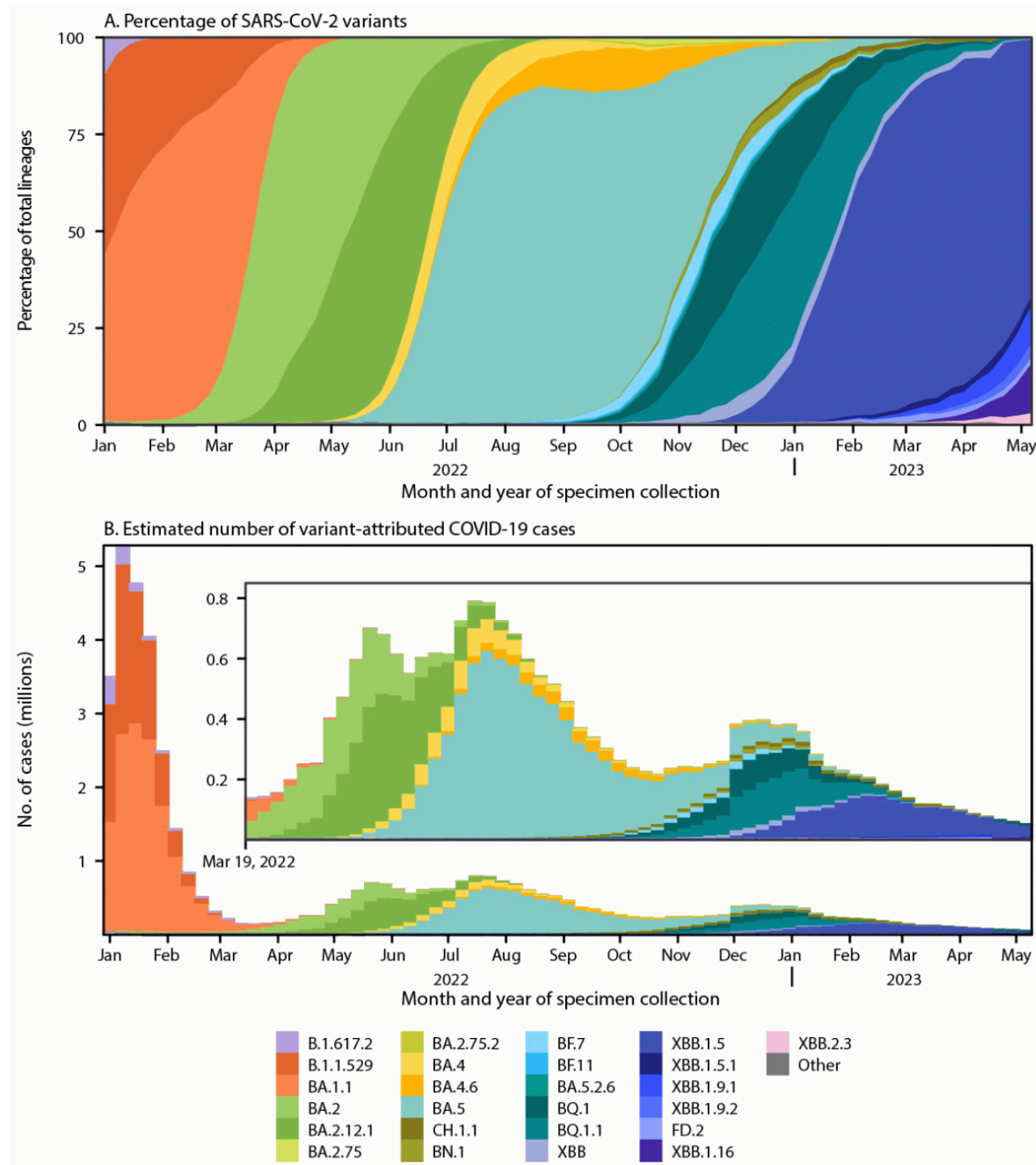


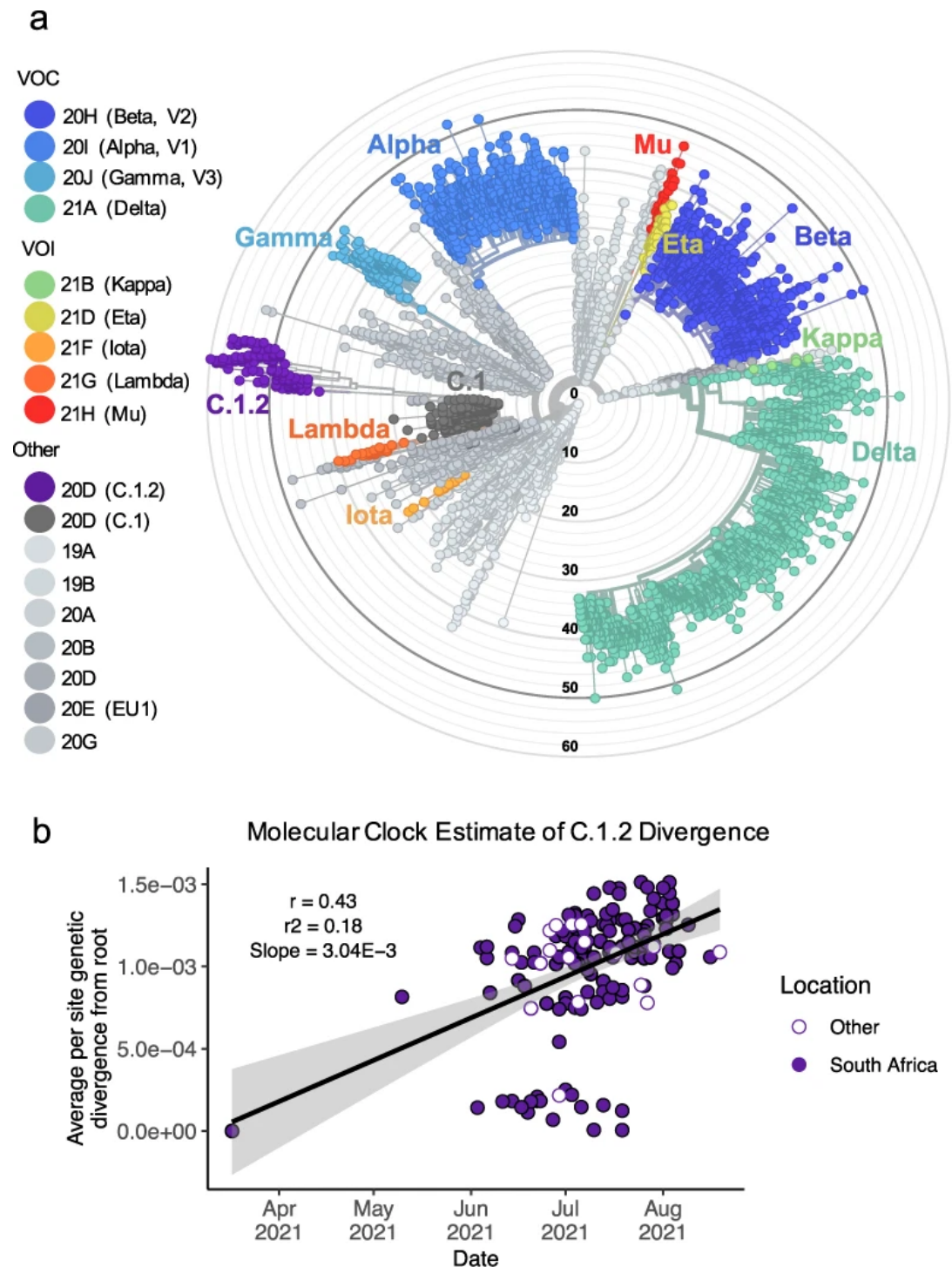
Pathogen evolution in epidemics & emerging fitness landscapes

Davide Zanchetta @ CoMuNe-Lab @ UniPd

EMPIRICAL PATTERNS IN EPIDEMIC DYNAMICS

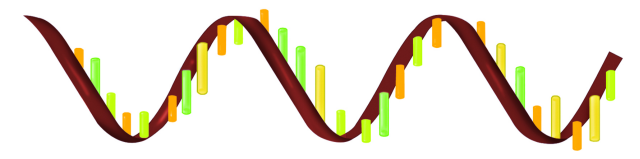


Ma, Kevin C. "Genomic surveillance for SARS-CoV-2 variants: circulation of omicron lineages—United States, January 2022–May 2023." *MMWR. Morbidity and mortality weekly report* 72 (2023).



Scheepers, Cathrine, et al. "Emergence and phenotypic characterization of the global SARS-CoV-2 C. 1.2 lineage." *Nature Communications* 13.1 (2022): 1976.

THE SHAPES OF EVOLUTION

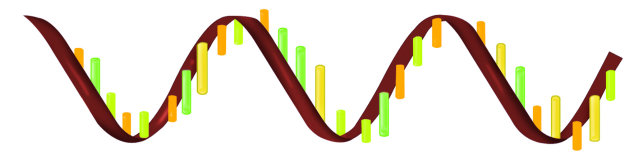


continuous trait $a \in \mathbb{R}^n$; evolution $\equiv a \rightarrow a + \delta a$

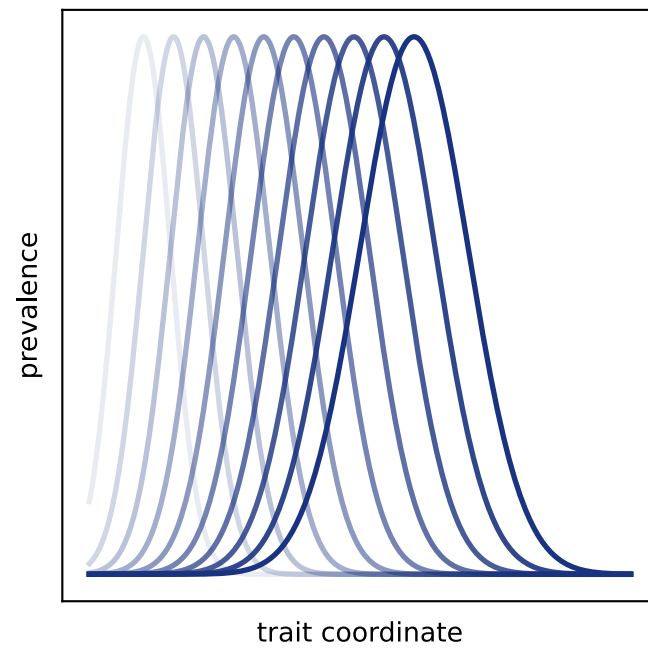
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Proceedings of the National Academy of Sciences 118.27 (2021): e2103398118.

THE SHAPES OF EVOLUTION



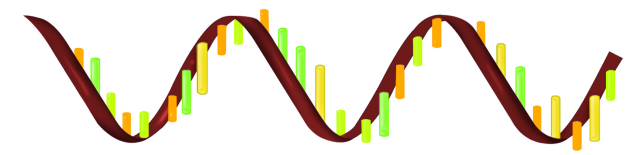
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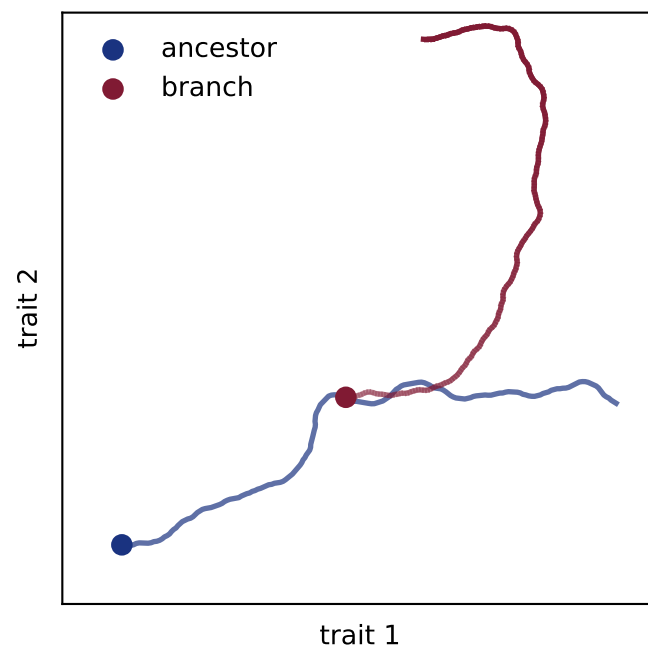
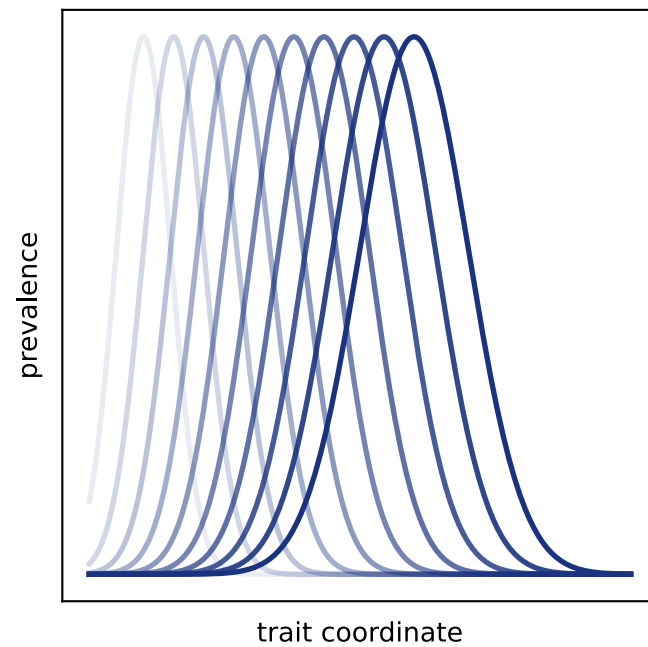
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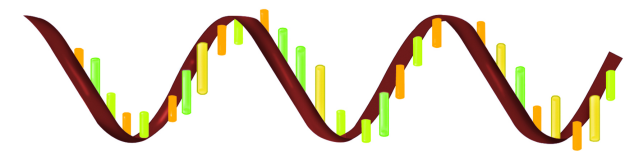
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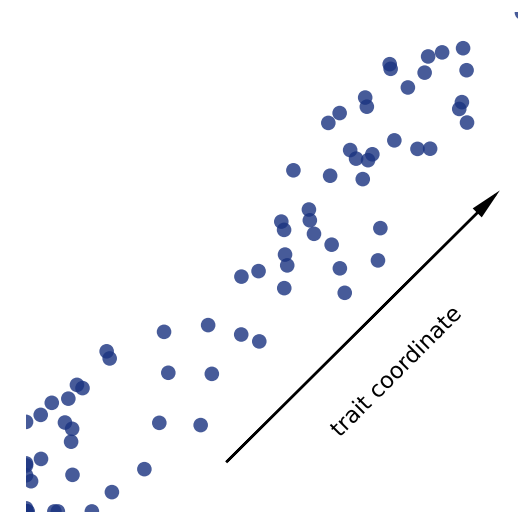
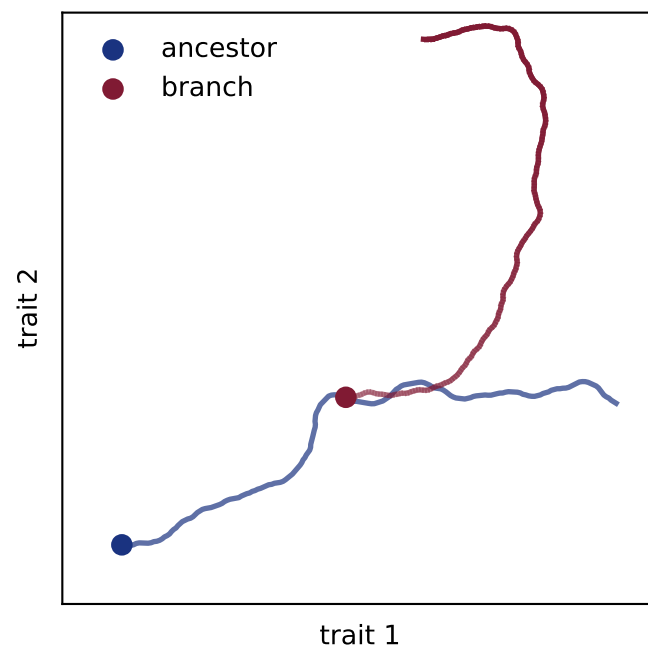
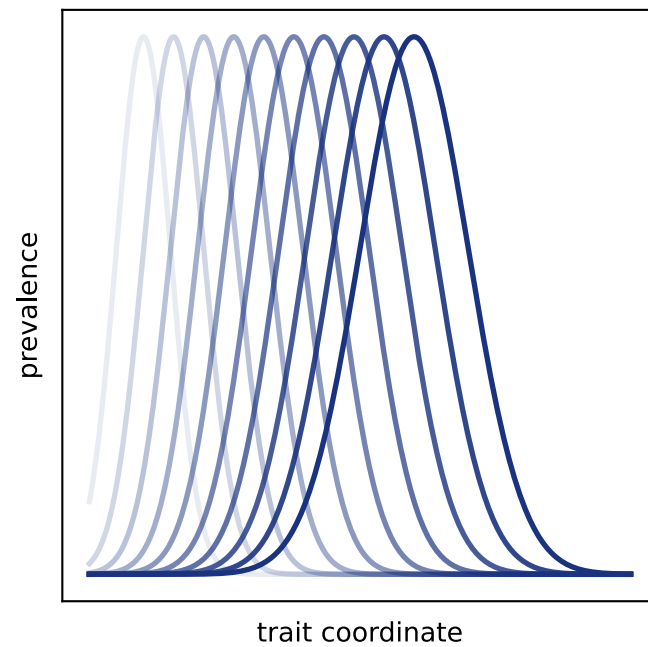
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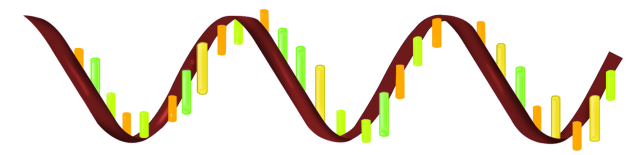
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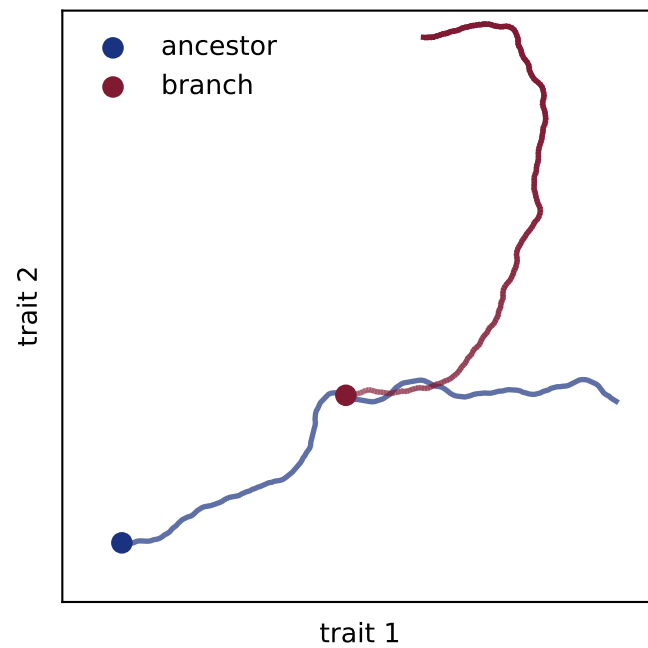
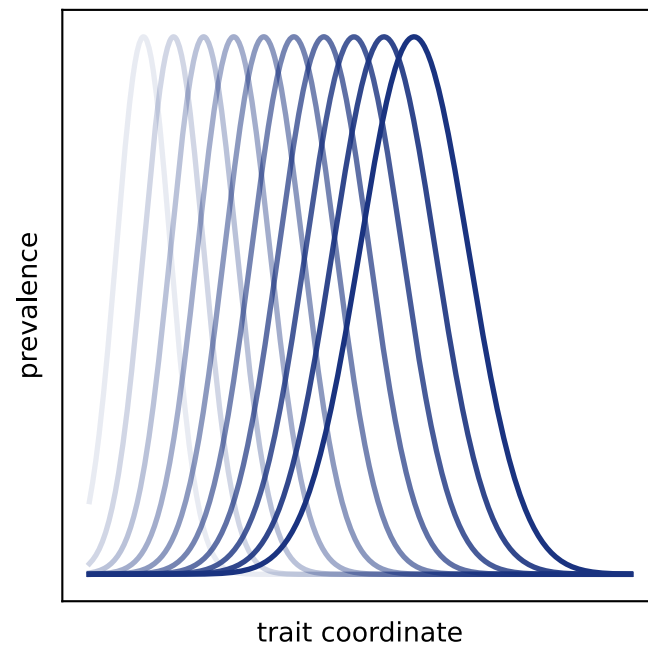
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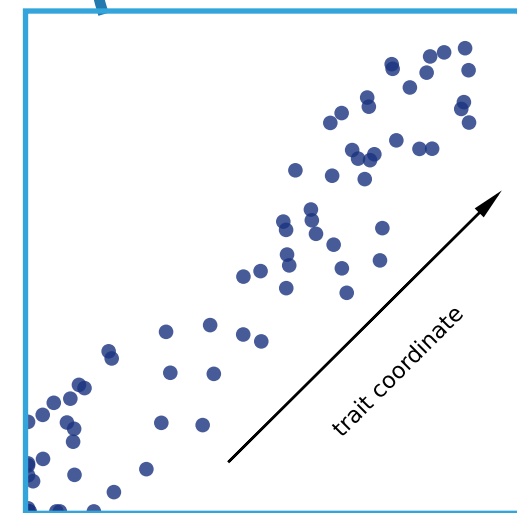
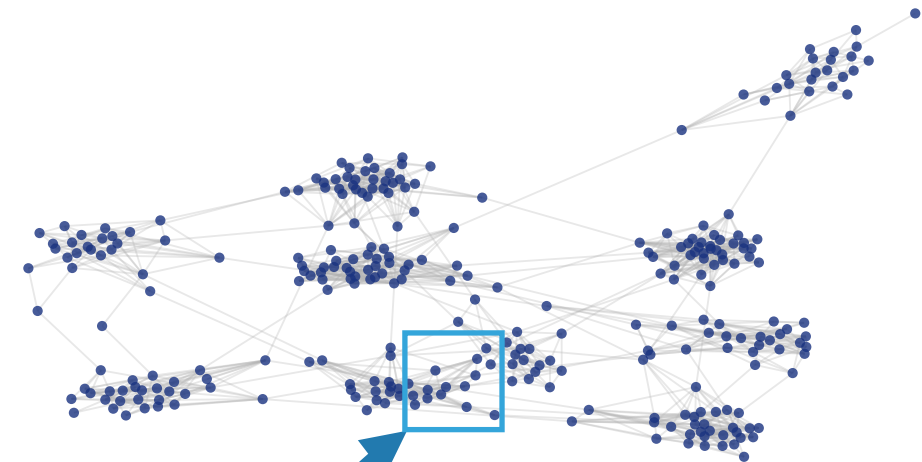
THE SHAPES OF EVOLUTION



continuous trait $a \in \mathbb{R}^n$; evolution $\equiv a \rightarrow a + \delta a$



globally heterogeneous

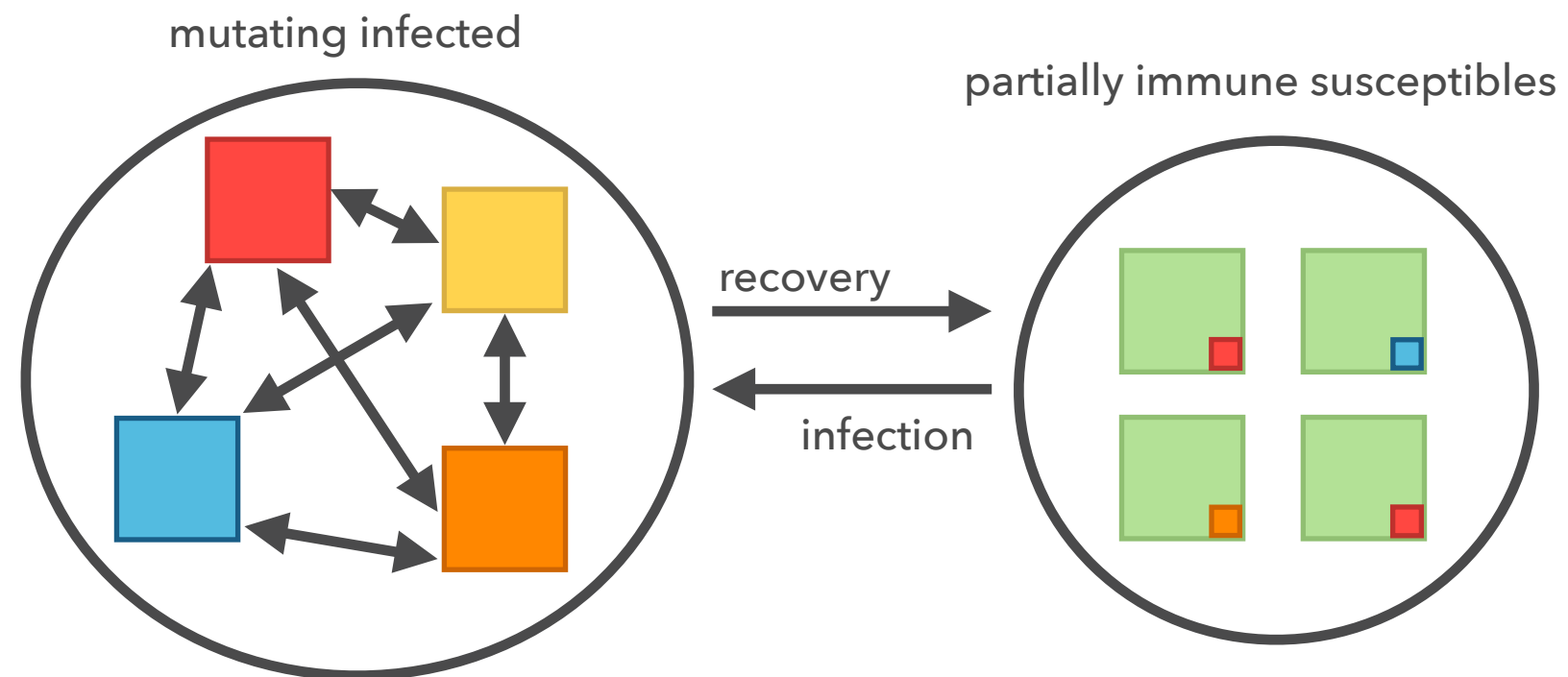


locally homogeneous

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MACROSCOPIC SCALE: MULTI-STRAIN SIS MODEL



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$$\partial_t \text{ susceptible} = - \begin{array}{c} \text{new} \\ \text{infections} \end{array} + \text{recovery}$$

$$\partial_t \text{ infected} = + \begin{array}{c} \text{new} \\ \text{infections} \end{array} - \text{recovery} + \begin{array}{c} \text{in-} \\ \text{mutations} \end{array} - \begin{array}{c} \text{out-} \\ \text{mutations} \end{array}$$

$$\sim \beta [S \cdot BI]_a \quad \sim I_a \quad \sim \eta [L_Q \cdot I]_a$$

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Genotype-antigenic mapping?

$$B \equiv d_\tau(Q)$$

τ = cross-immunity strength

MDD, "Diffusion geometry unravels the emergence of functional clusters in collective phenomena."
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AFB et al. "Latent geometry emerging from network-driven processes."
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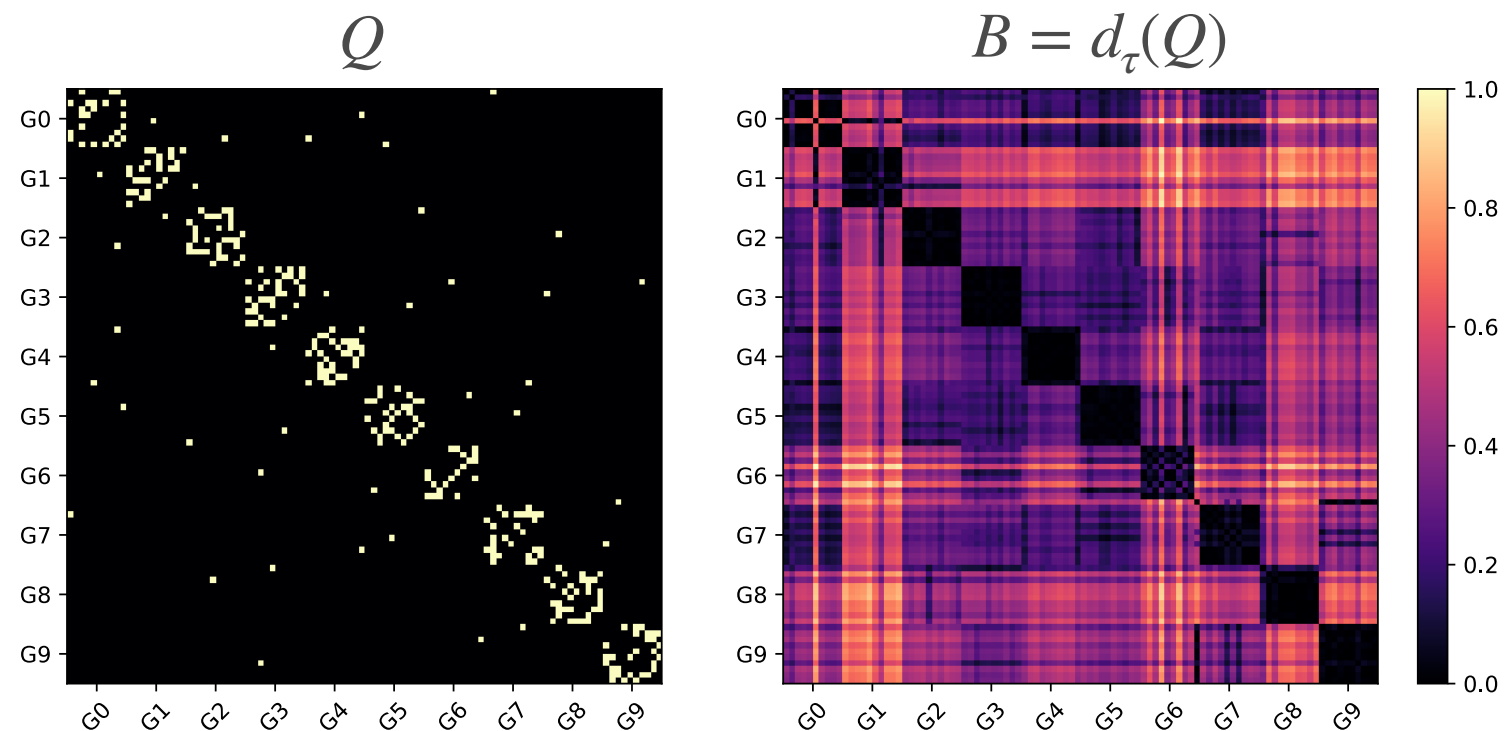
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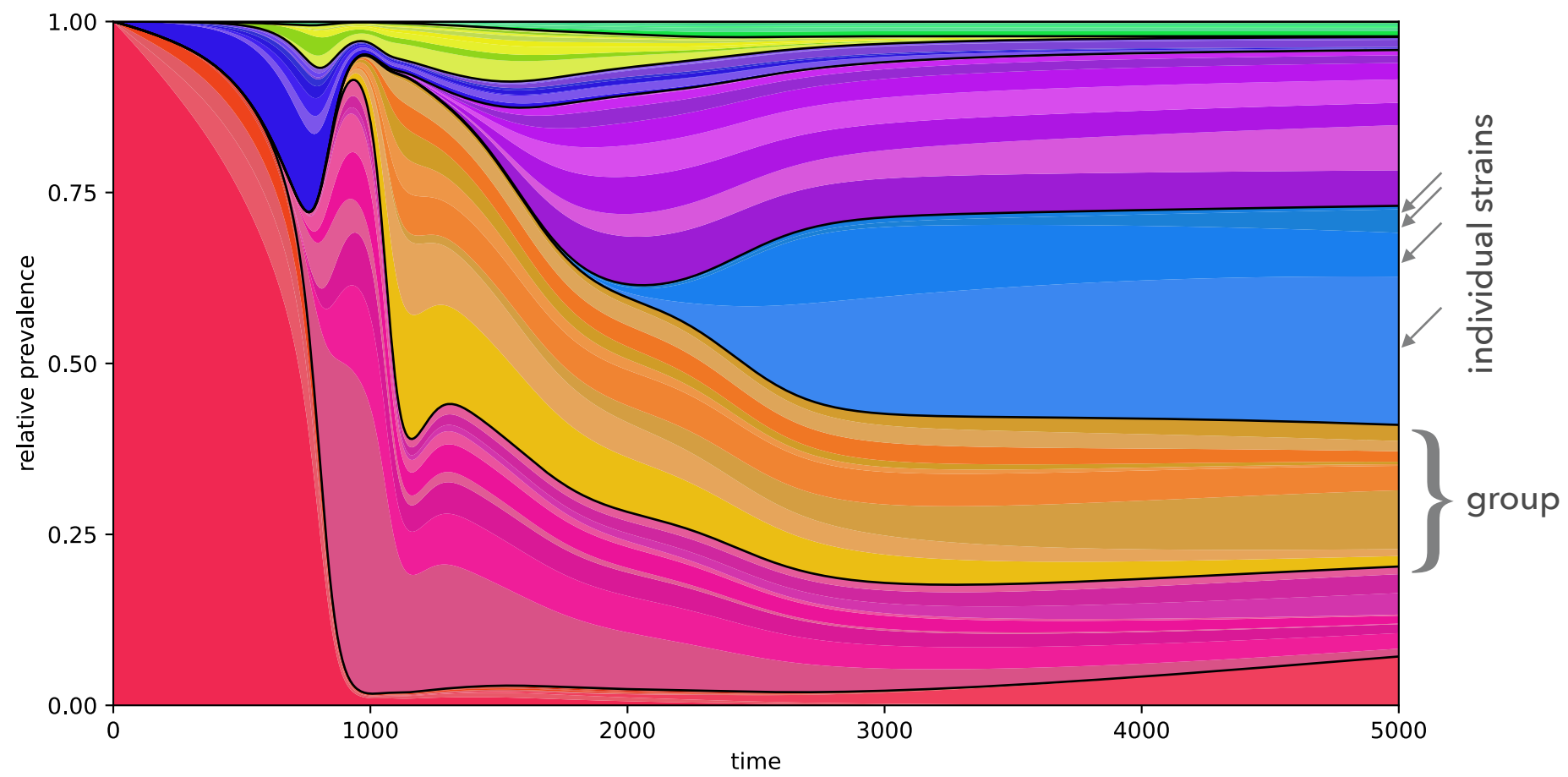
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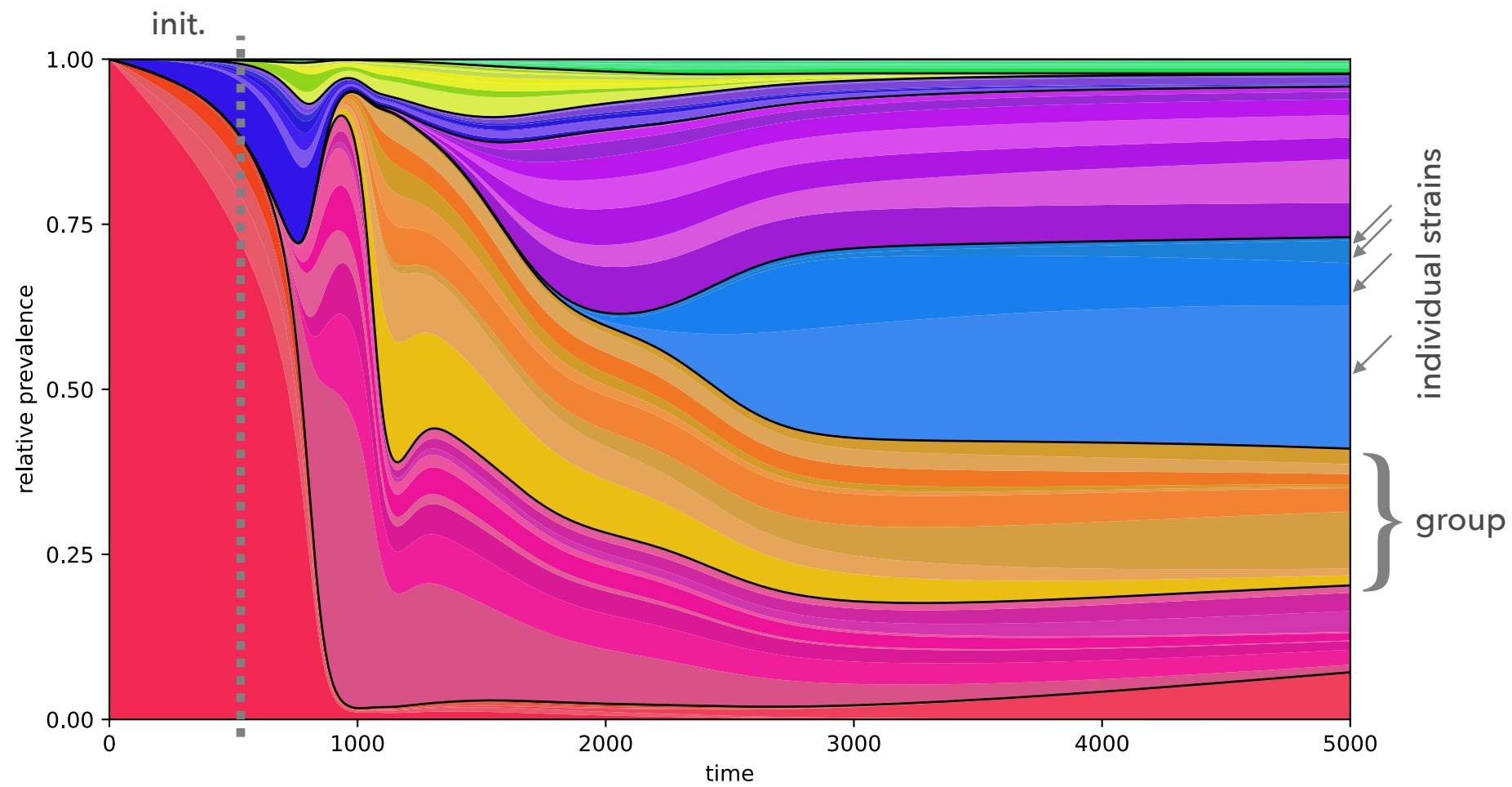
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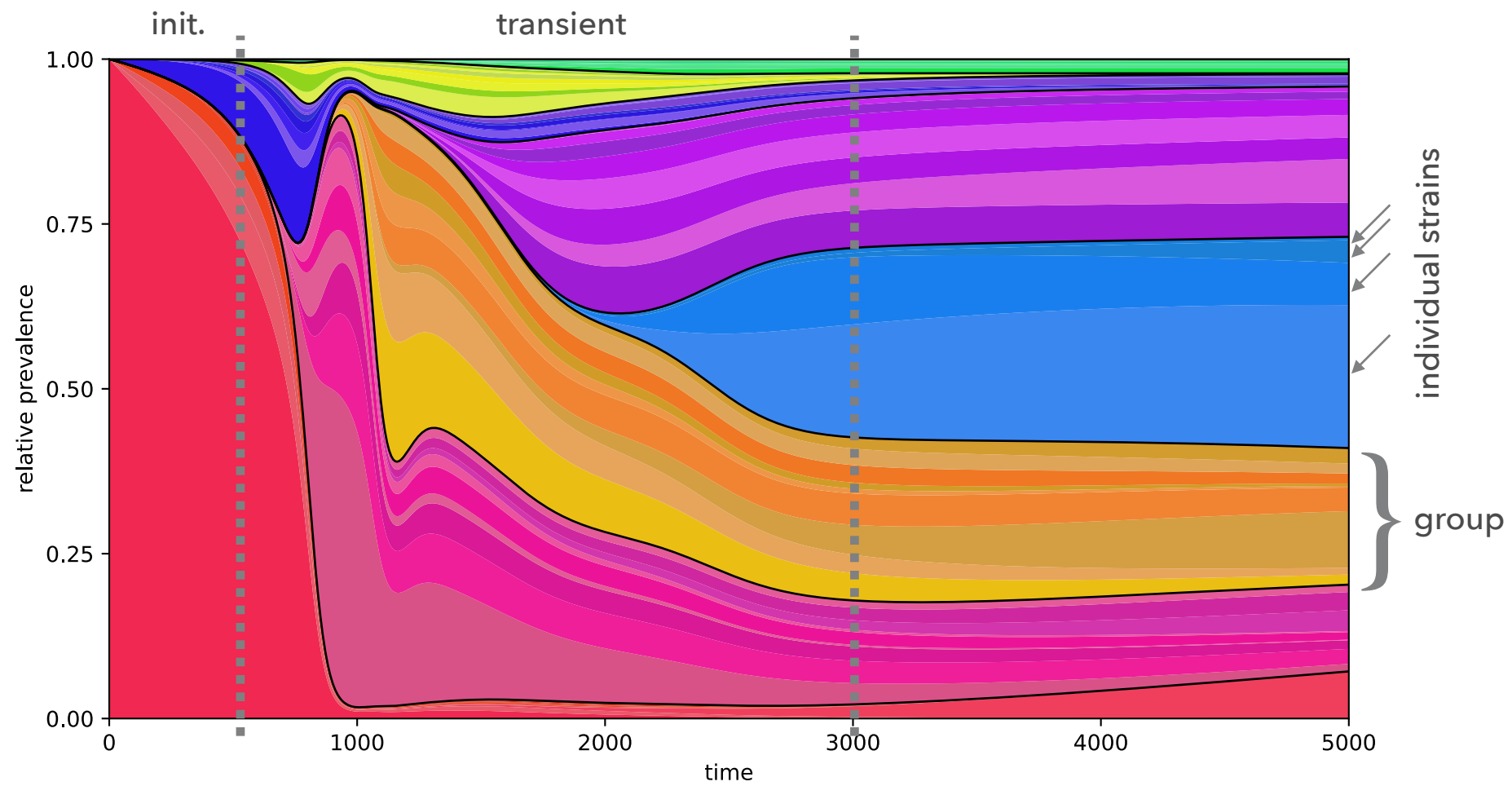
PHENOMENOLOGY OF EVO-EPI DYNAMICS



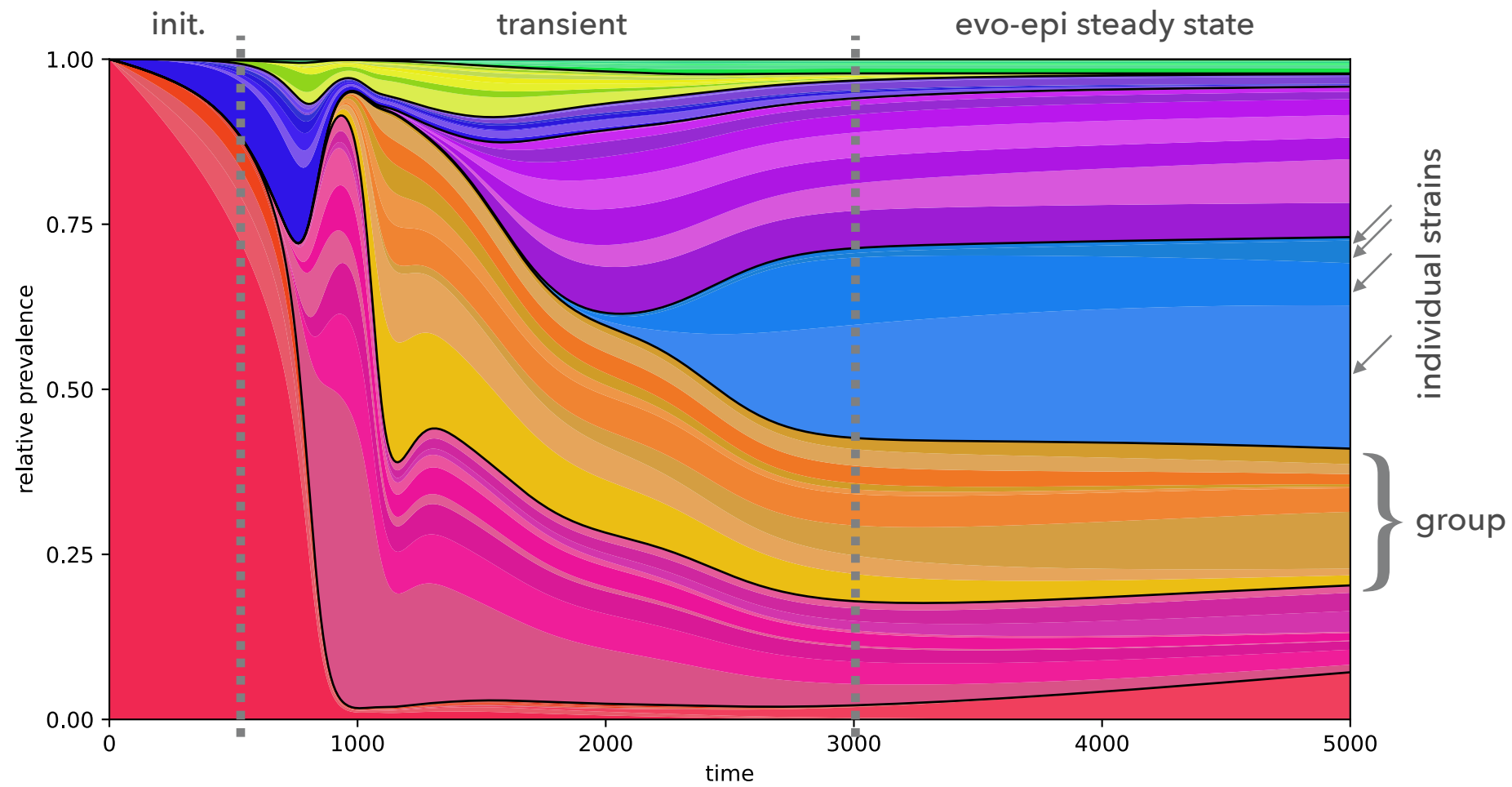
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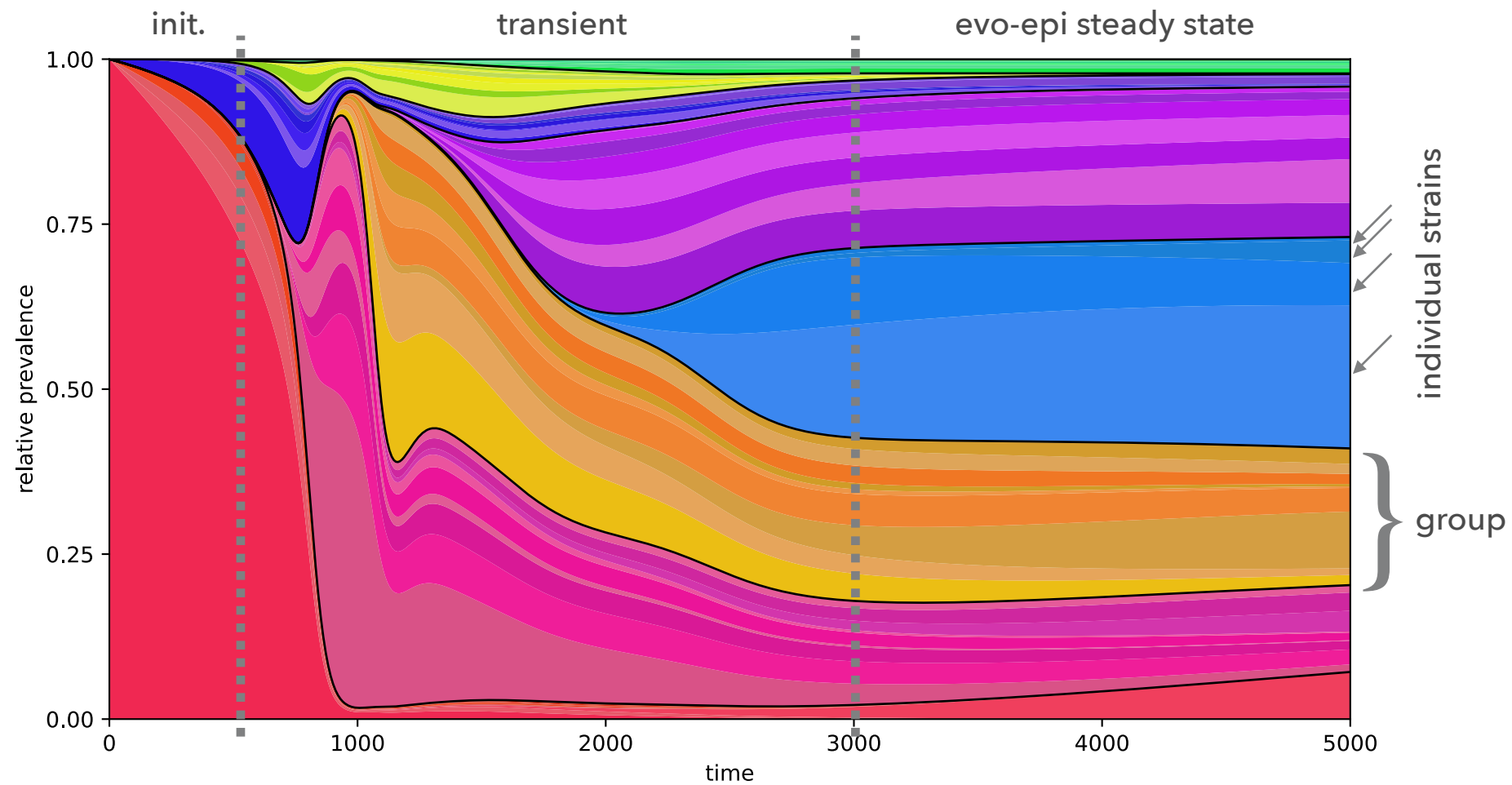
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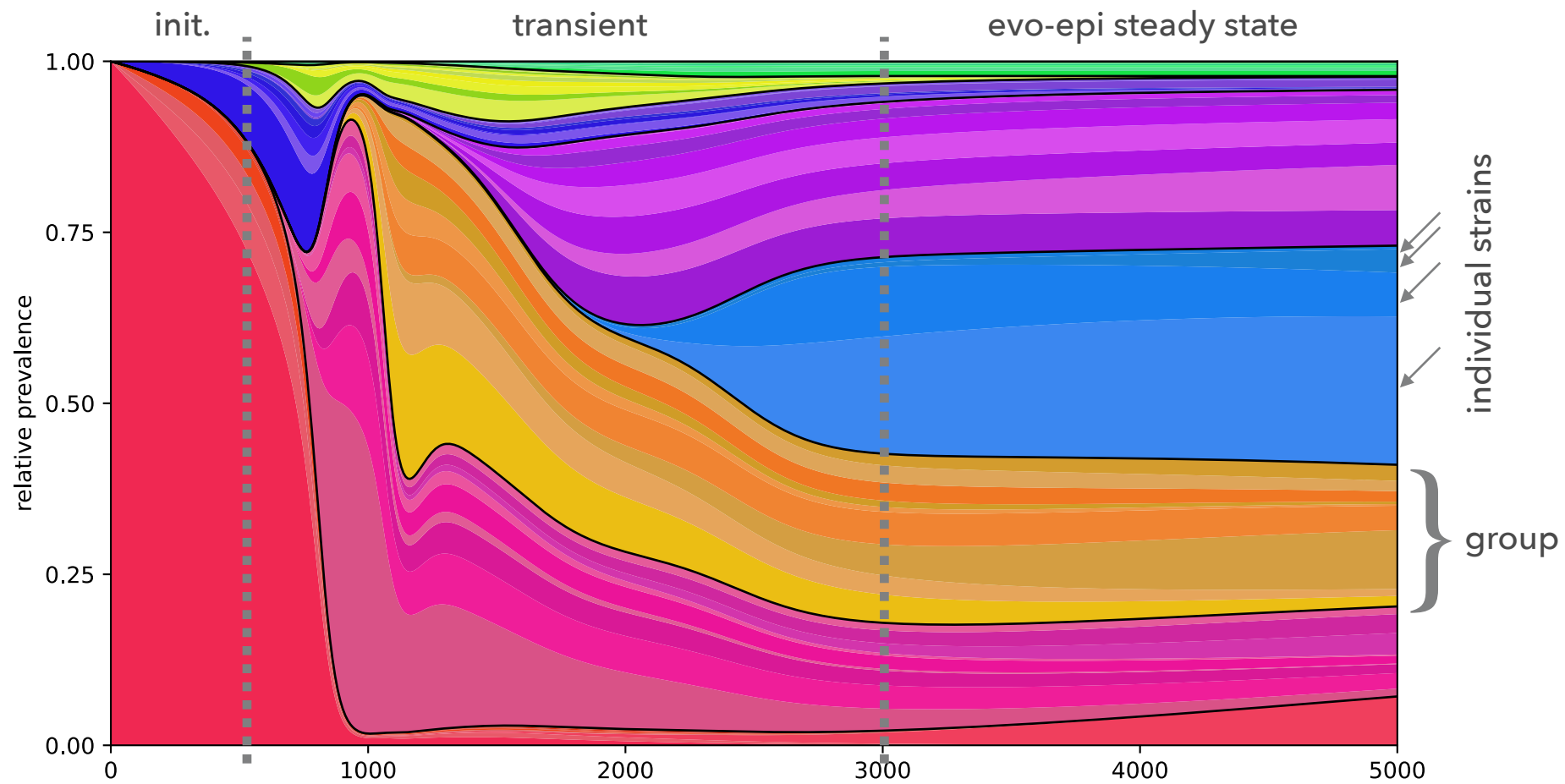
PHENOMENOLOGY OF EVO-EPI DYNAMICS



replicator-mutator

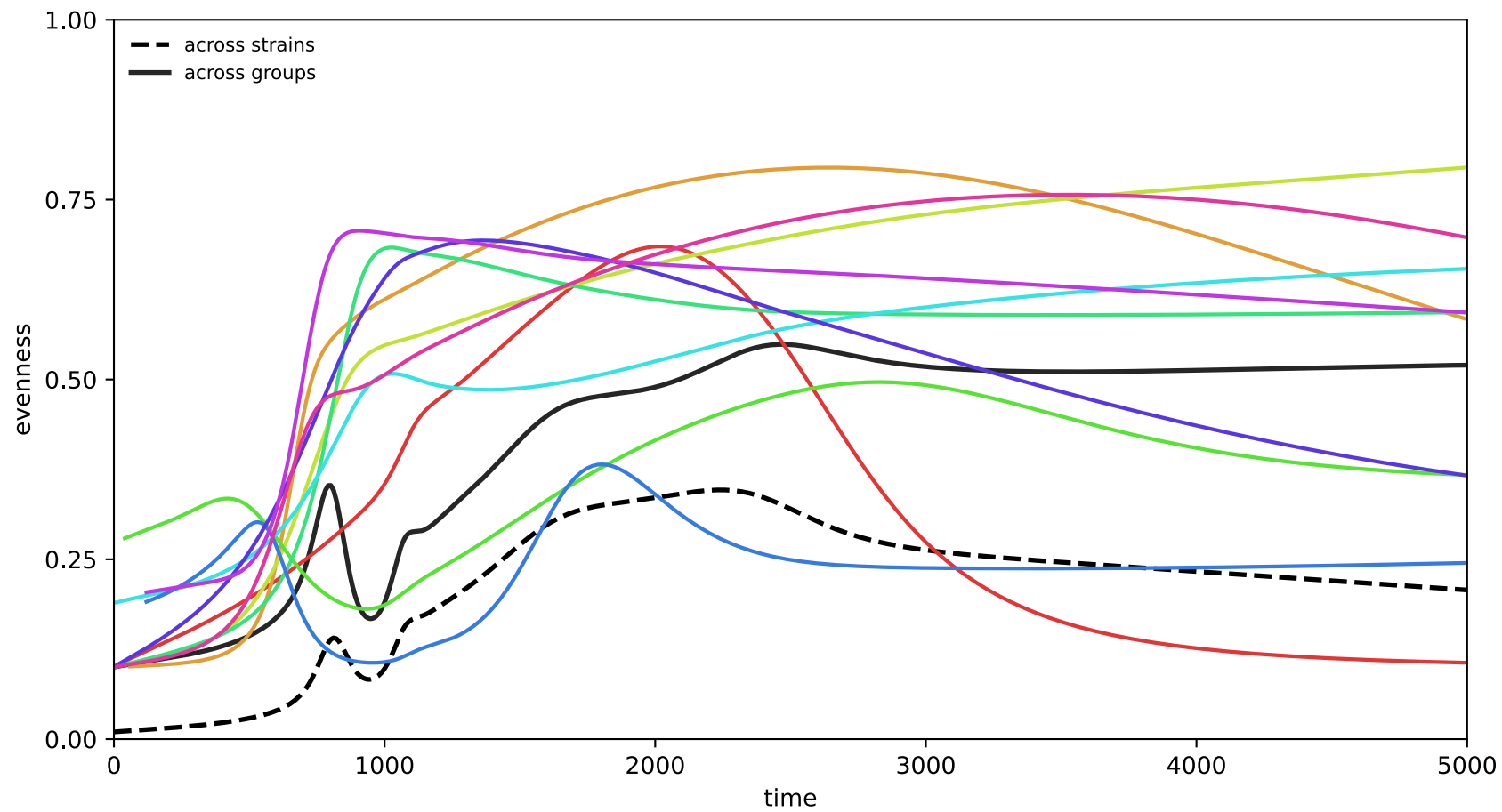
$$\dot{p}_a \approx \phi_a(p)p_a + \eta \left(L_Q p \right)_a$$

PHENOMENOLOGY OF EVO-EPI DYNAMICS

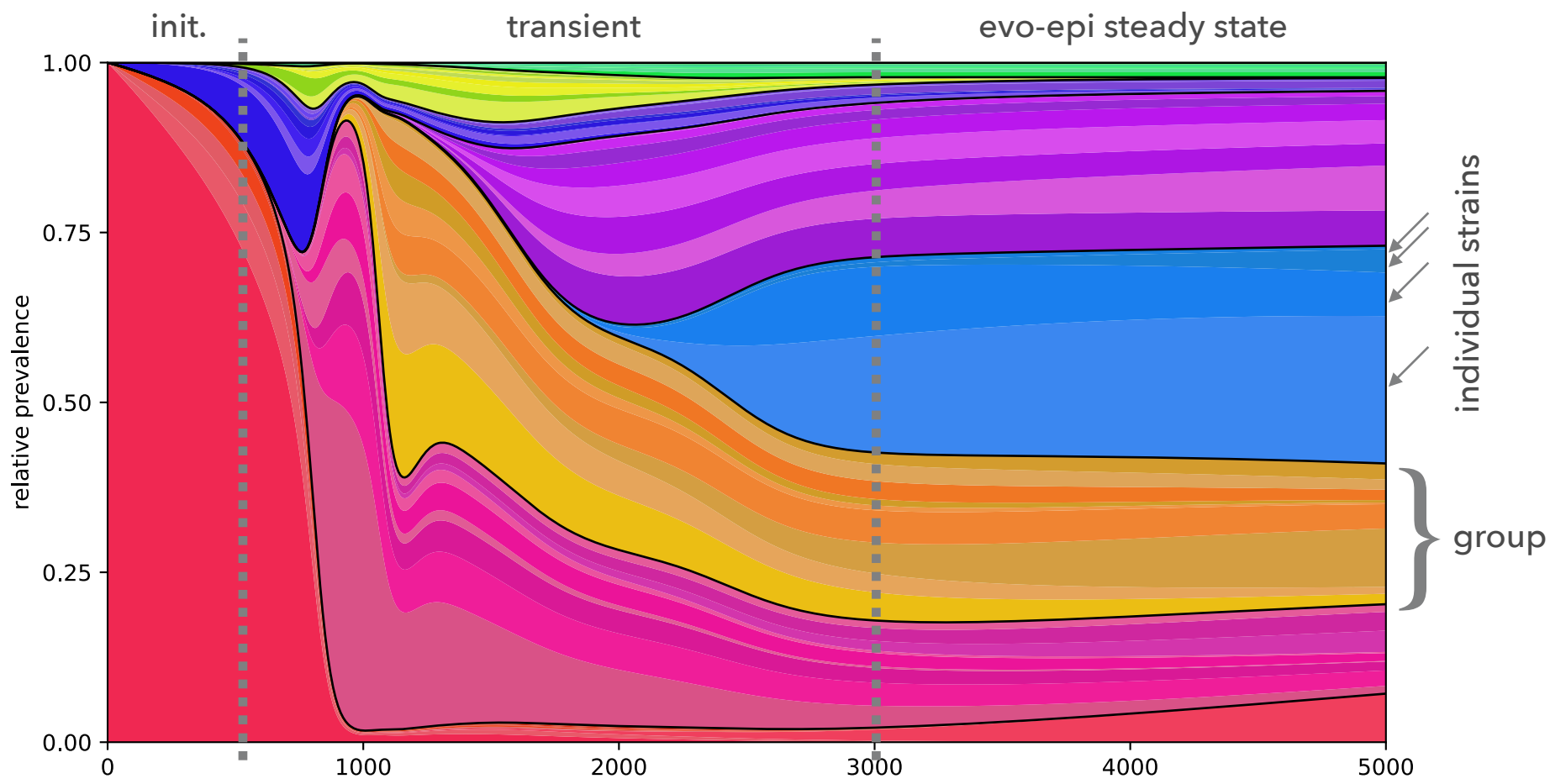


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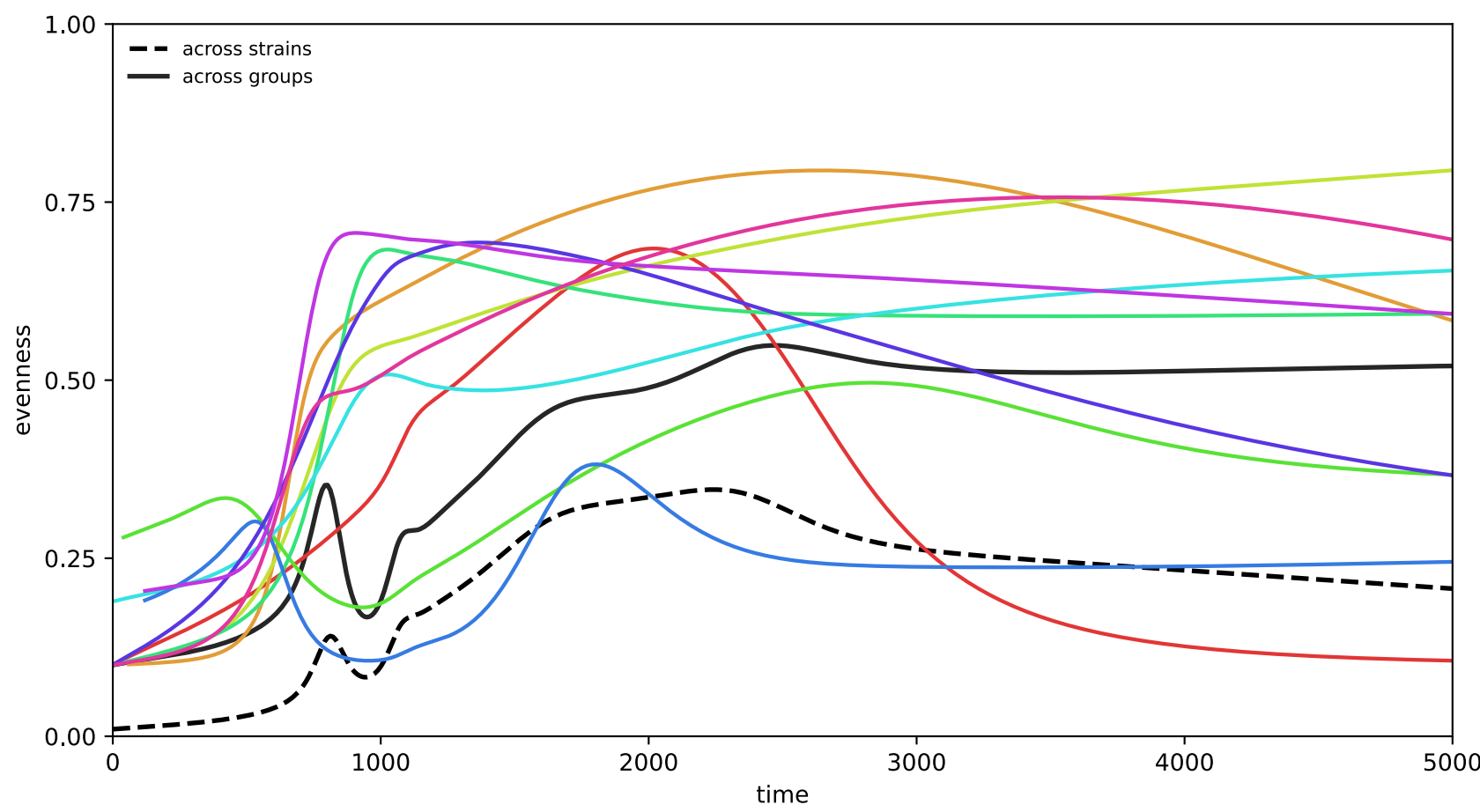


PHENOMENOLOGY OF EVO-EPI DYNAMICS



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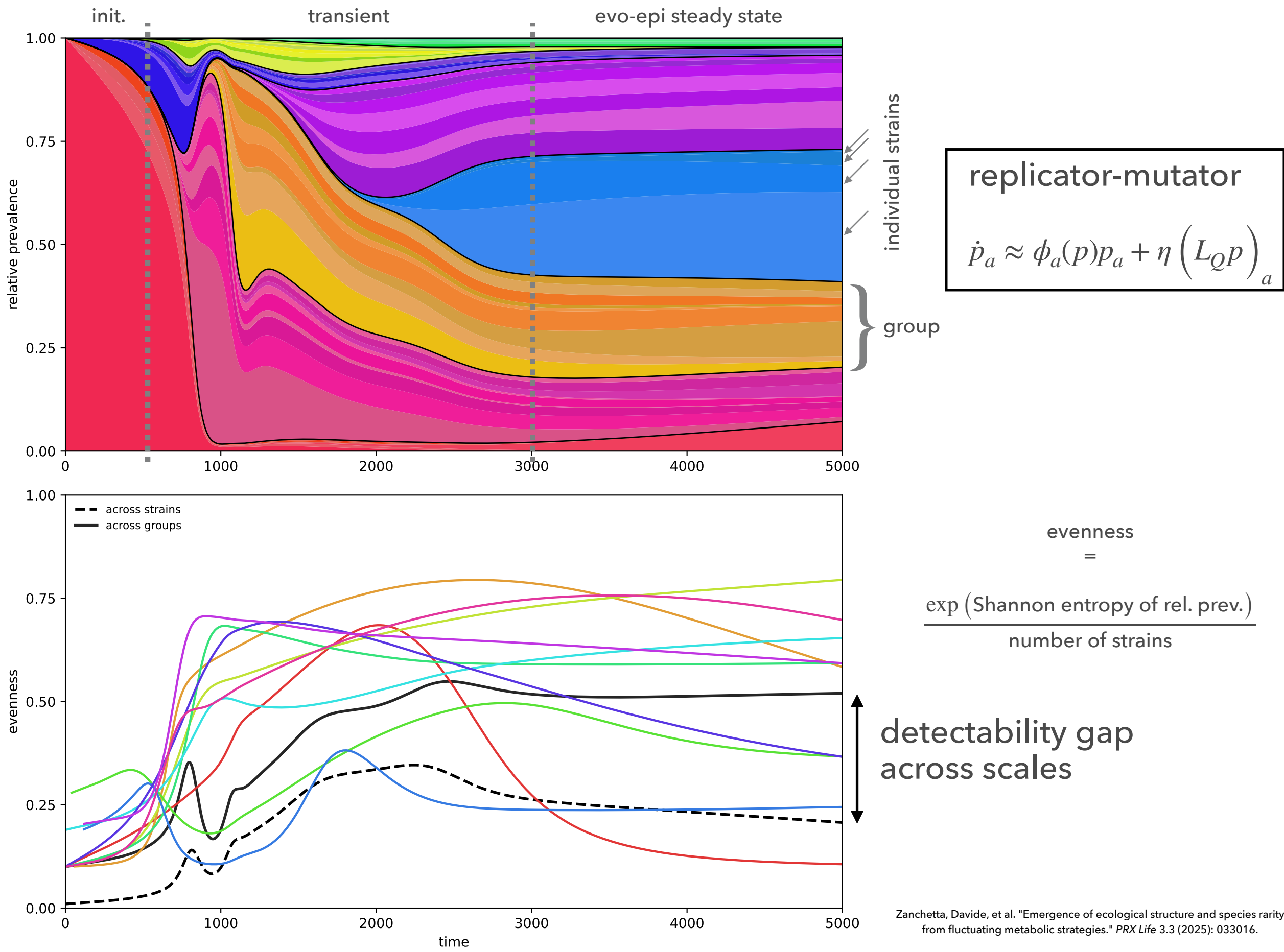


evenness

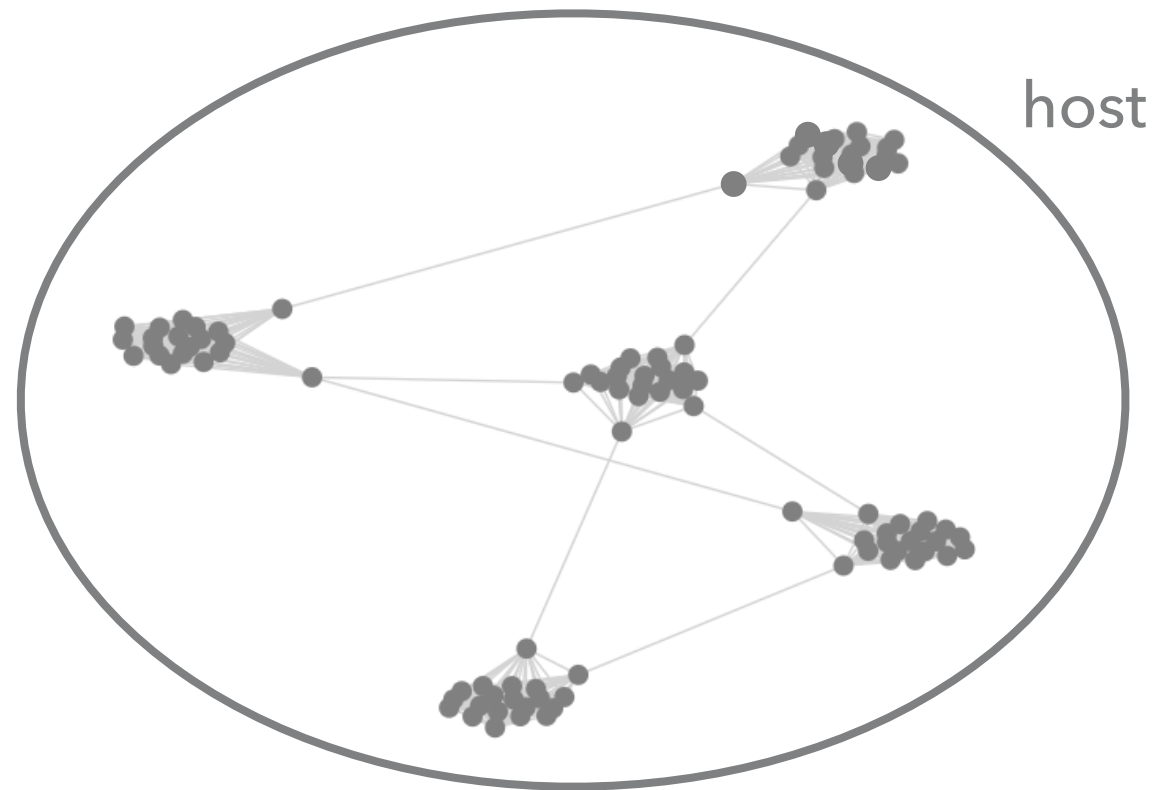
=

$$\frac{\exp \left(\text{Shannon entropy of rel. prev.} \right)}{\text{number of strains}}$$

PHENOMENOLOGY OF EVO-EPI DYNAMICS

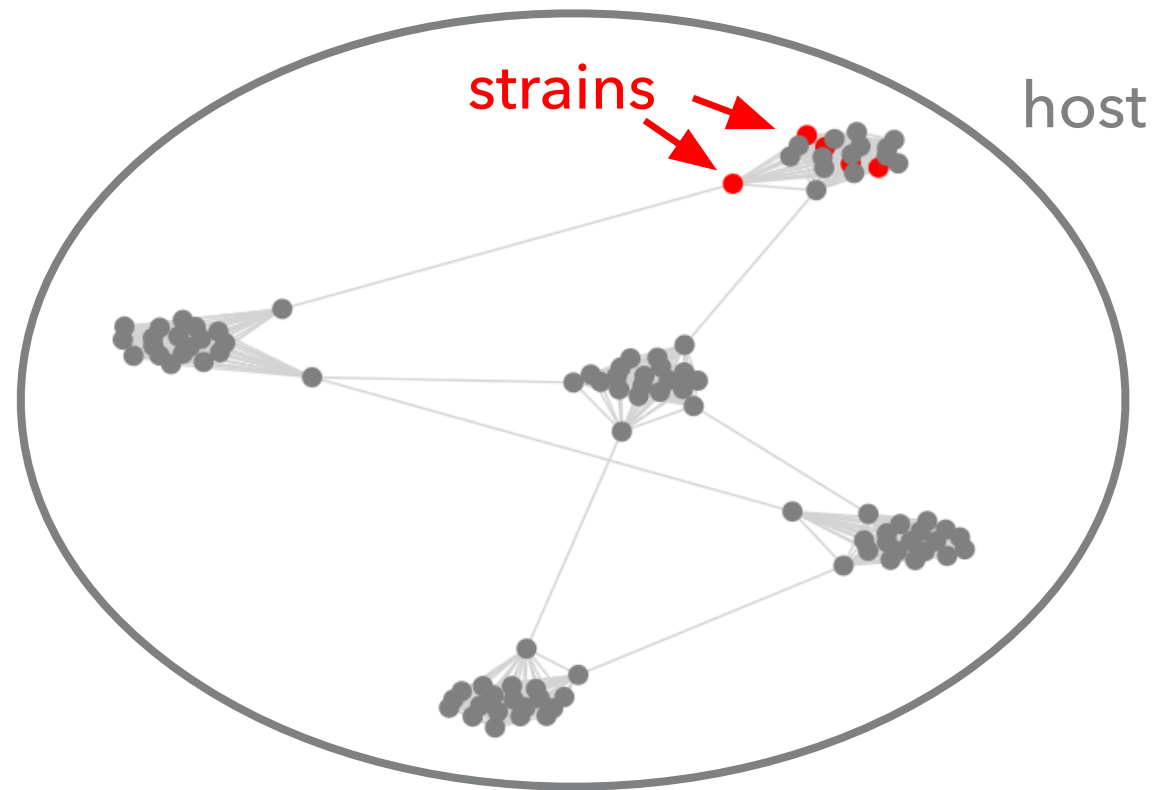


SCALING DOWN: WITHIN-HOST DYNAMICAL IMMUNITY



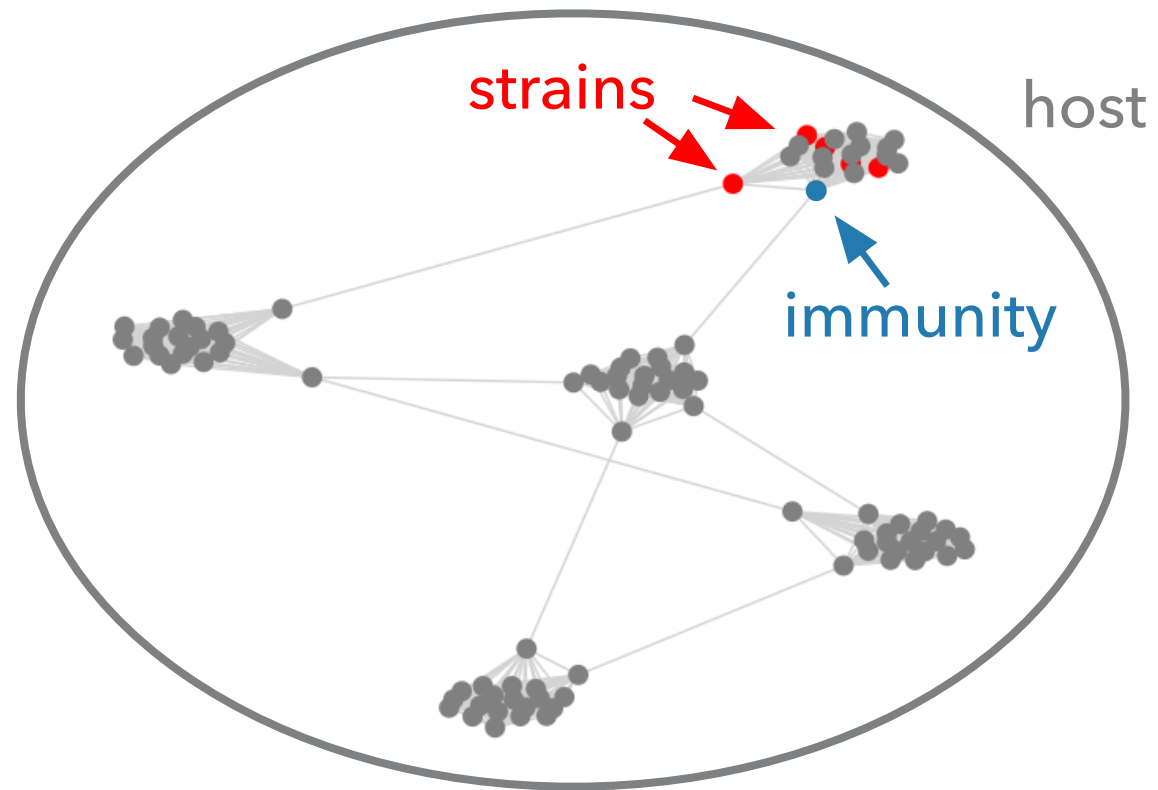
metacommunity model of within-host evolution
under immune response

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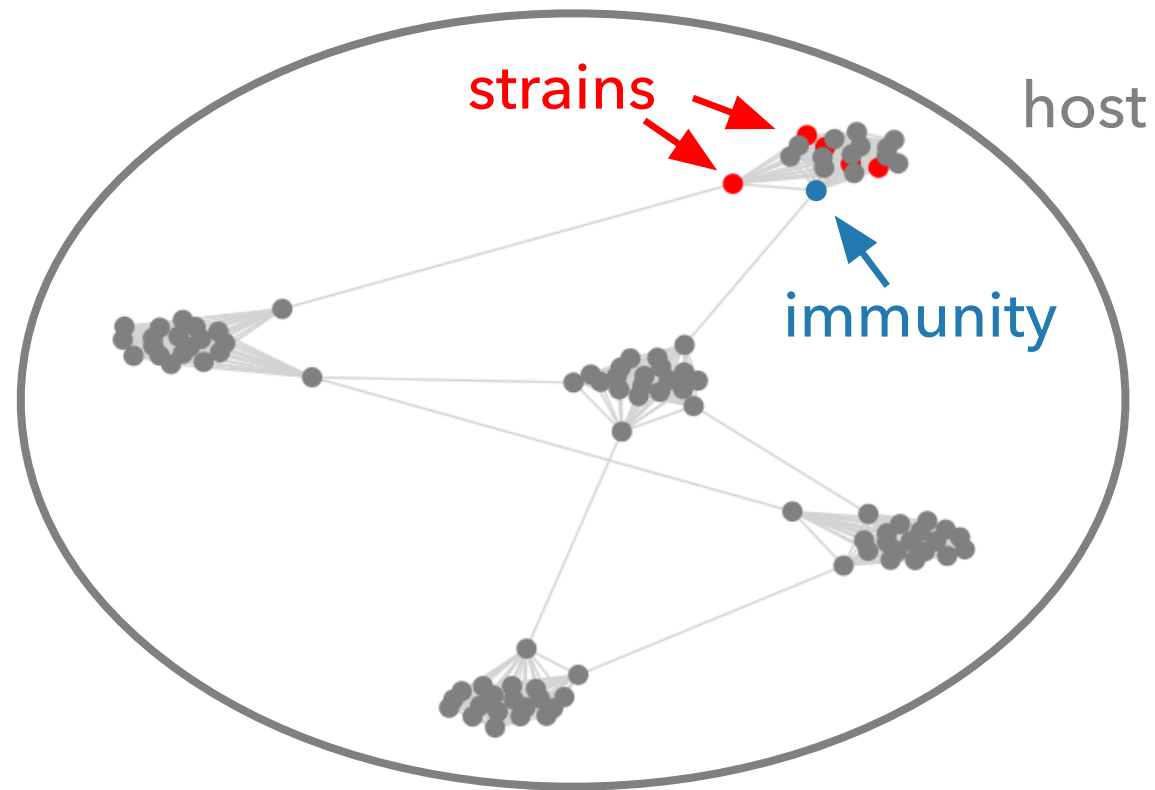
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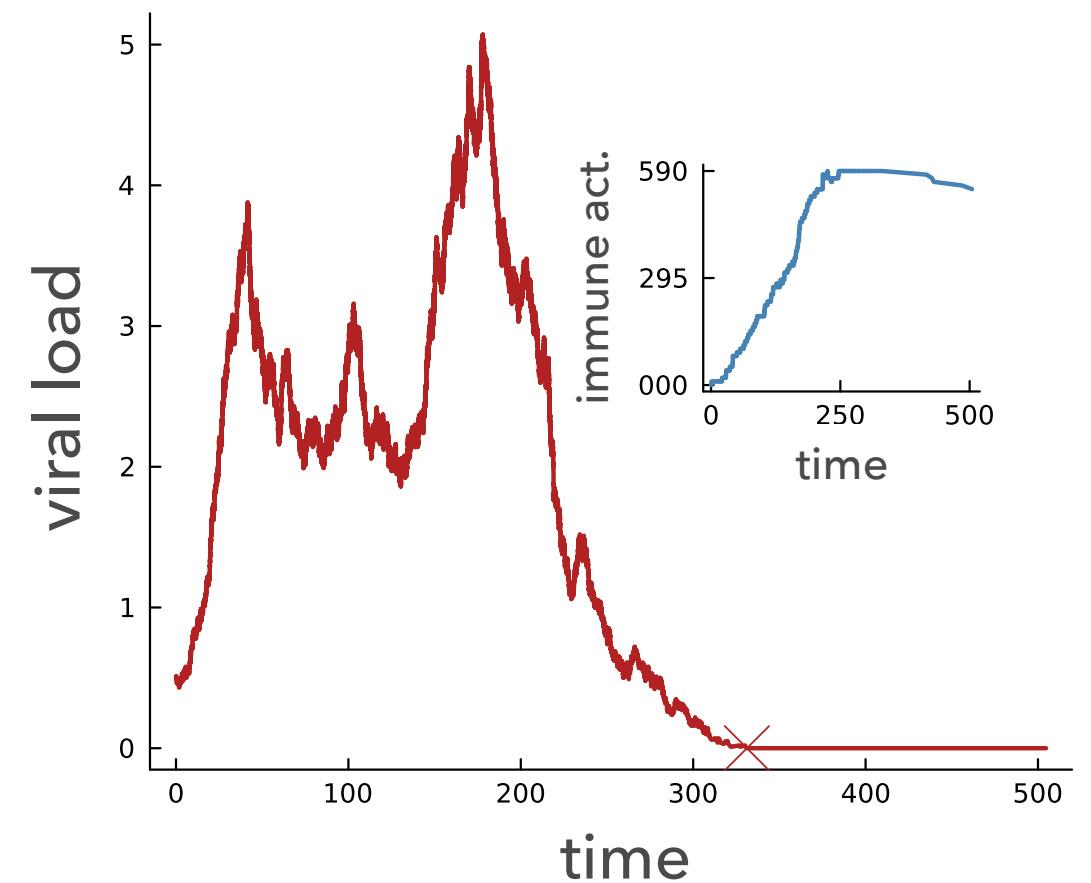


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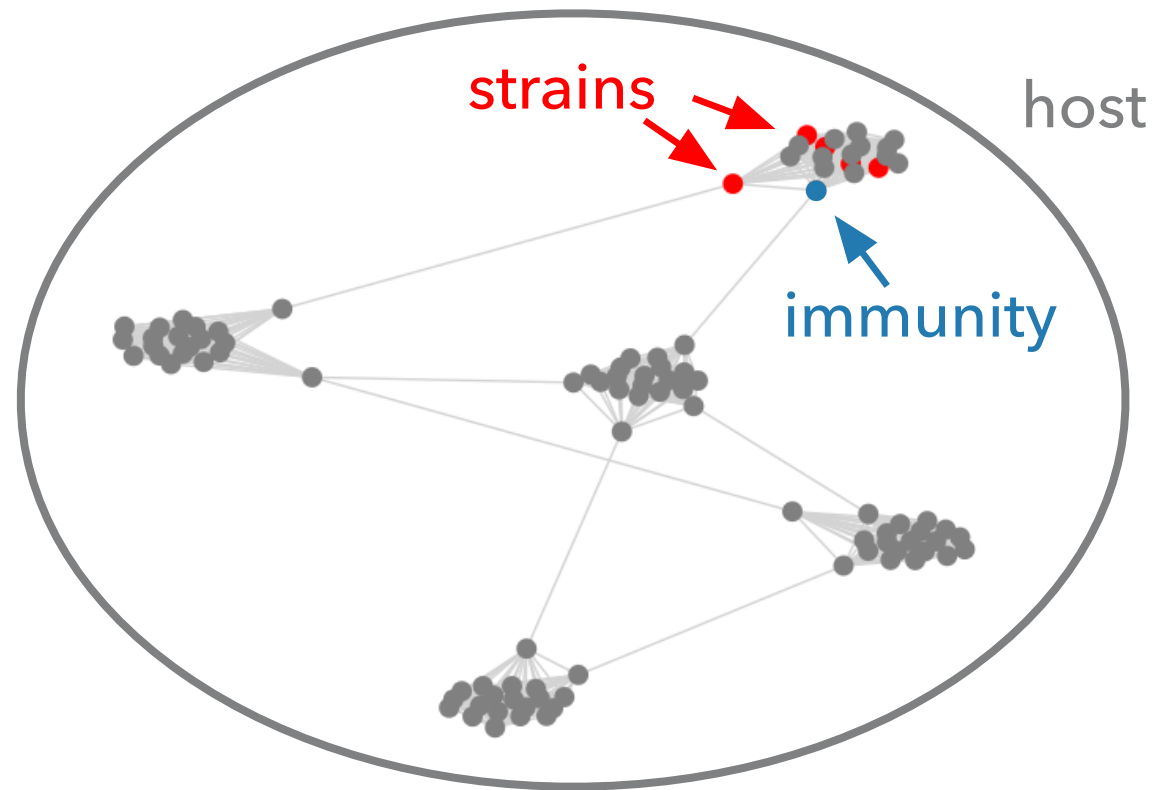
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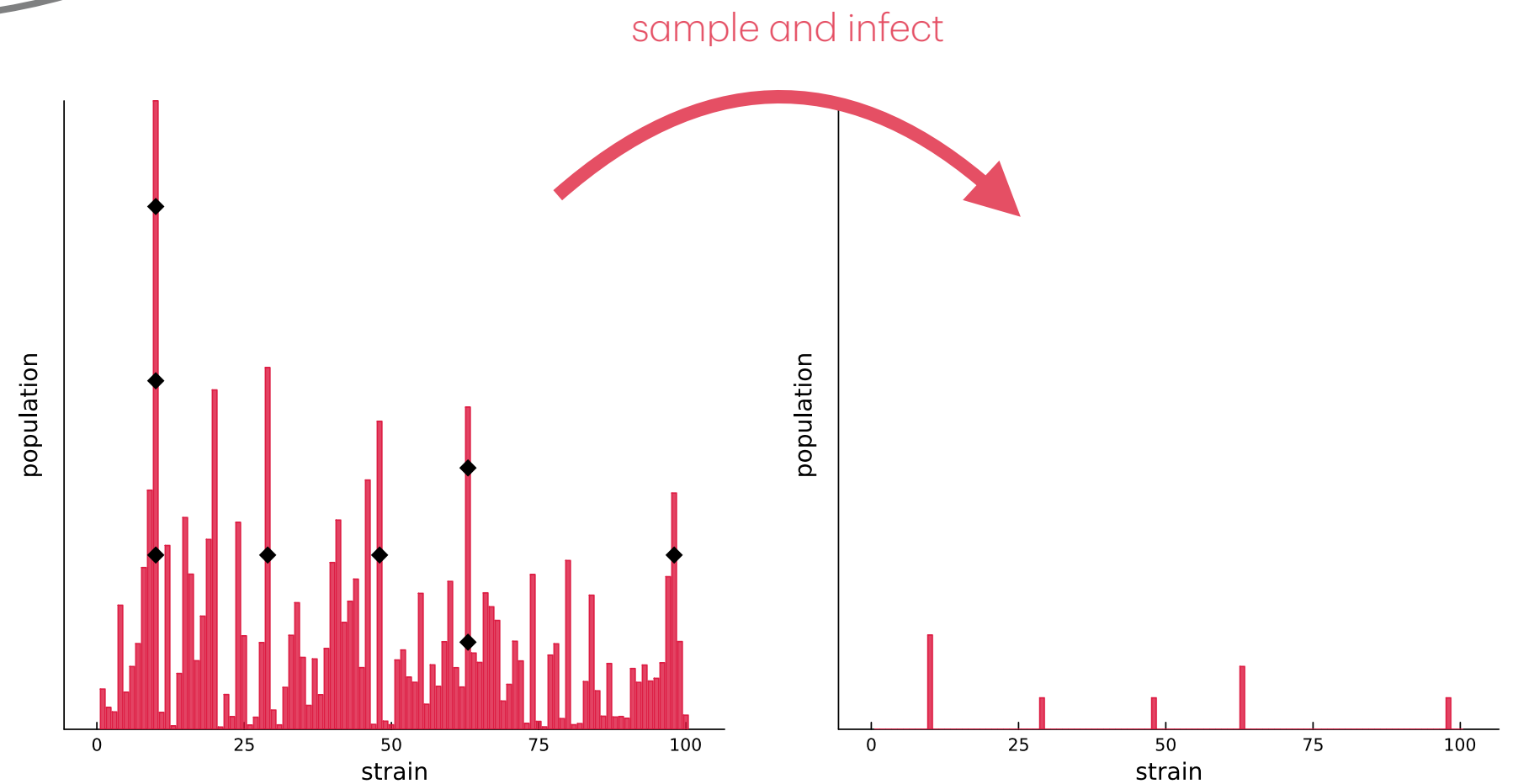
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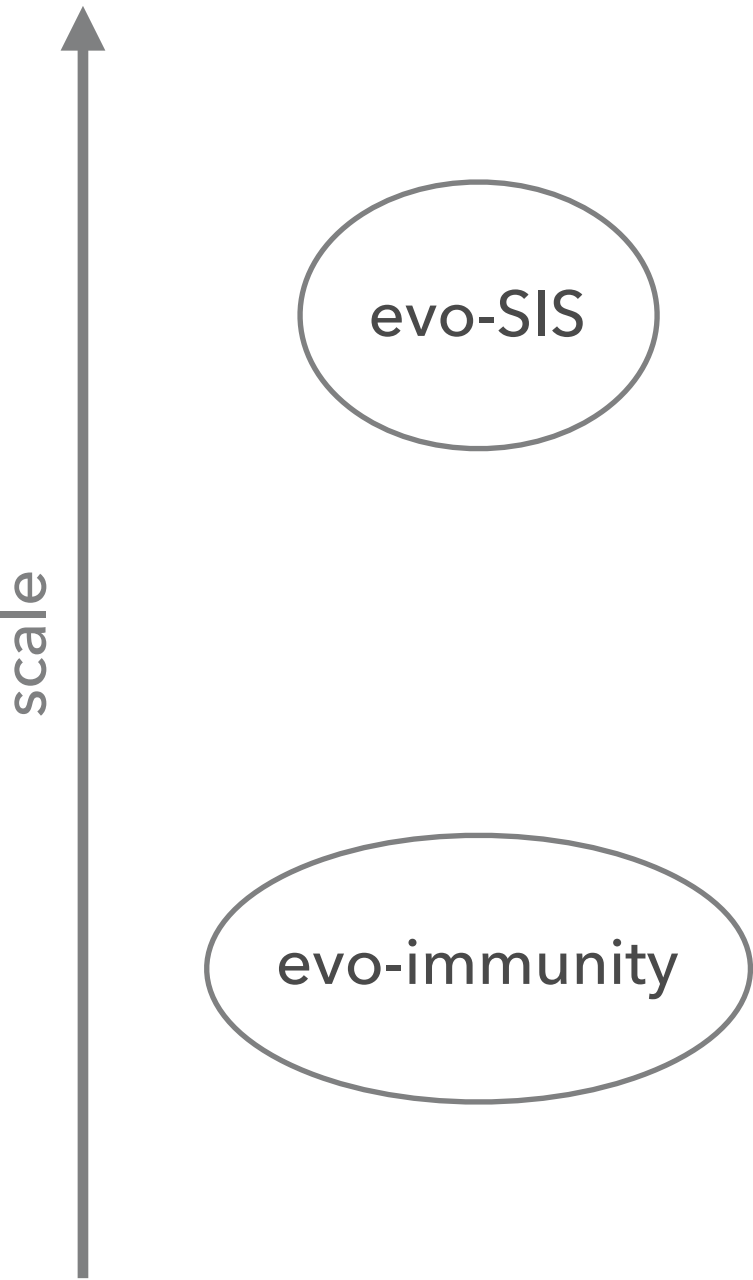
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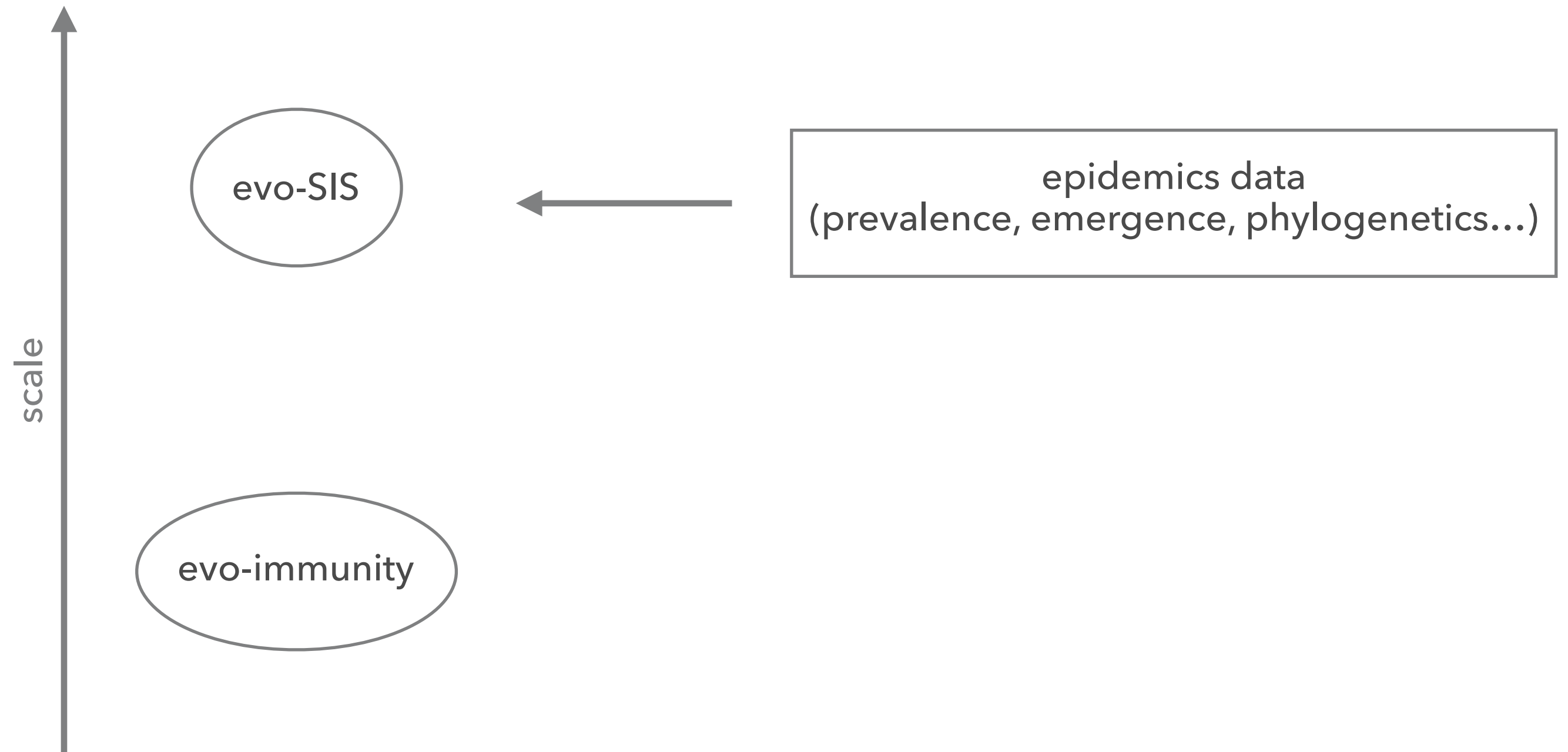
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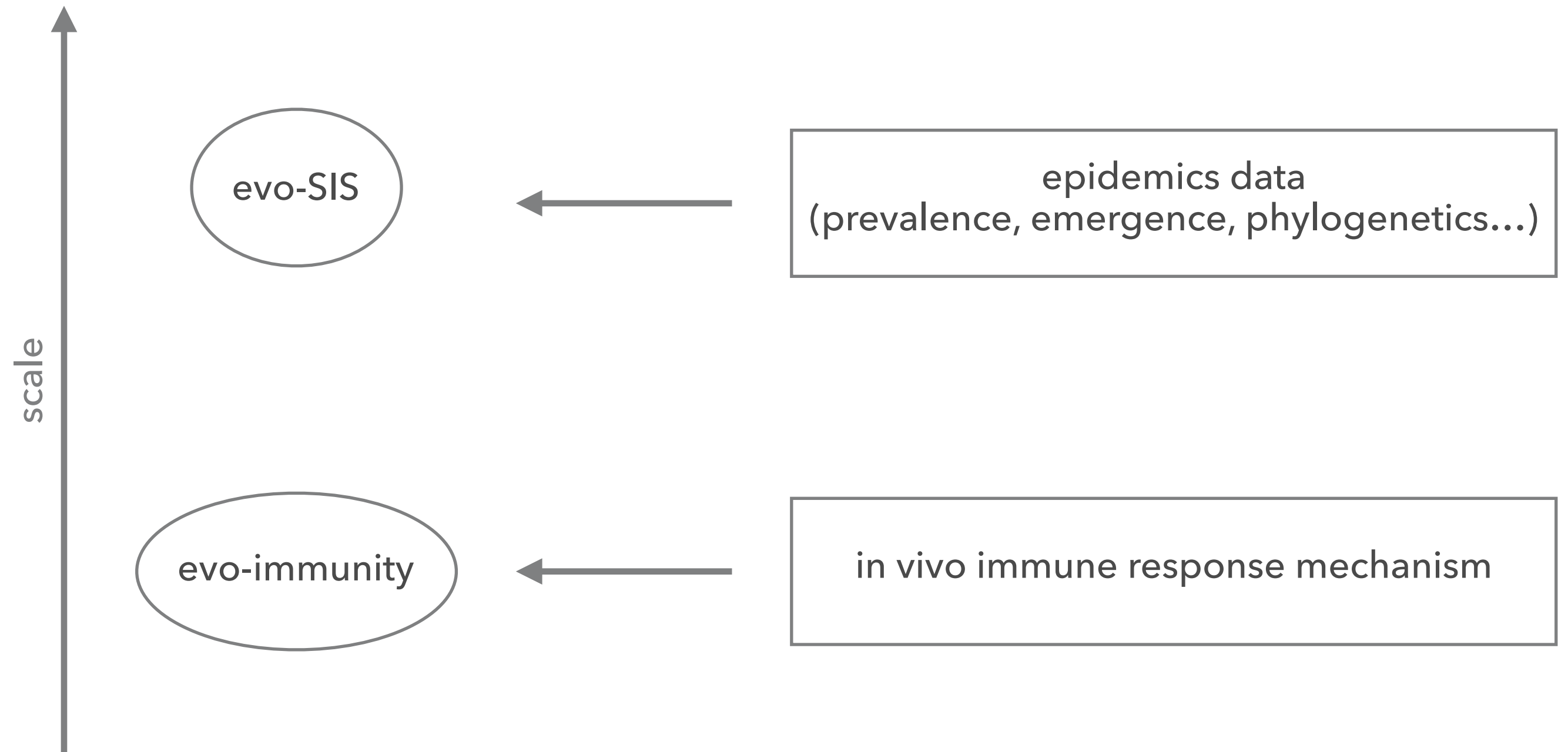
FRAMEWORK & PROGRAM



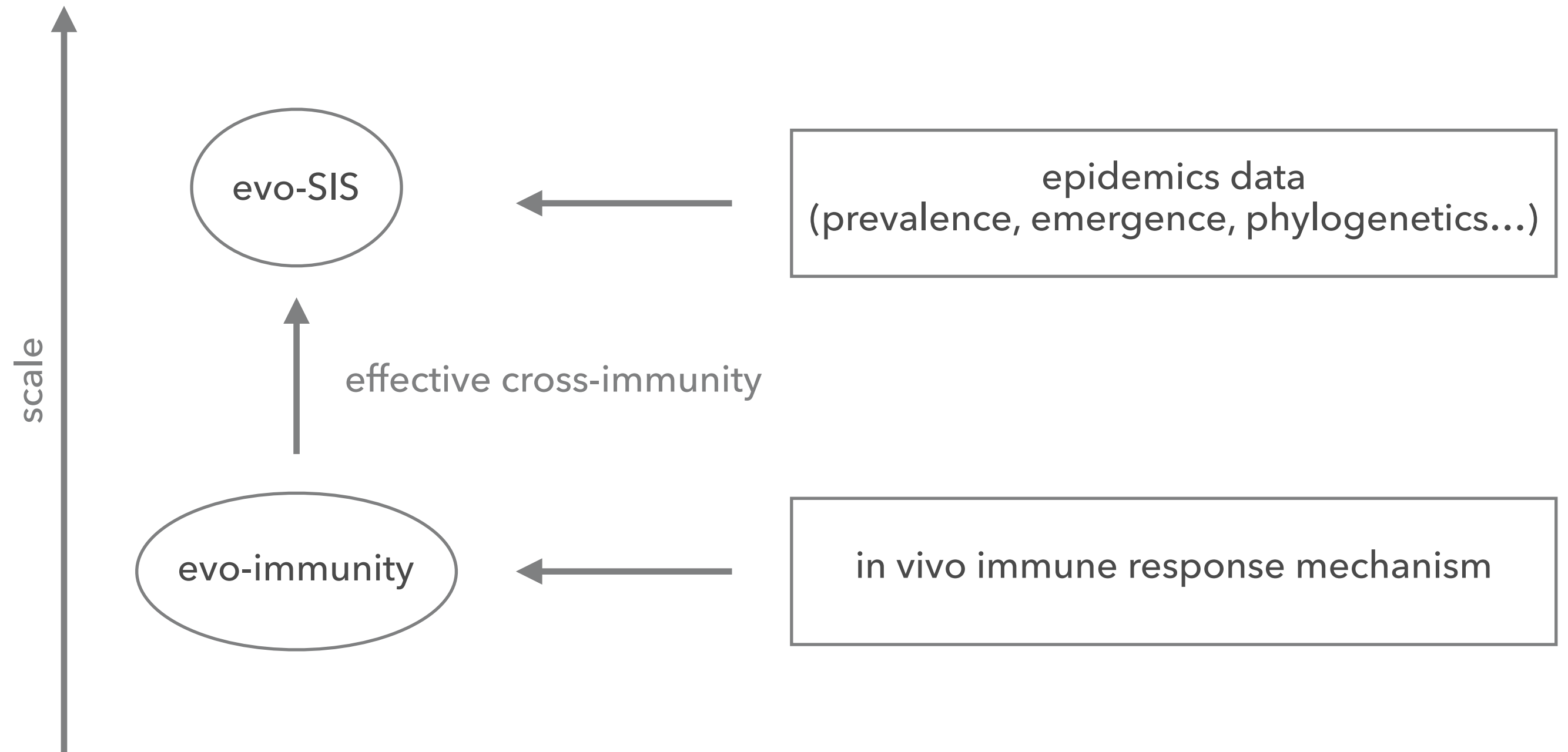
FRAMEWORK & PROGRAM



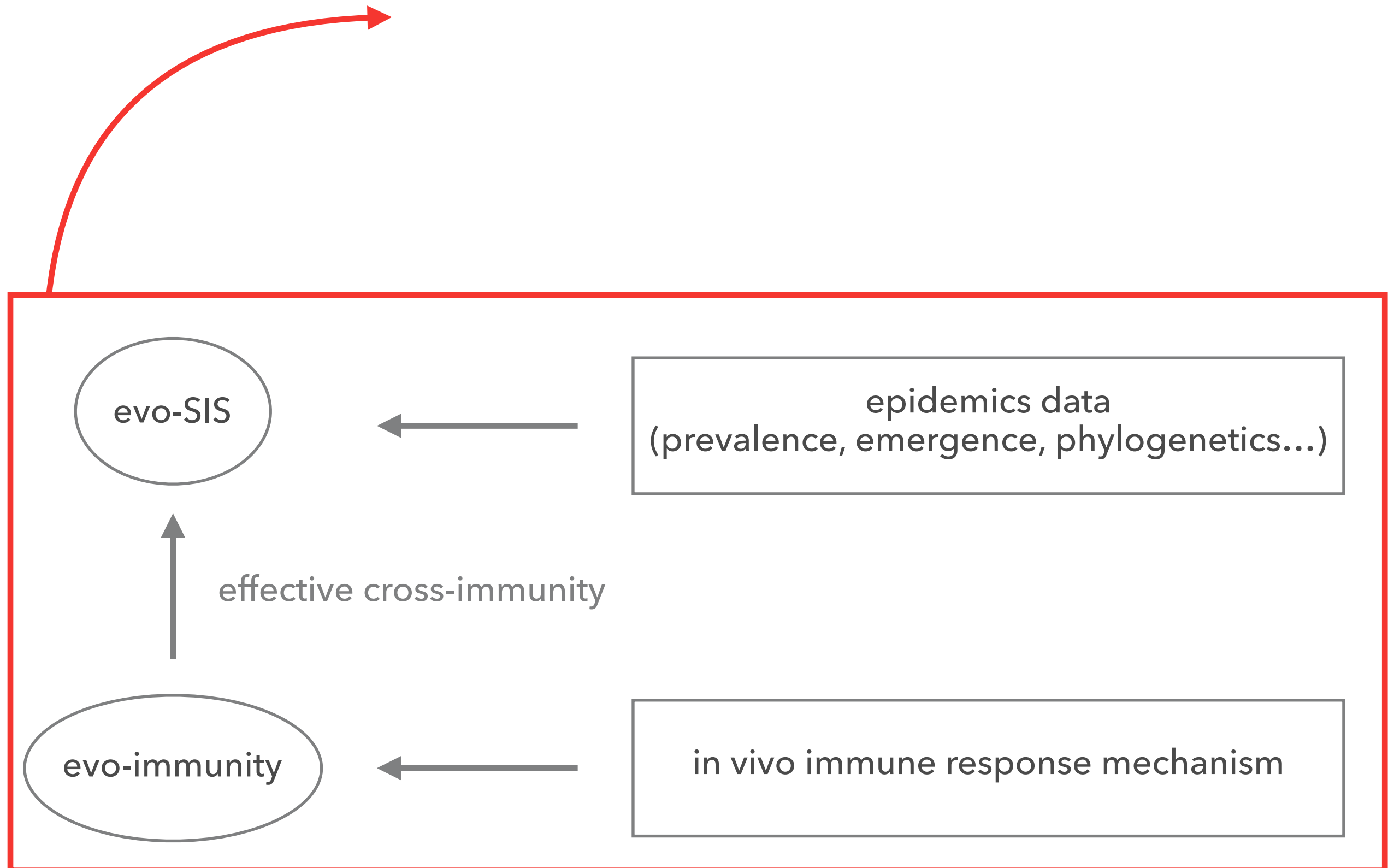
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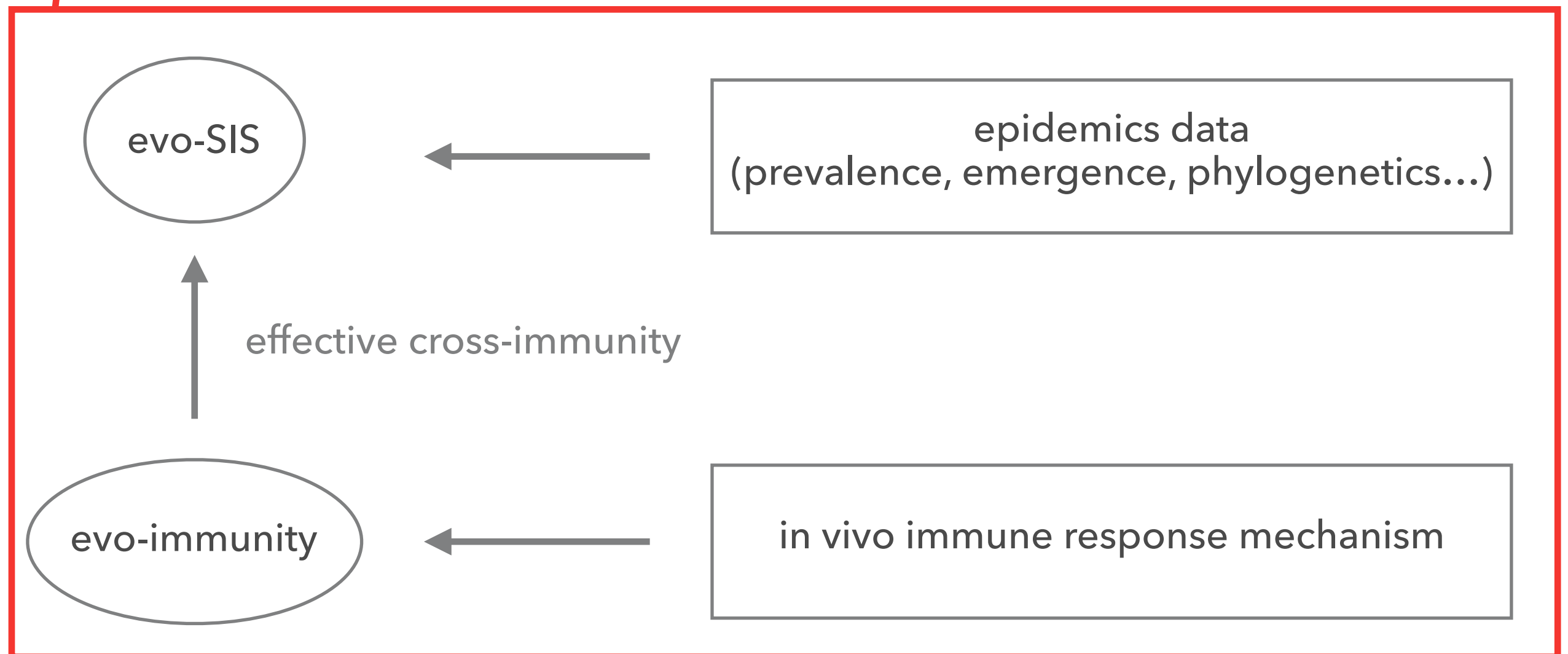


FRAMEWORK & PROGRAM



FRAMEWORK & PROGRAM

- > global diversity patterns (e.g. strain segregation)
- > vaccine design and deployment
- > assessment of outbreak vulnerability



SUMMARY

- > mutation space constrains pathogen evolution
- > antigenic interaction emerges from sequence landscape
- > seeking theoretical insight to boost epidemic management

CREDITS

CoMuNe LAB @ University of Padova

PI: Manlio De Domenico



International
**Human Frontier
Science Program**
Organization



EXTRA SLIDE 1: MULTISTRAIN SIS MODEL

$$\dot{S}_{x,a} = -\beta \frac{1}{N} \sum_{y=1}^N \frac{1}{M} \sum_{b=1}^M A_{xy} B_{ab} S_{x,a} I_{y,b} + \gamma I_{x,a}$$

$$\dot{I}_{x,a} = \beta \frac{1}{N} \sum_{y=1}^N \frac{1}{M} \sum_{b=1}^M A_{xy} B_{ba} S_{x,b} I_{y,a} - \gamma I_{x,a} + \eta \frac{1}{M} \sum_{b=1}^M (Q_{ab} I_{x,b} - Q_{ba} I_{x,a})$$

EXTRA SLIDE 2: METACOMMUNITY & IMMUNITY

pathogen population dynamics

$$X_i \xrightarrow{\alpha(1-\eta k_i)} X_i + X_i$$

$$X_i \xrightarrow{\alpha\eta} X_i + X_j, j \in \text{n.n.}(i)$$

$$X_i \xrightarrow{\delta_i(t)} \emptyset, \delta_i(t) = \delta_i^- + \delta_i^+ Y_i(t)$$

host immune response

$$(Y_i = 0) \xrightarrow{\phi_+[X_i]} (Y_i = 1)$$

$$(Y_i = 1) \xrightarrow{\phi_-} (Y_i = 0)$$

$$(Y_i = 1) + (Y_j = 0) \xrightarrow{\rho_{ij}} (Y_i = 1) + (Y_j = 1)$$