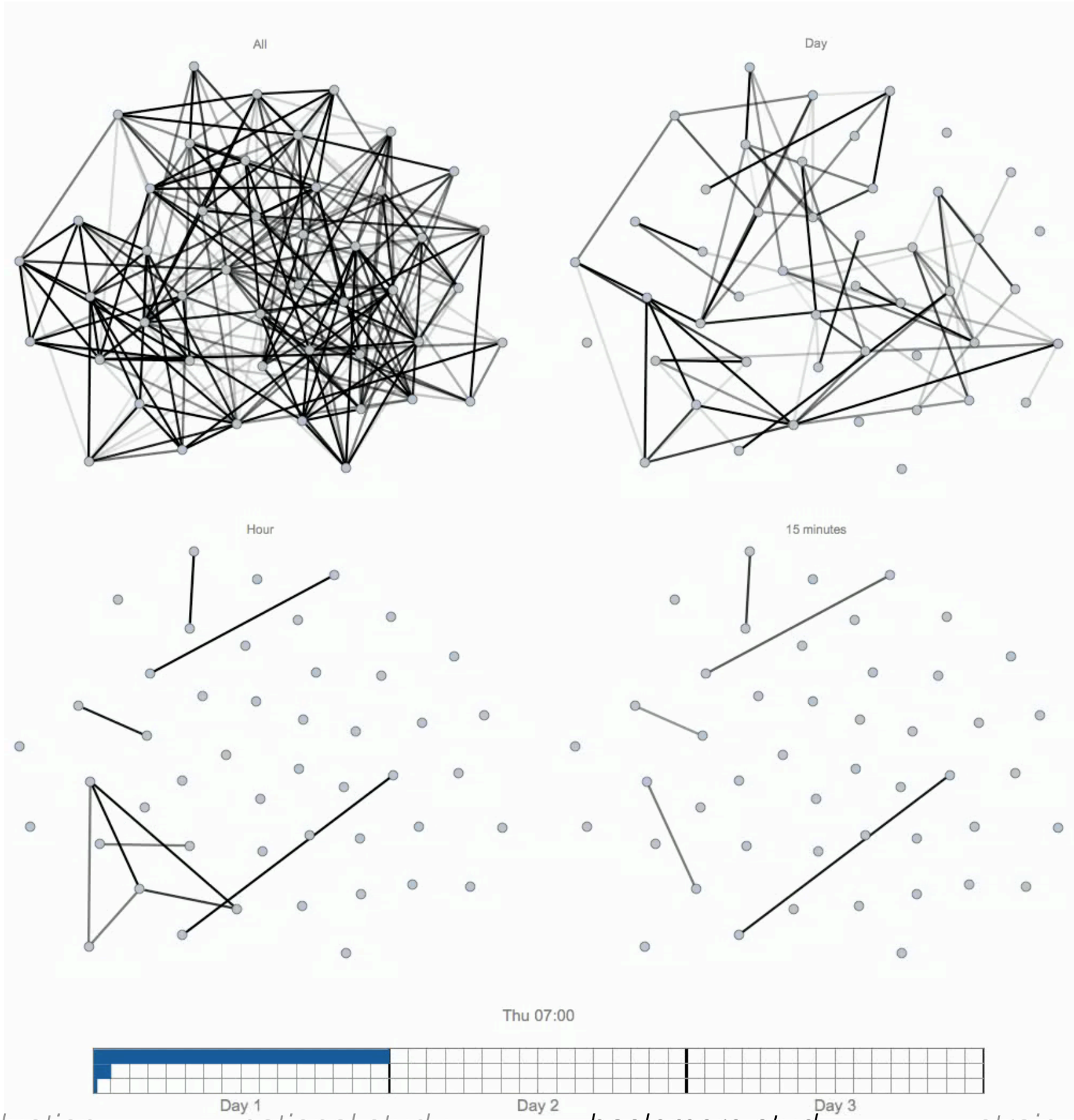
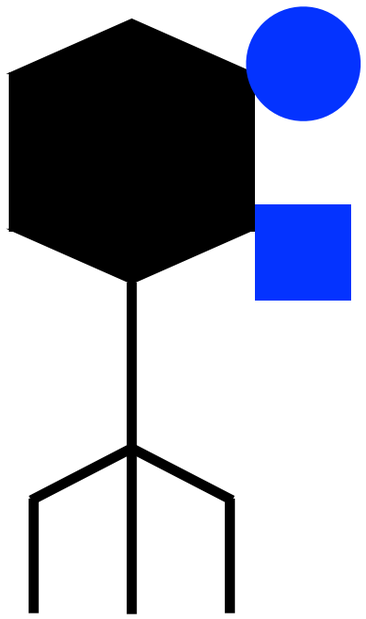
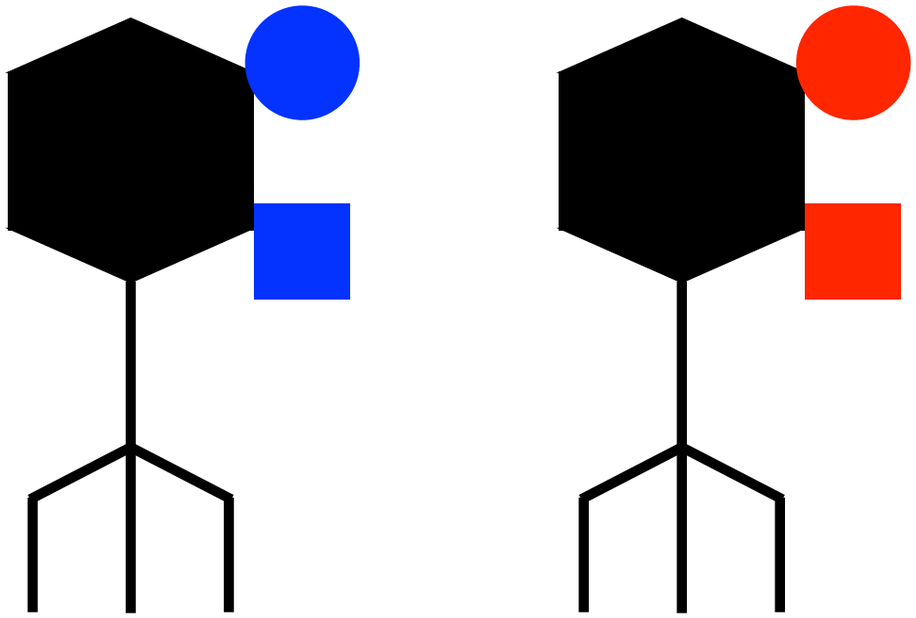


Strain dynamics



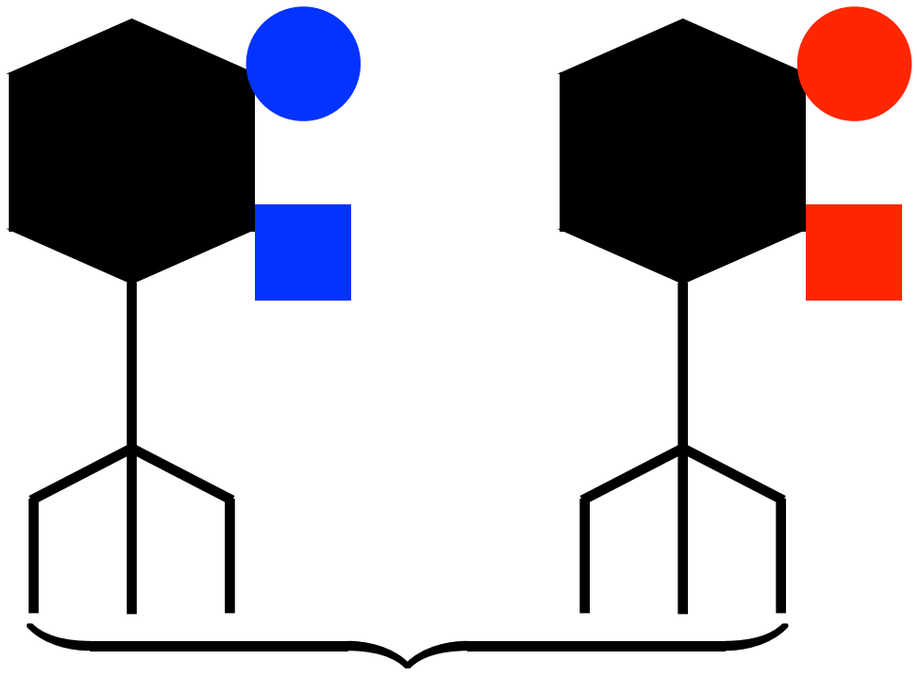
Buckee *et al.*, PNAS (2004)

Strain dynamics



Buckee *et al.*, PNAS (2004)

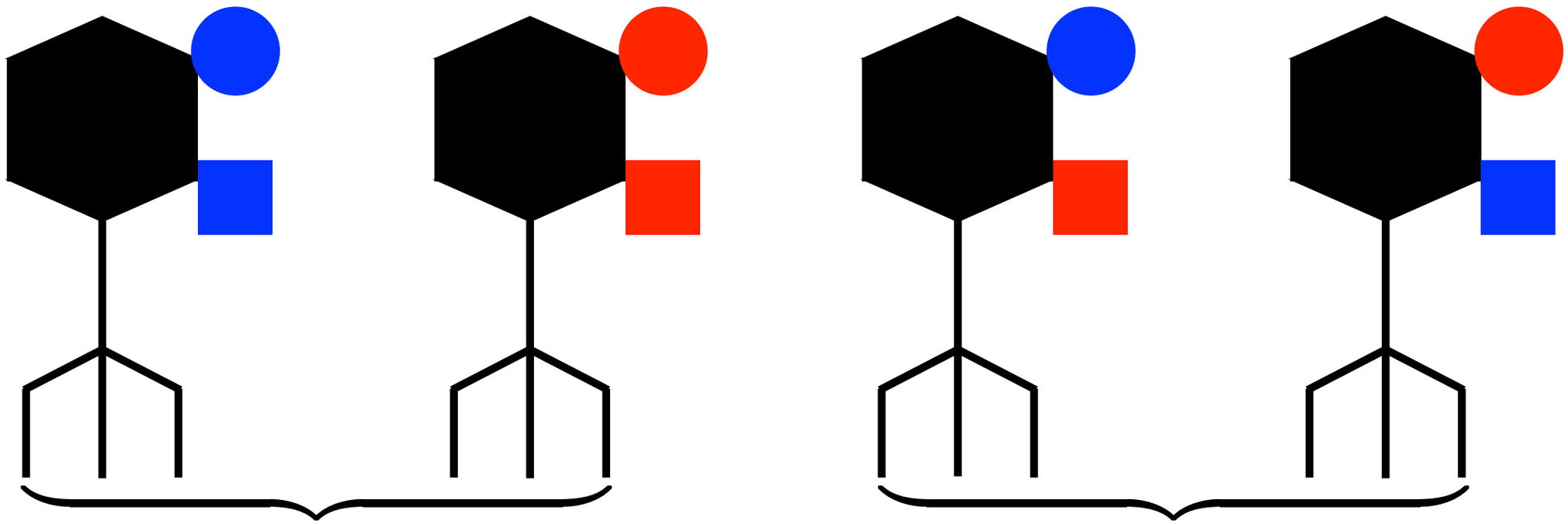
Strain dynamics



Discordant set

Buckee *et al.*, PNAS (2004)

Strain dynamics



Discordant set

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Buckee *et al.*, PNAS (2004)

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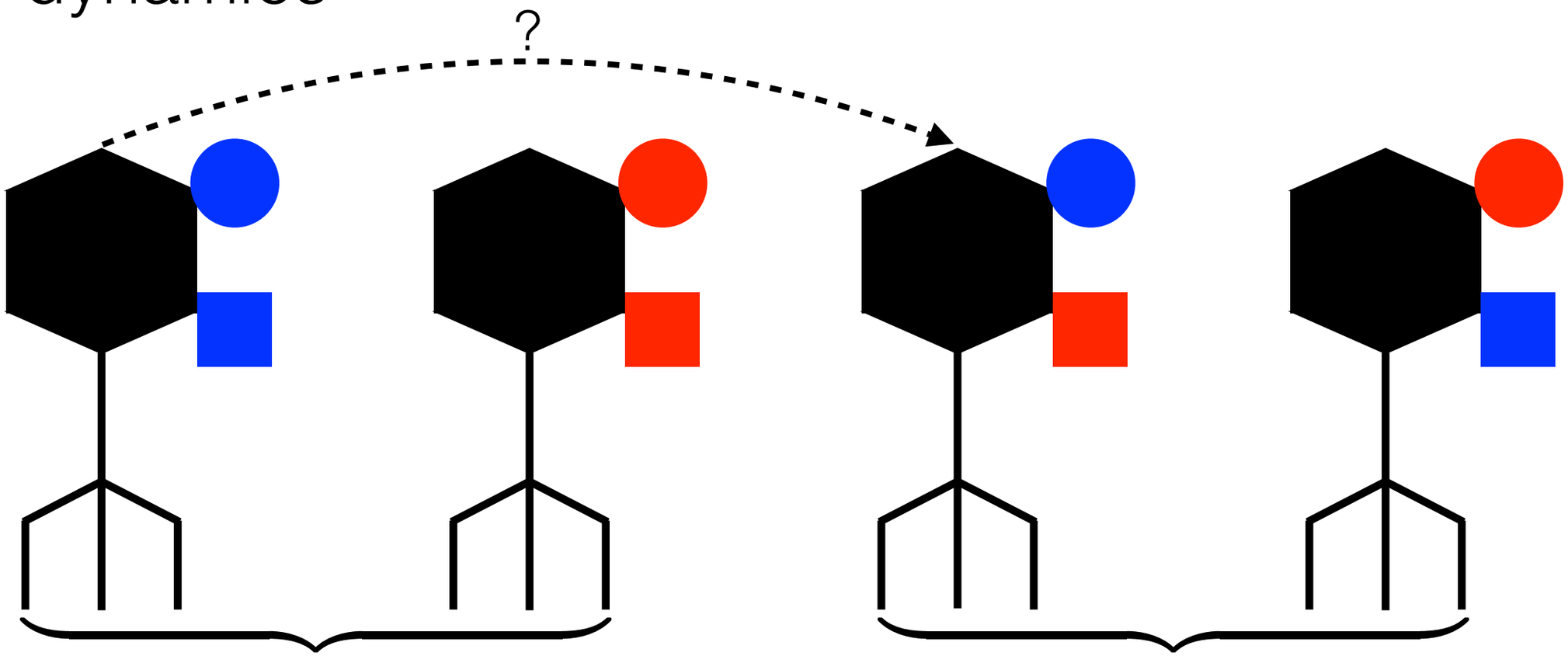

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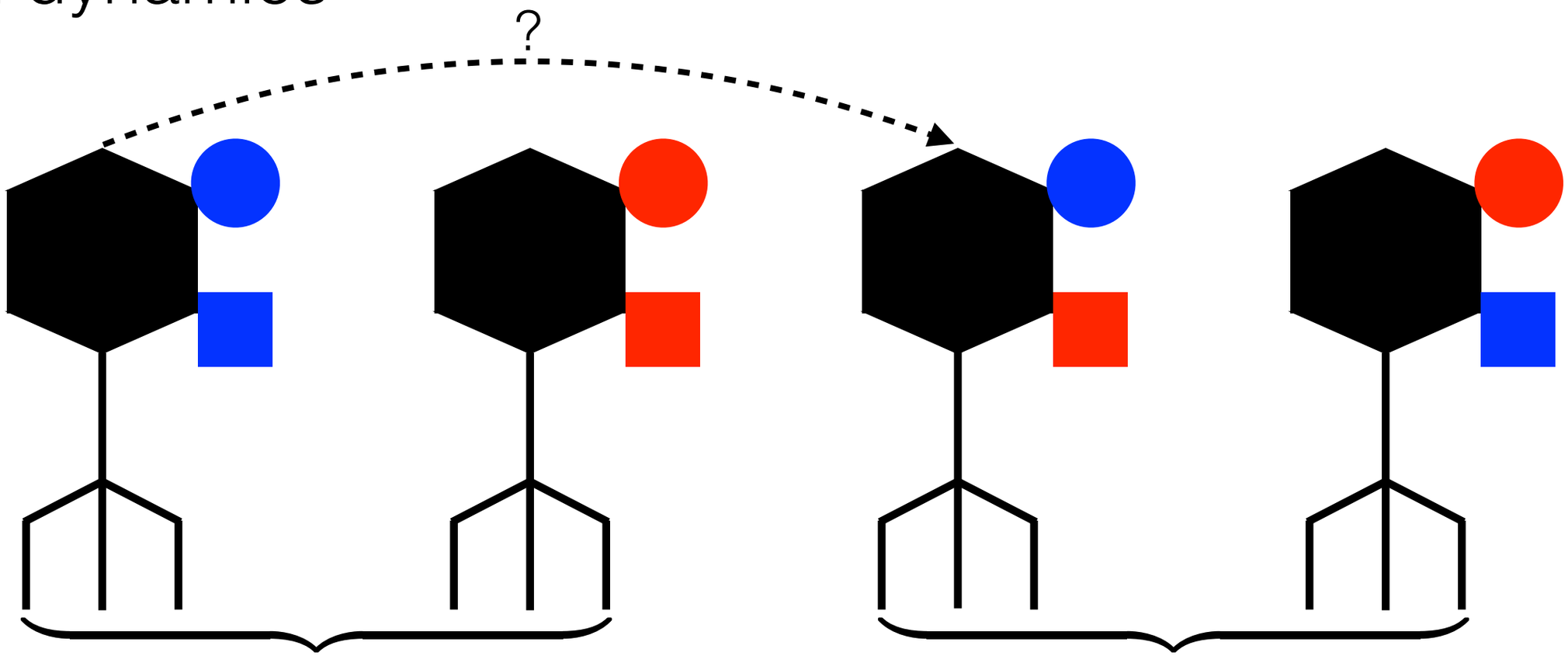
Strain dynamics



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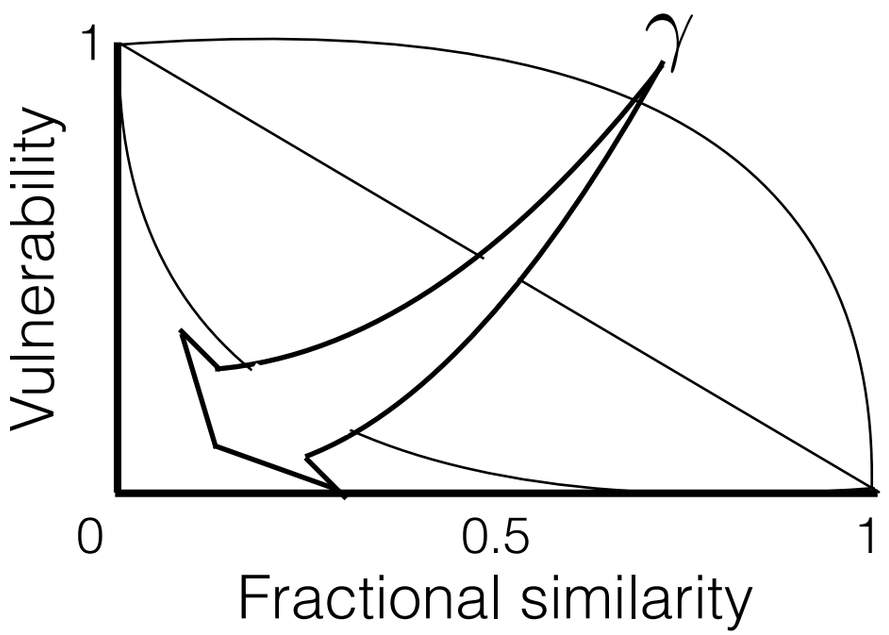
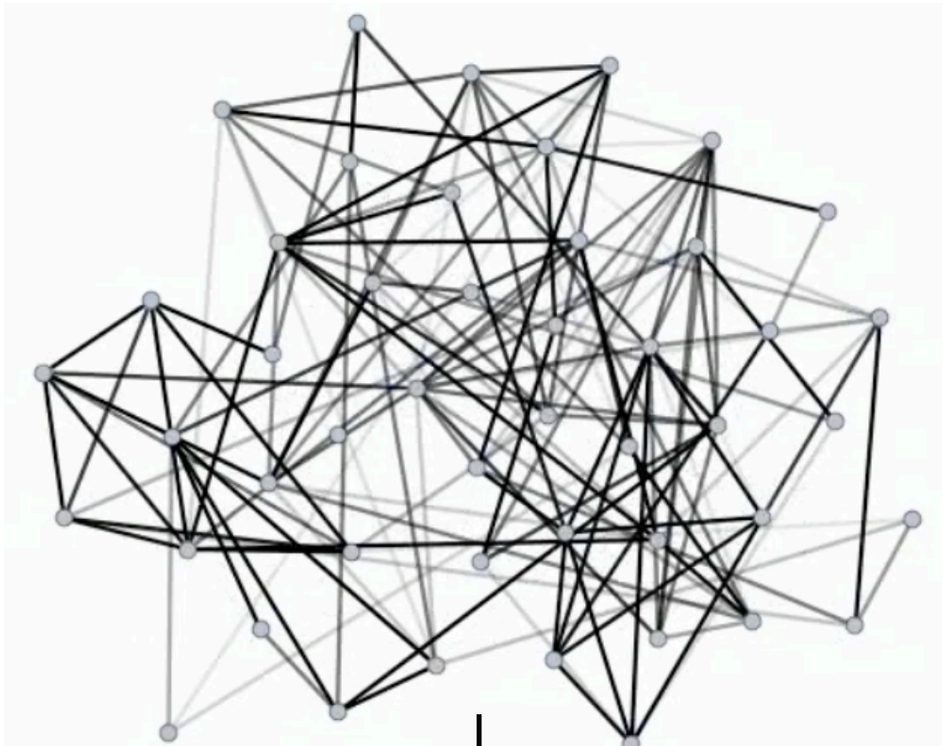


$$v = (1 - f^{1/\gamma})^{\gamma}$$

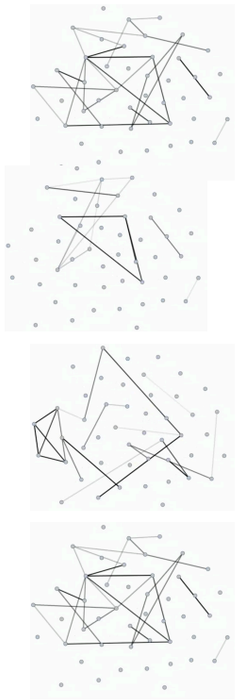
Buckee *et al.*, PNAS (2004)

Simulating transmission

Day



Quarter-day

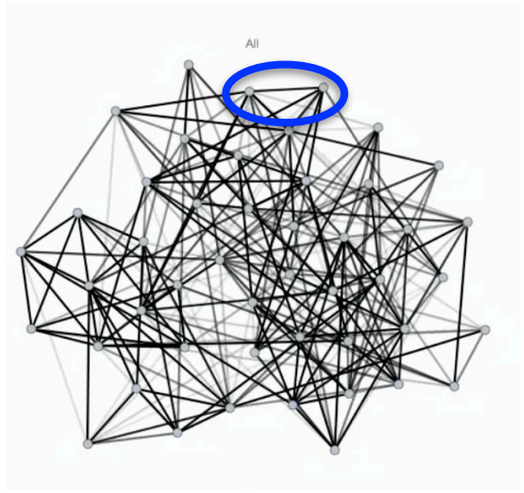


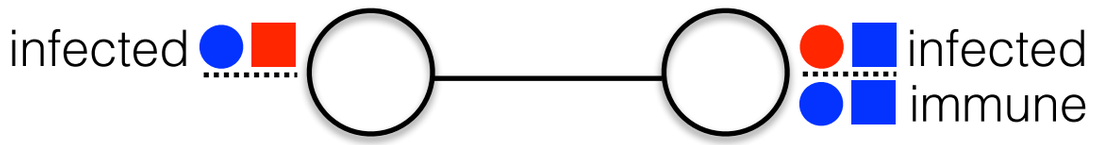
Hour

introduction - *national study* - *haslemere study* - *strain dynamics*

5840 iterations total
(one ‘year’, 16h/day)

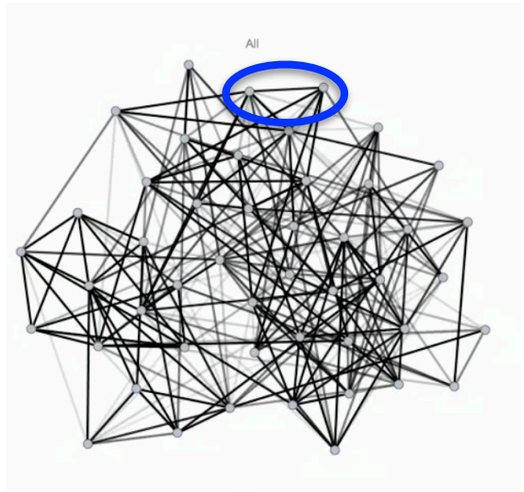
Simulating transmission

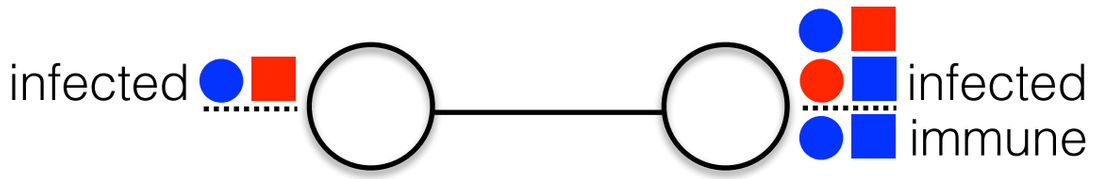




Event	Probability
Infection	$v\beta$
Lose immunity	σ
Clear infection	μ
Mutation	τ

Simulating transmission





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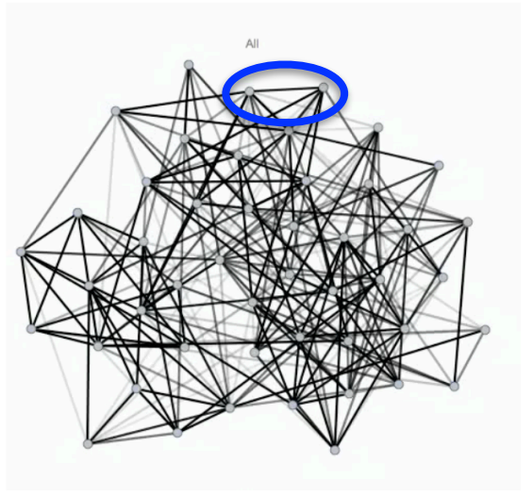

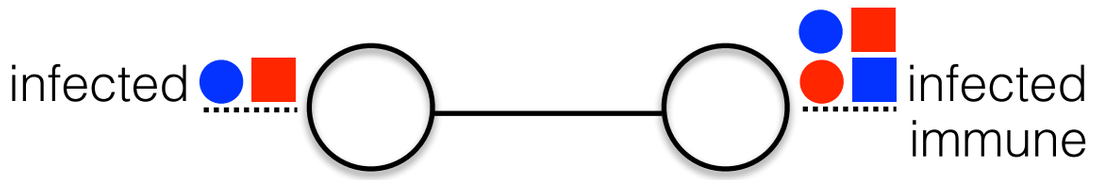

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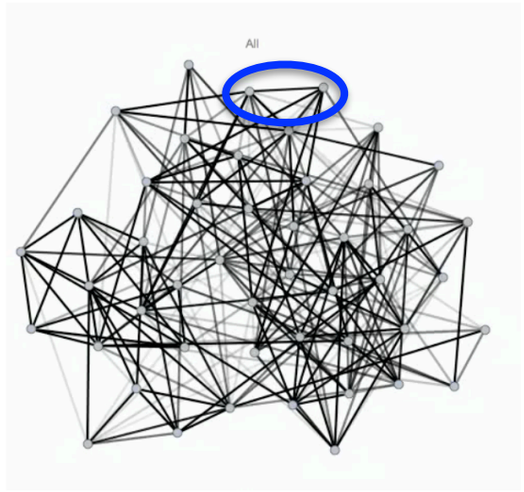
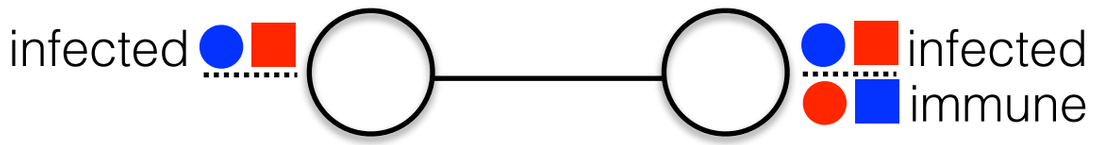
Simulating transmission





Event	Probability
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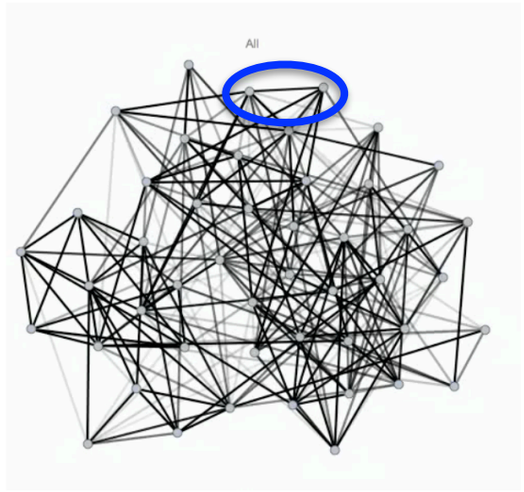
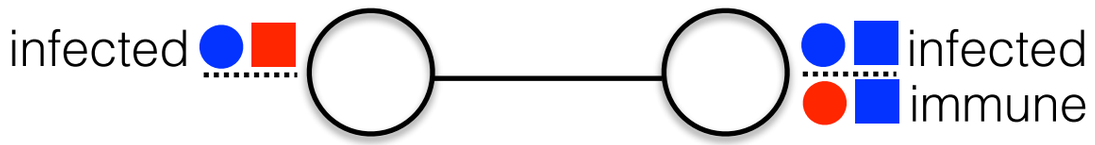
Simulating transmission





Event	Probability
Infection	$v\beta$
Lose immunity	σ
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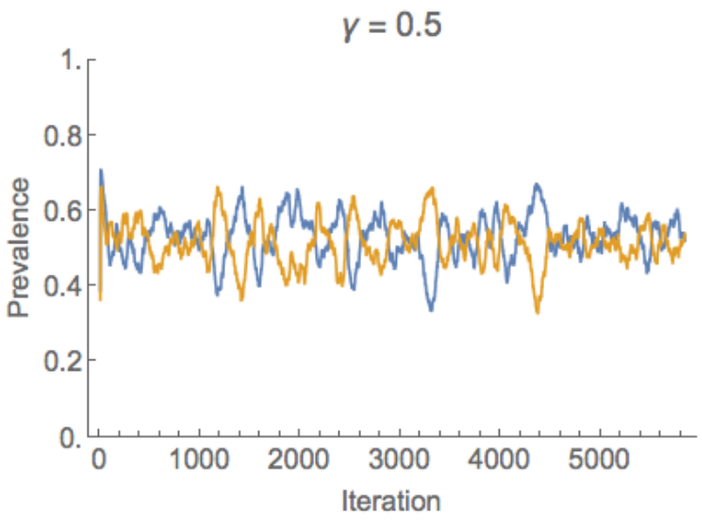
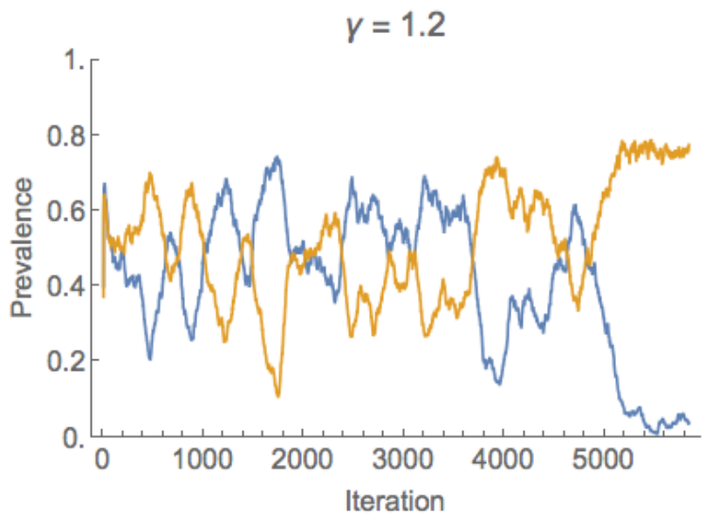
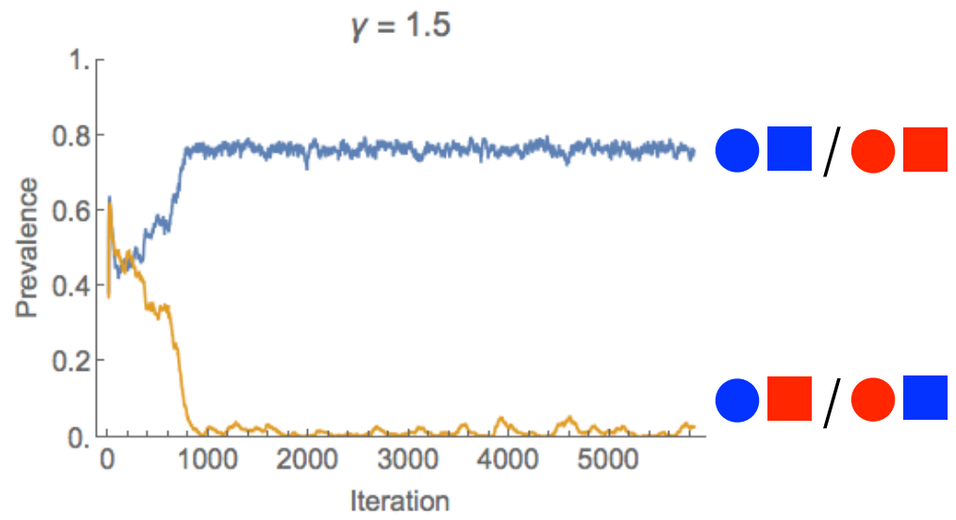
Typical output

Increasing cross immunity →

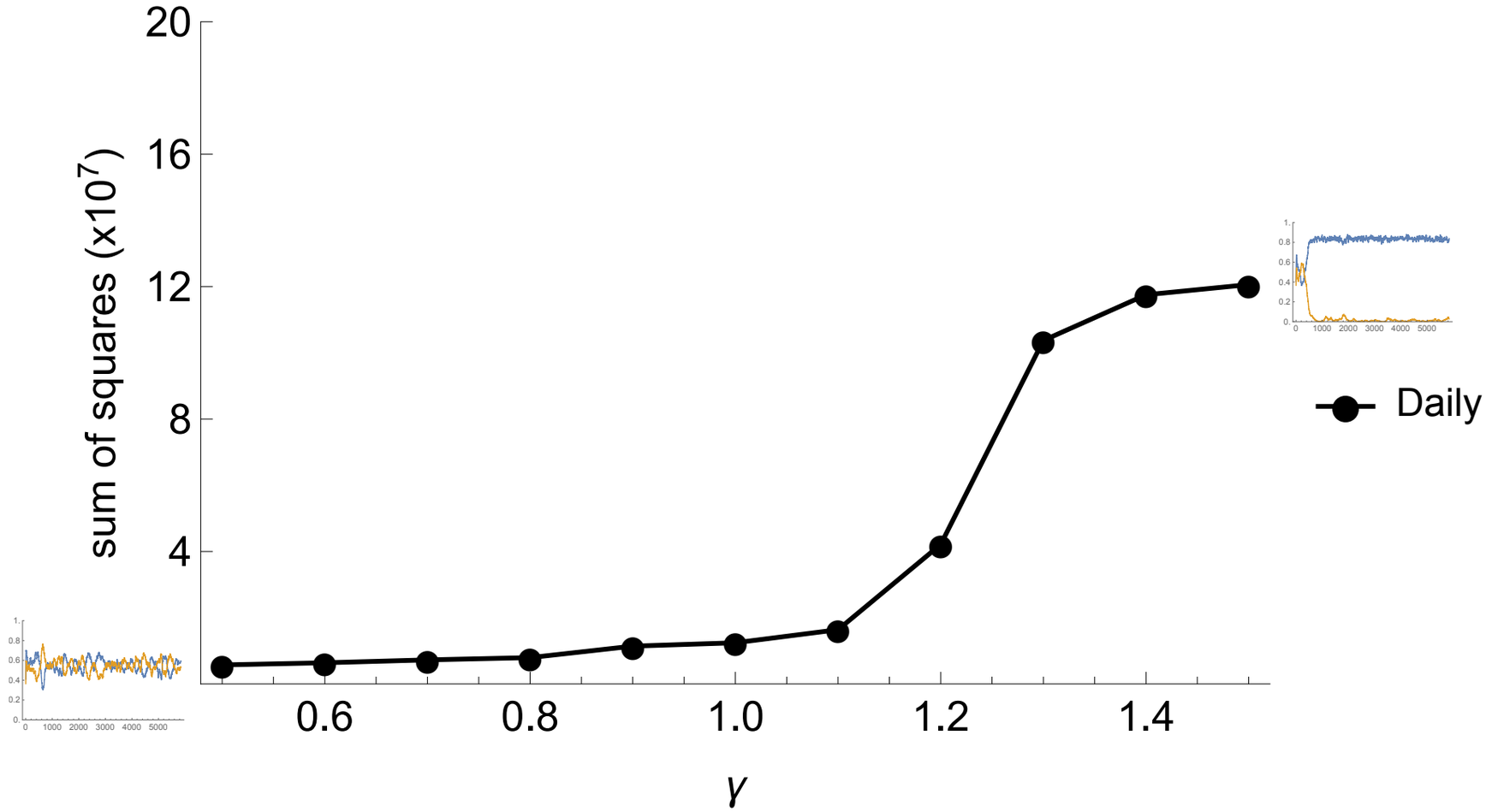






The transition to strain structure

The transition to strain structure



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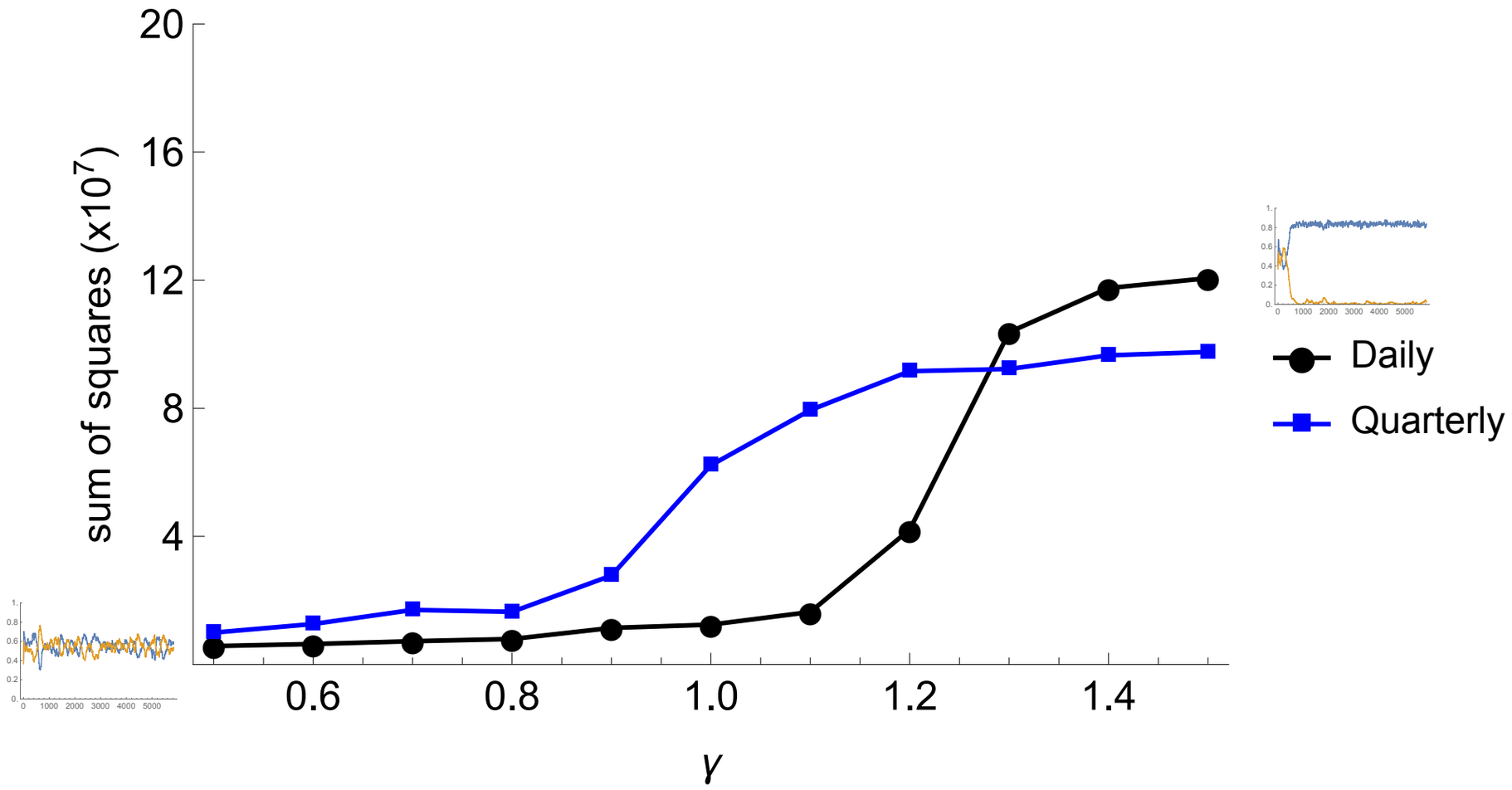

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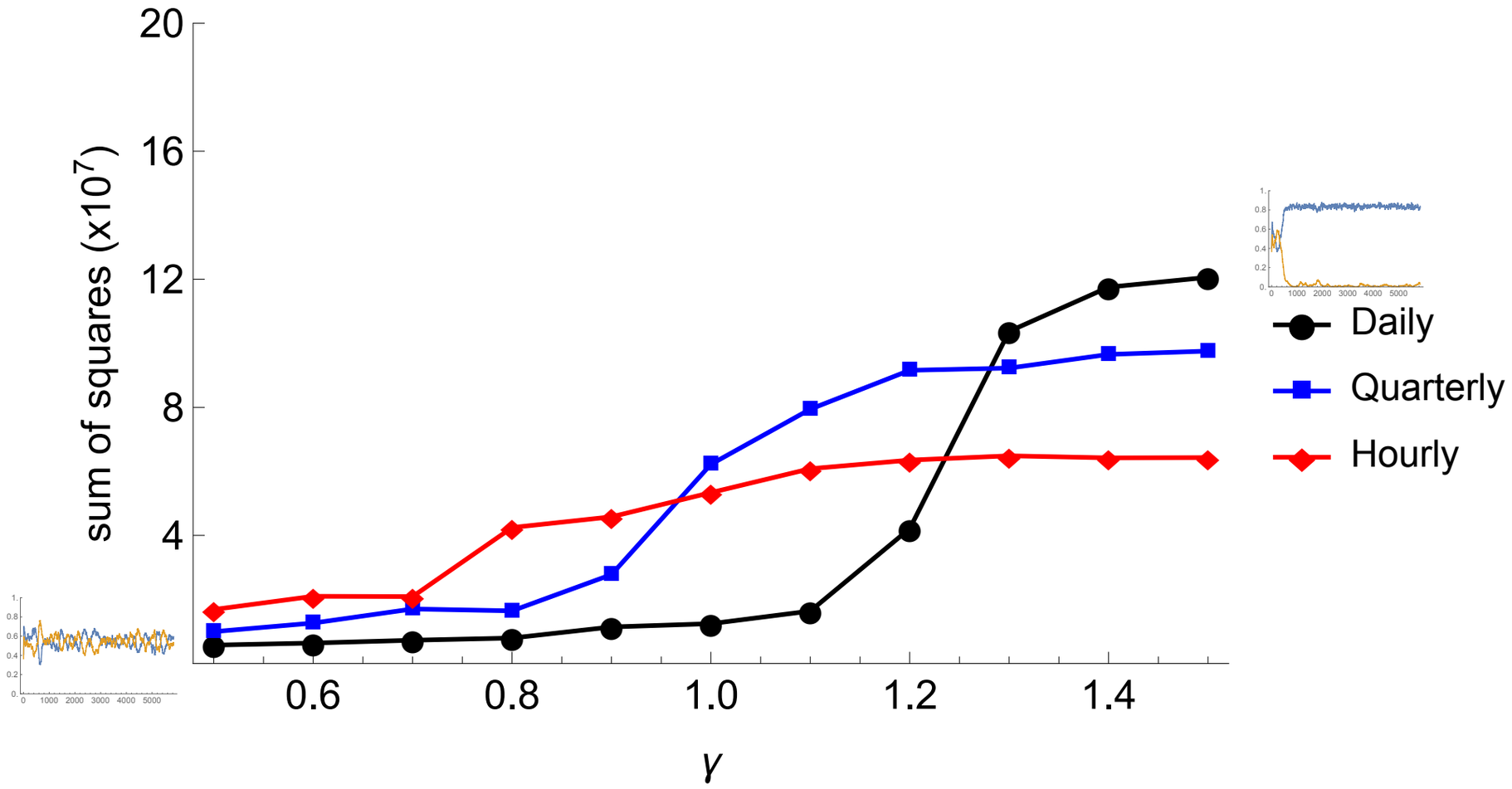
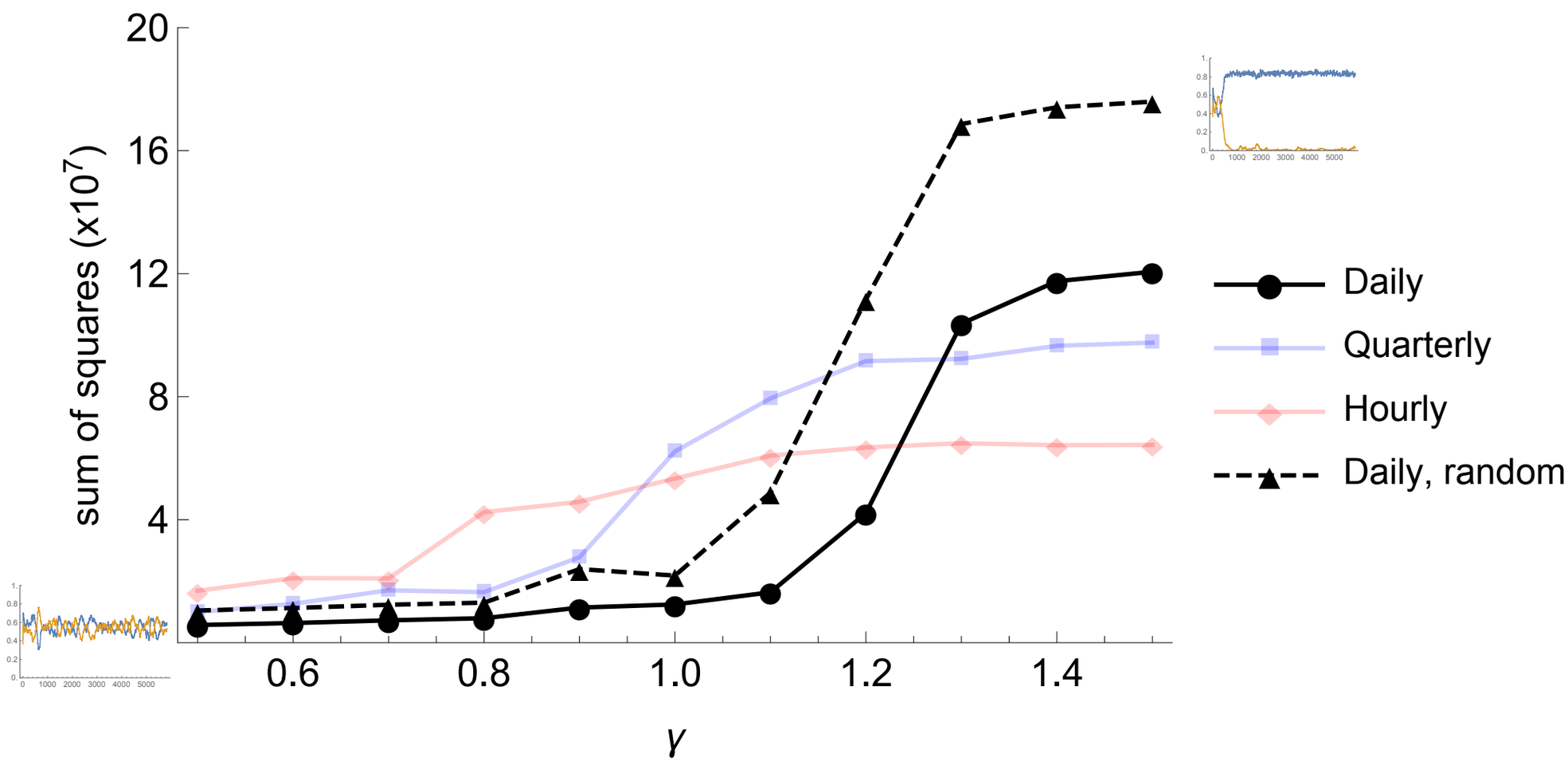
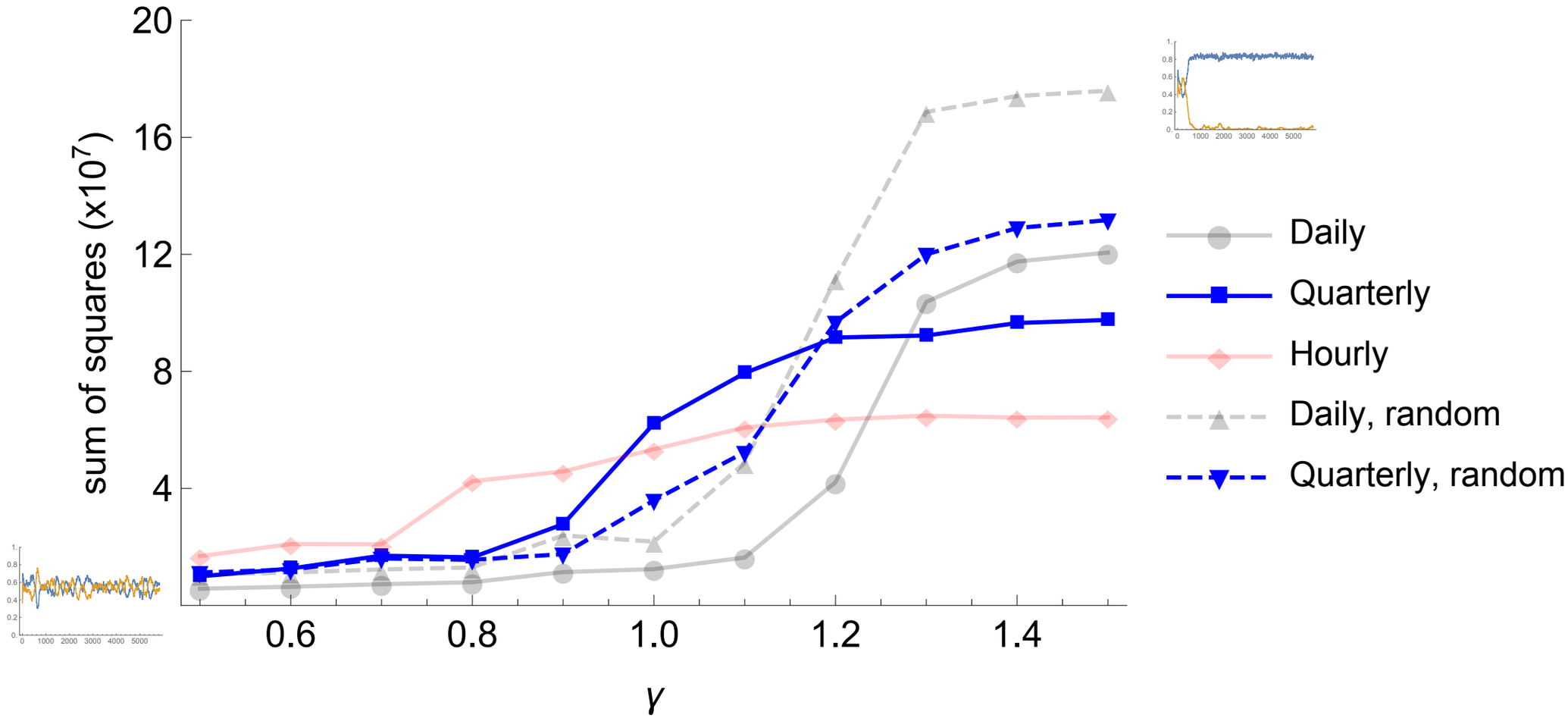


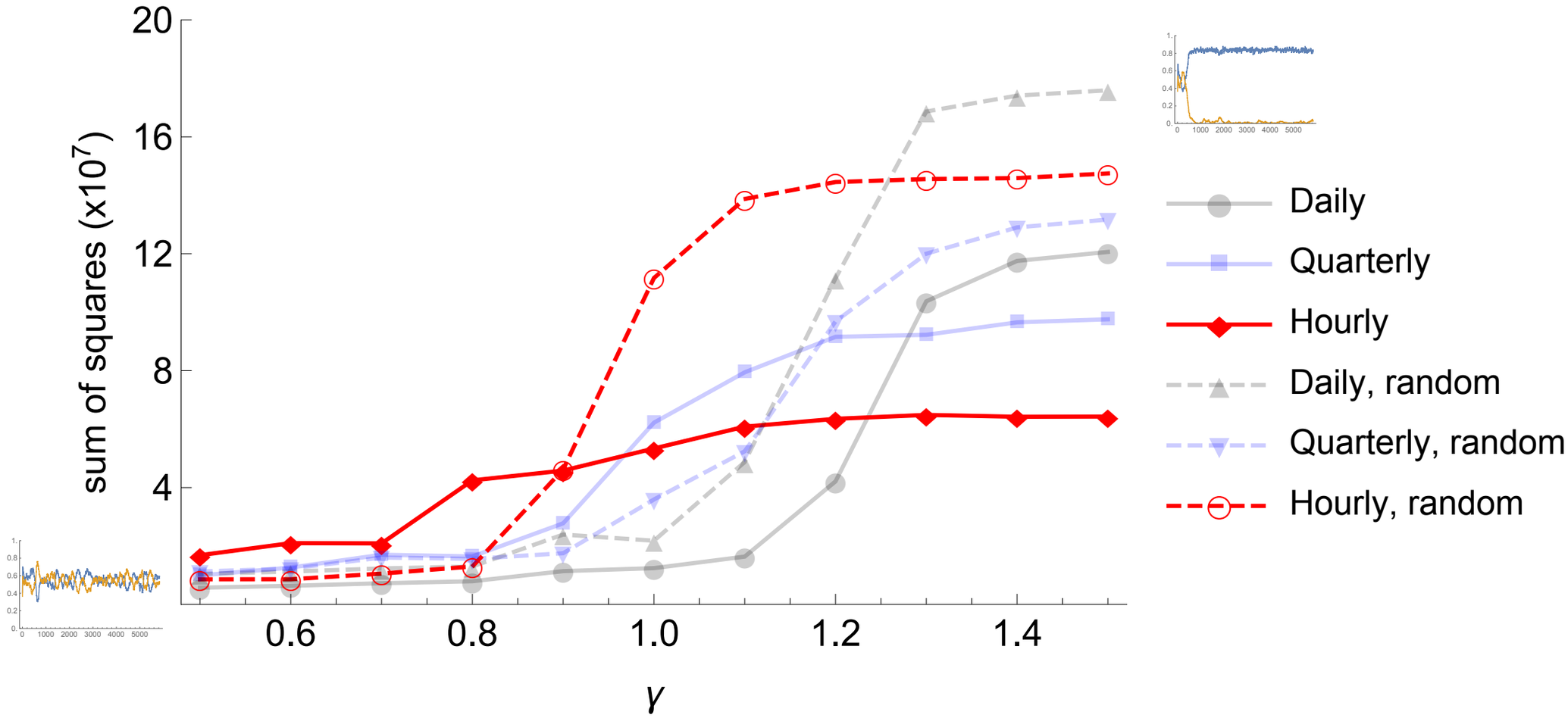
The transition to strain structure



The transition to strain structure

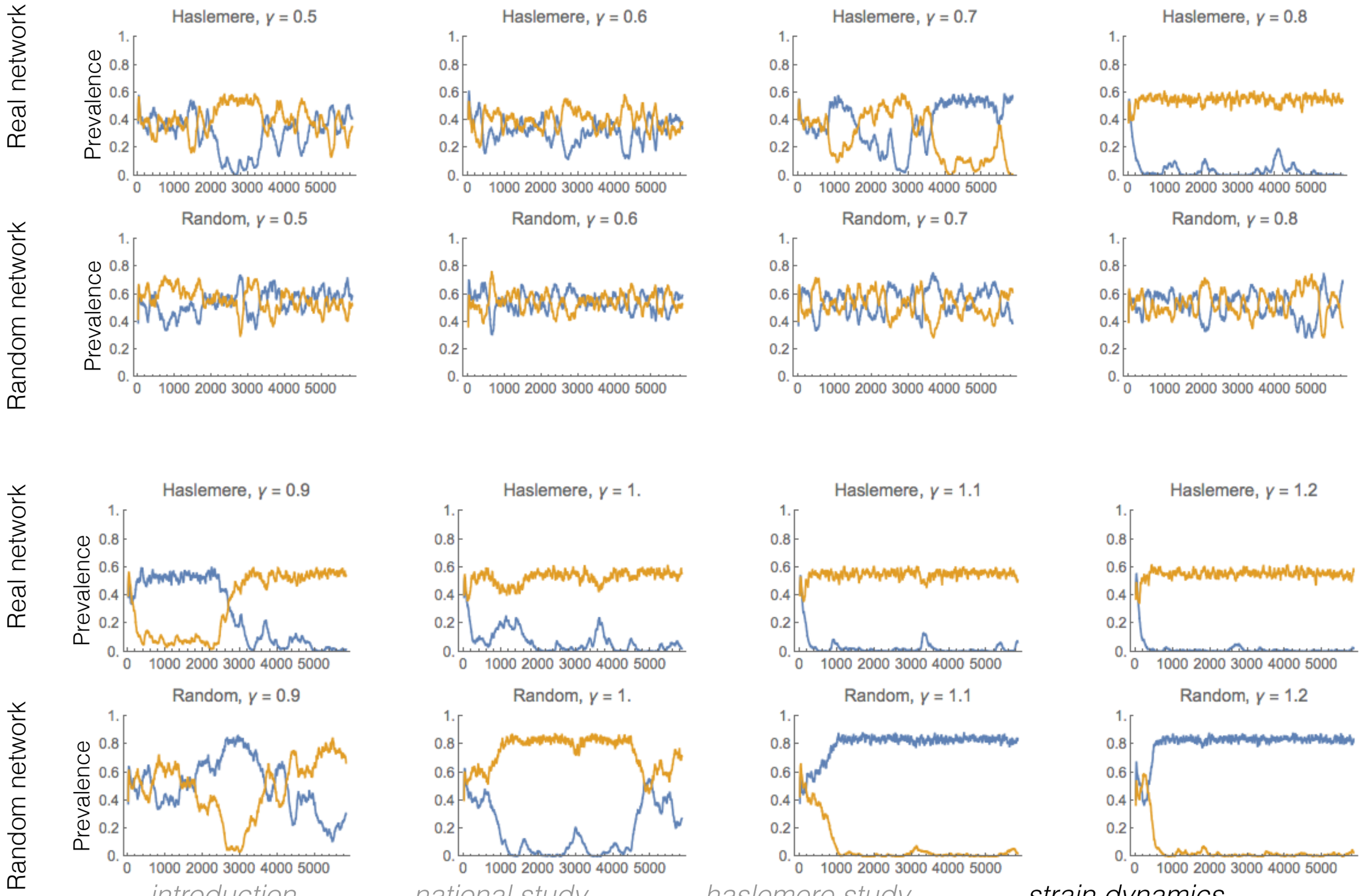


The transition to strain structure



Immunity over time

For the real network, strain structure emerges at lower levels of cross immunity



Thank you!