

Evolutionary insights from mathematical modelling of vaccine escape

Maria A. Gutierrez

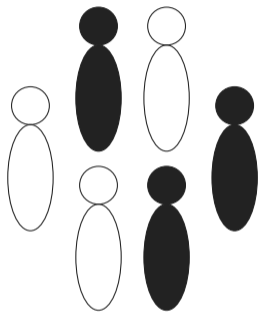
PhD candidate, with Julia Gog



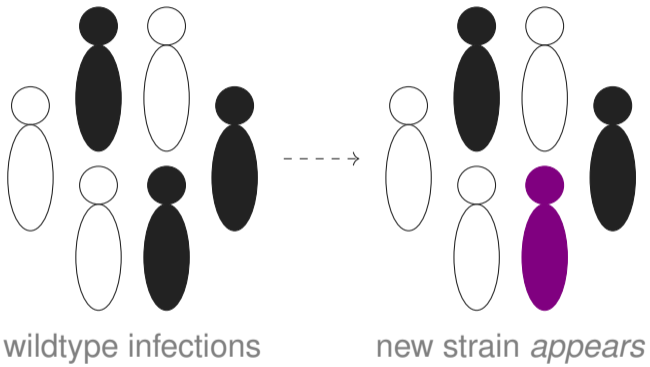
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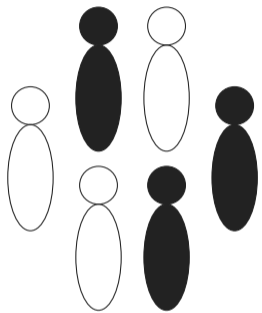




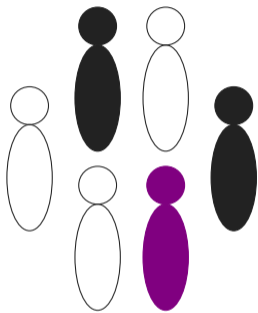


wildtype infections

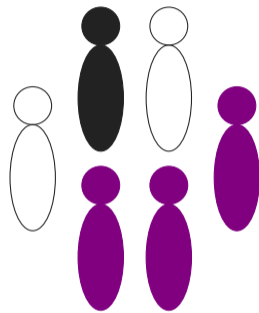




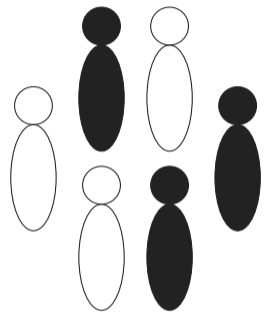
wildtype infections



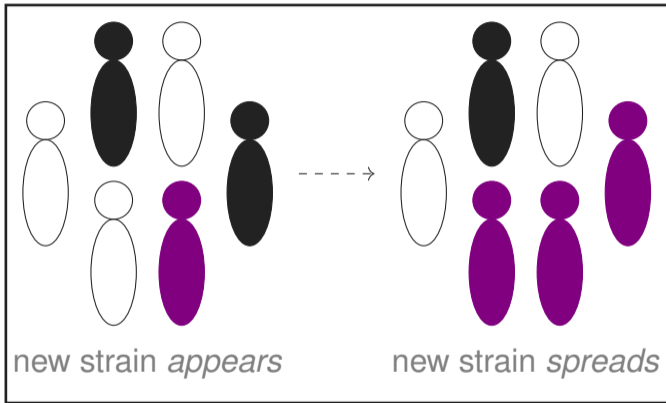
new strain *appears*



new strain *spreads*

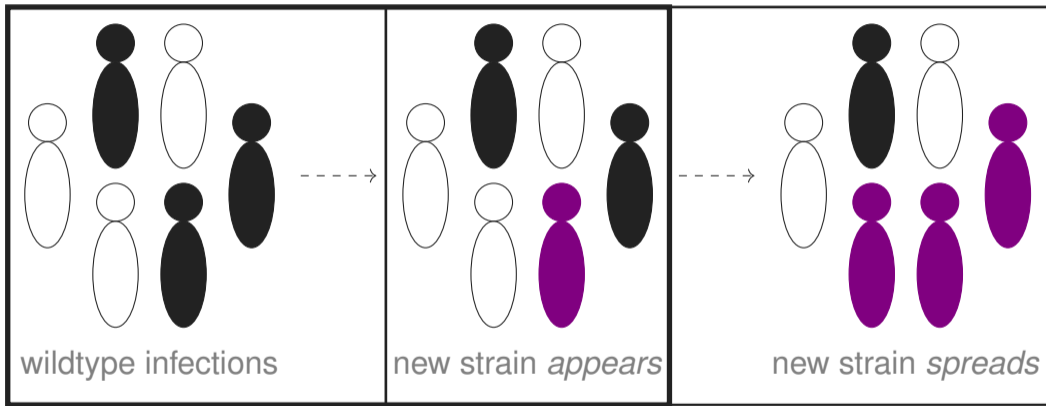


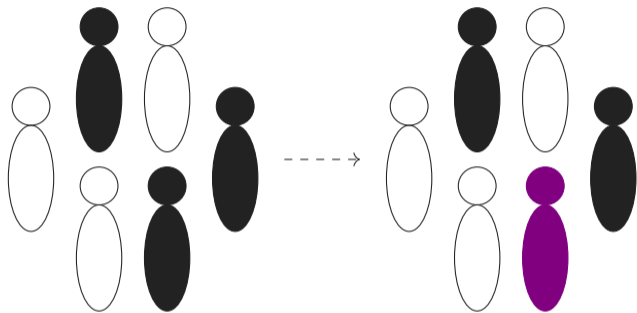
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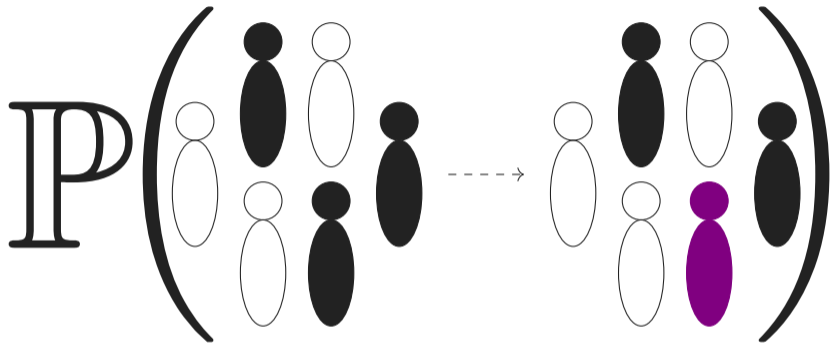


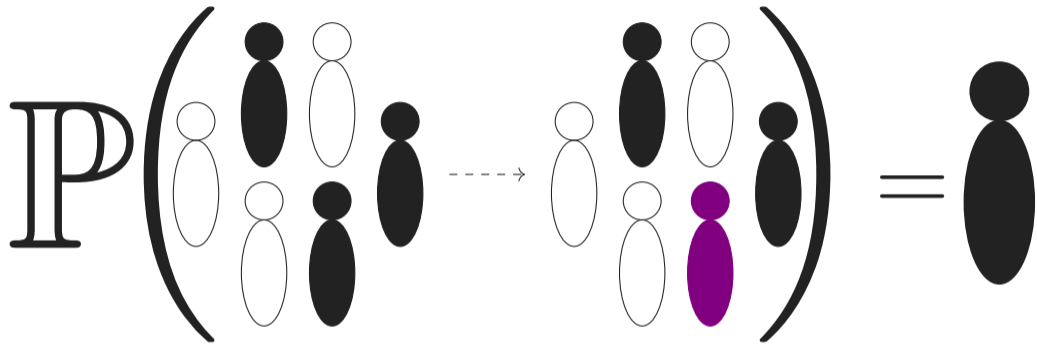
new strain *appears*

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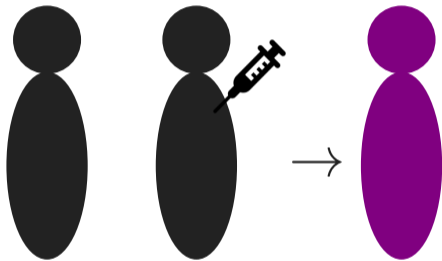


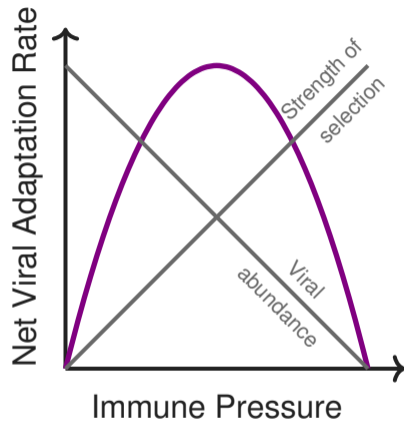
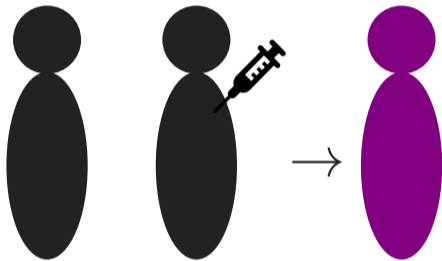




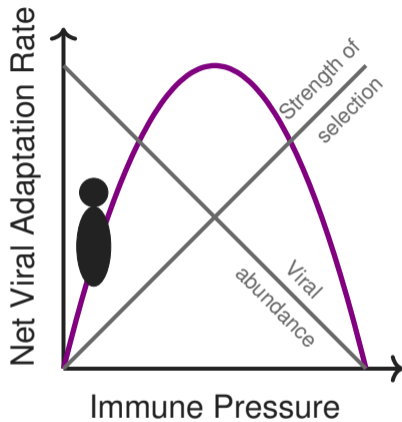
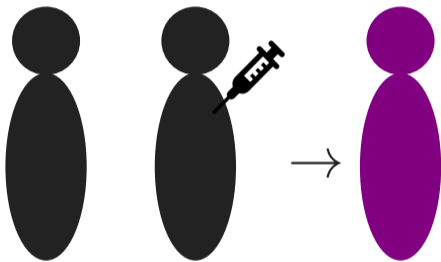


Hartfield et al. 2014, Gog et al. 2021,
Rella et al. 2021, Saad-Roy et al. 2021

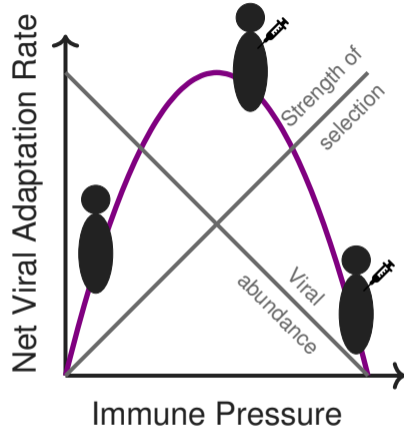
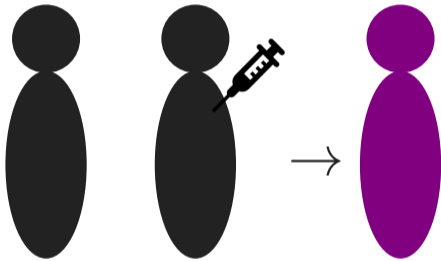




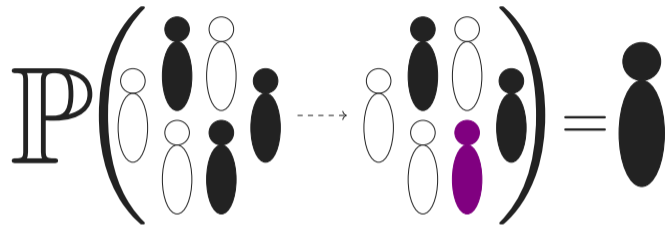
Grenfell *et al.*, Science 2004



Grenfell *et al.*, Science 2004

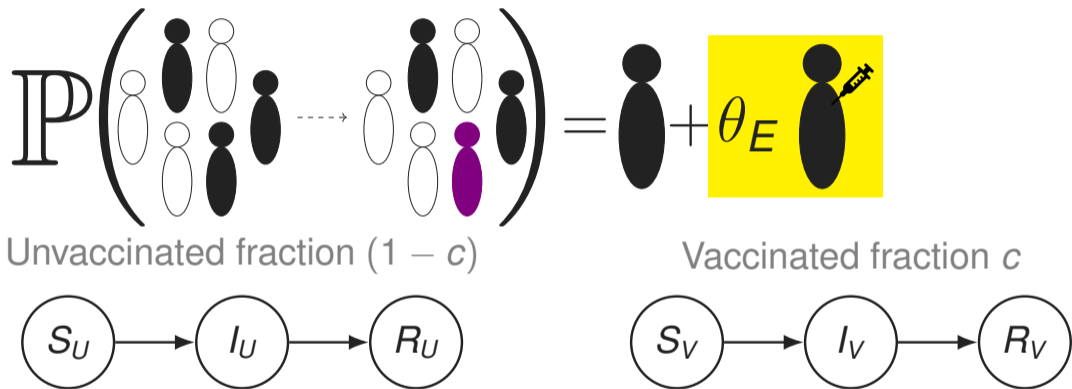


Grenfell *et al.*, Science 2004

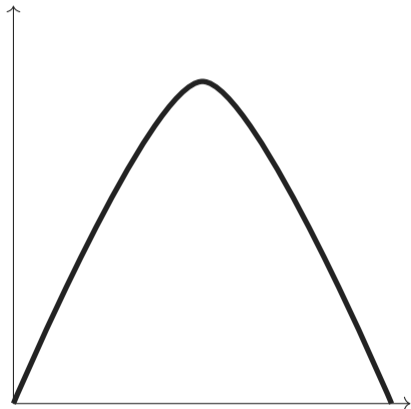


$$\mathbb{P} \left(\begin{array}{c} \text{[Initial State]} \xrightarrow{\text{dotted arrow}} \text{[Final State]} \end{array} \right) = \text{[Susceptible]} + \theta_E \text{[Infected with Injection]}$$

The diagram illustrates a probabilistic transition between two states of a population. The initial state, shown in a large left parenthesis, consists of seven stylized human figures arranged in two rows: the top row has a white figure on the left and a black figure on the right; the bottom row has a white figure on the left, a black figure in the middle, and a black figure on the right. A dotted arrow points to the final state, also in a large right parenthesis, which has the same arrangement but with a purple figure in the bottom-middle position. This transition is equated to the sum of a single black figure and a yellow square containing a black figure with a syringe icon, with the Greek letter θ_E placed between the plus sign and the yellow square.

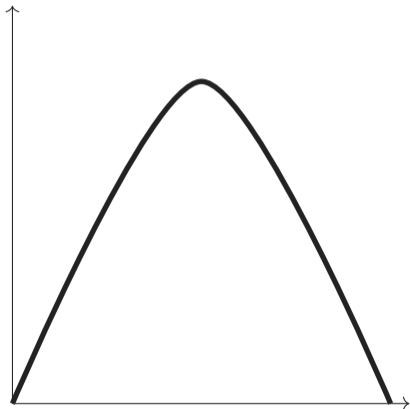


escape pressure (normalised) $P(c)/P(0)$

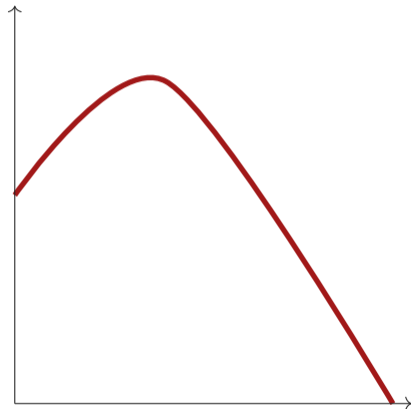


vaccination coverage (c)

escape pressure (normalised) $P(c)/P(0)$

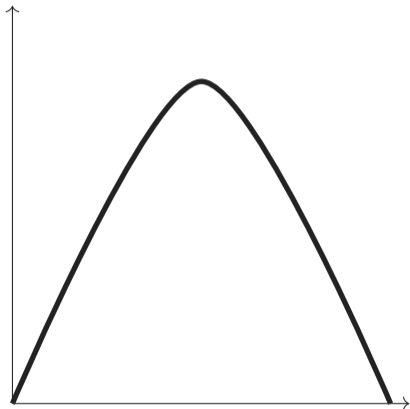


vaccination coverage (c)

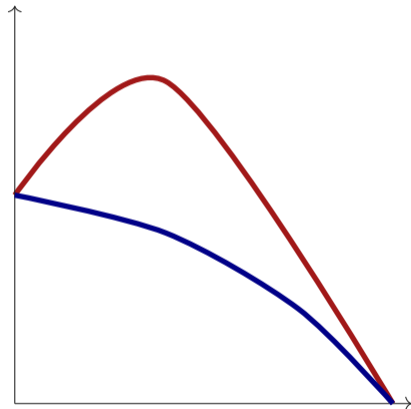


vaccination coverage (c)

escape pressure (normalised) $P(c)/P(0)$

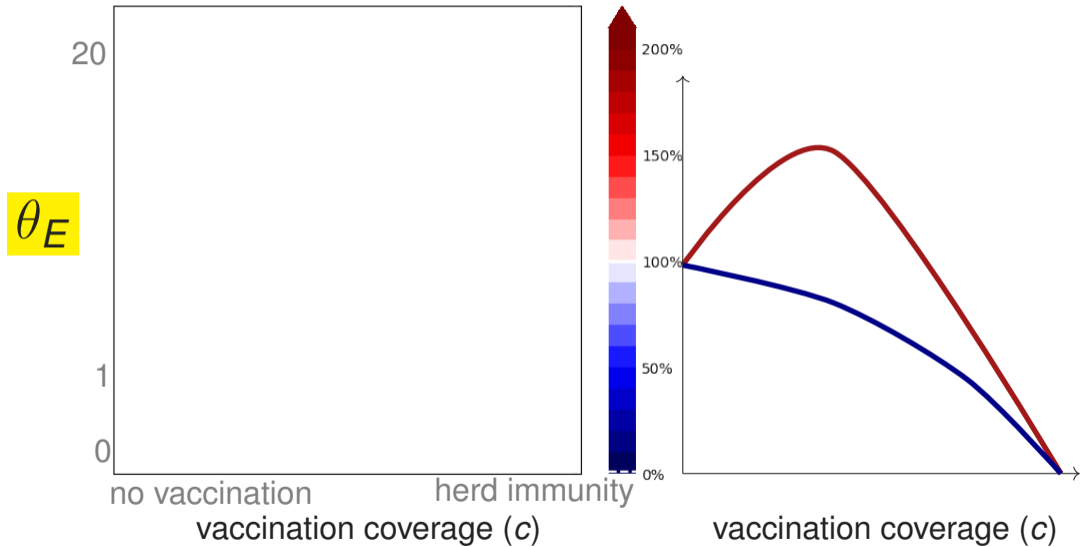


vaccination coverage (c)

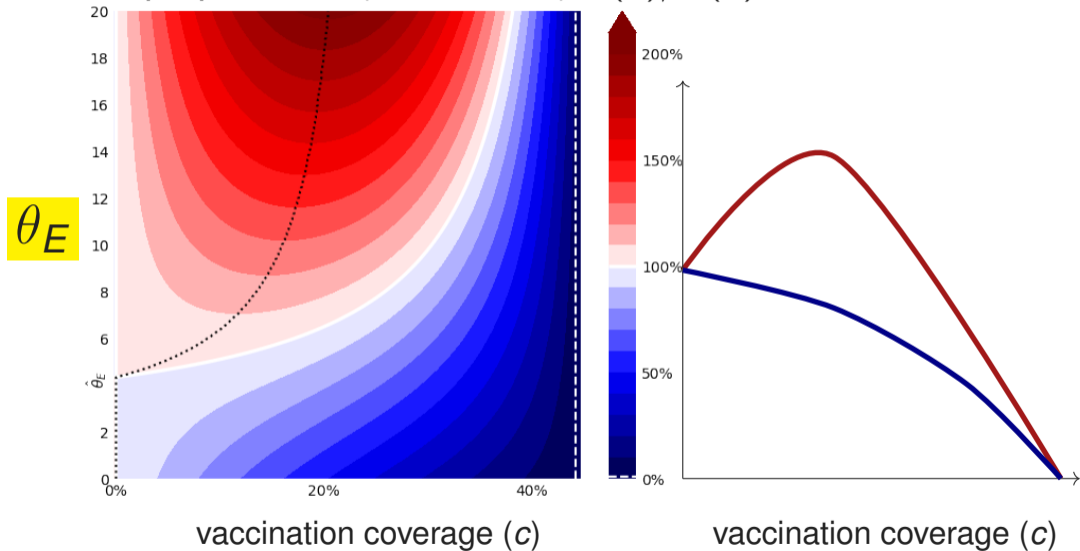


vaccination coverage (c)

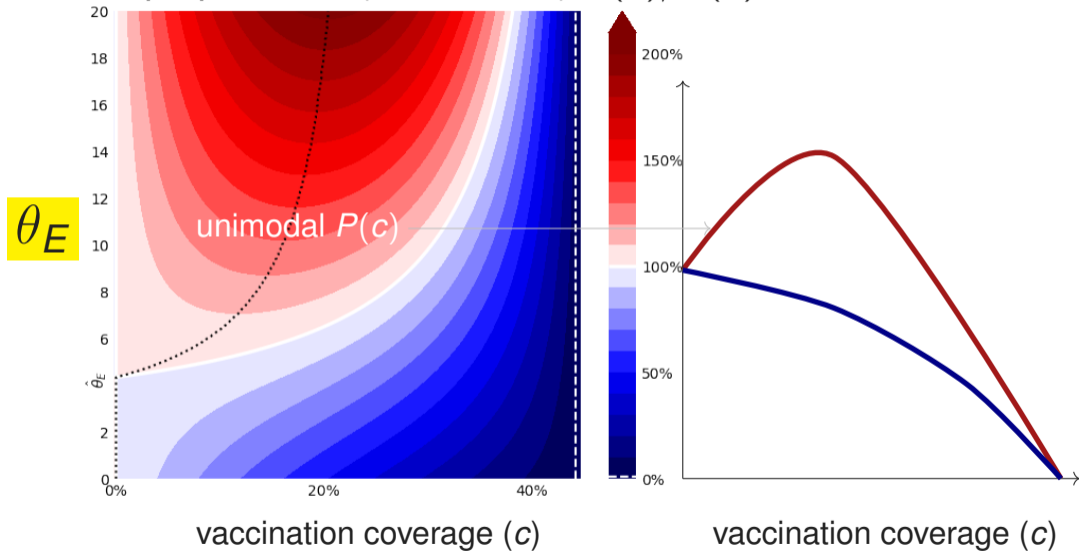
escape pressure (normalised) $P(c)/P(0)$



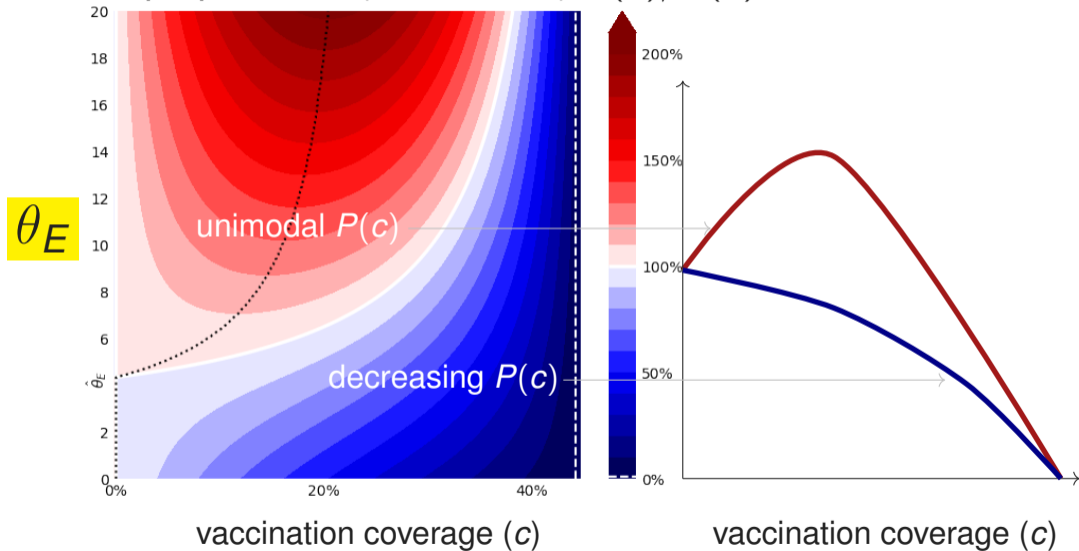
escape pressure (normalised) $P(c)/P(0)$



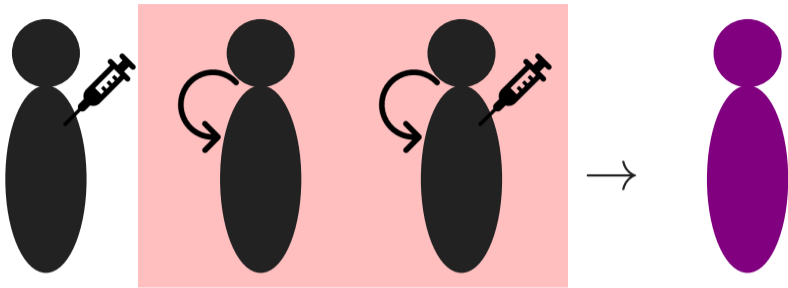
escape pressure (normalised) $P(c)/P(0)$

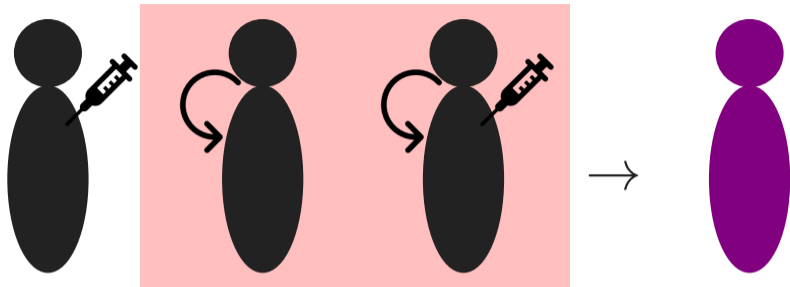


escape pressure (normalised) $P(c)/P(0)$

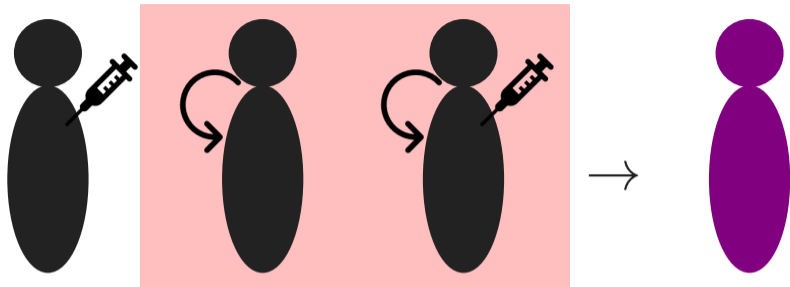






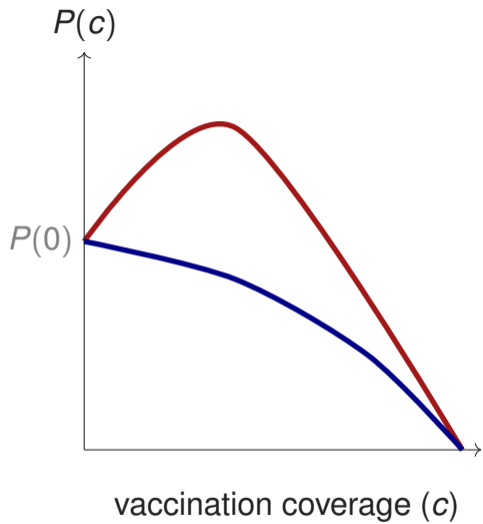


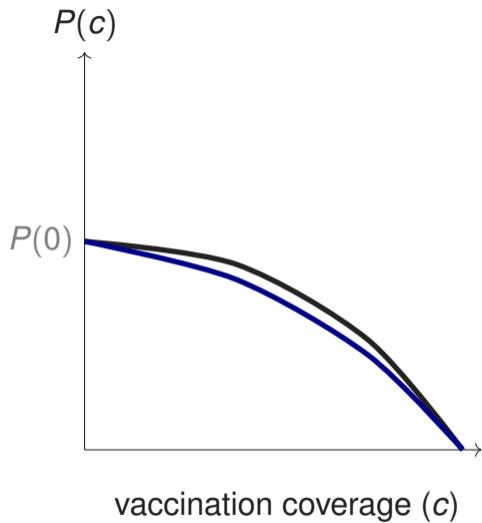
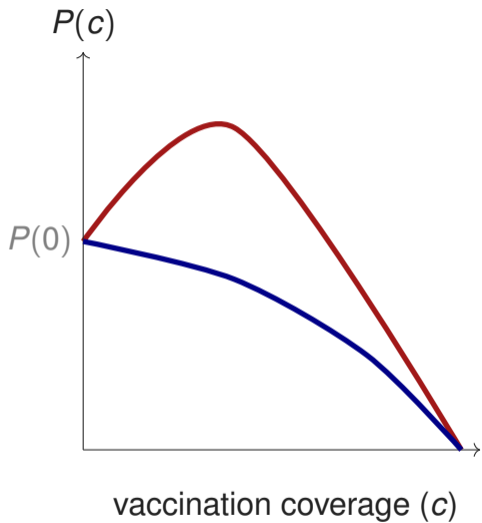
$$\mathbb{P} \left(\begin{array}{c} \text{[Group of 7 black silhouettes]} \\ \text{---} \\ \text{[Group of 7 silhouettes, one purple]} \end{array} \right) = \text{[Black silhouette]} + \theta_E \text{[Black silhouette with syringe]}$$

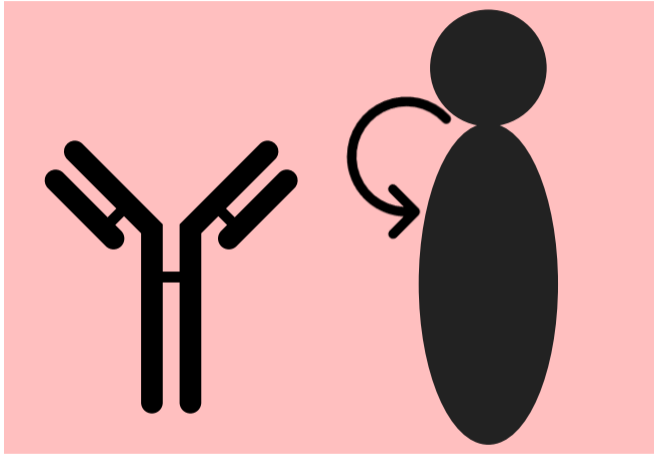


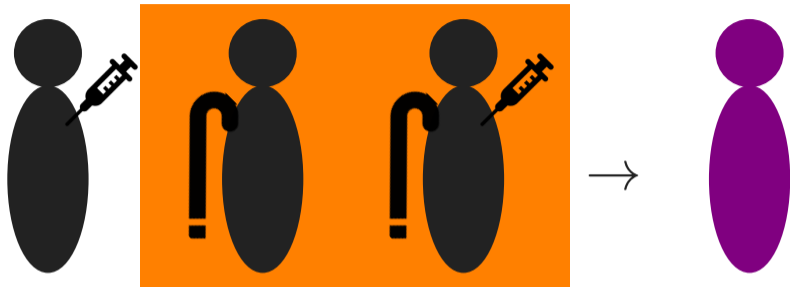
$$\mathbb{P} \left(\begin{array}{c} \text{[Group of 5 black silhouettes]} \\ \text{---} \\ \text{[Group of 5 silhouettes, one purple]} \end{array} \right) = \text{[1 black silhouette]} + \theta_E \text{[1 black silhouette with syringe]} + \theta_E \text{[1 black silhouette with arrow]} + \theta_E \text{[1 black silhouette with arrow and syringe]}$$

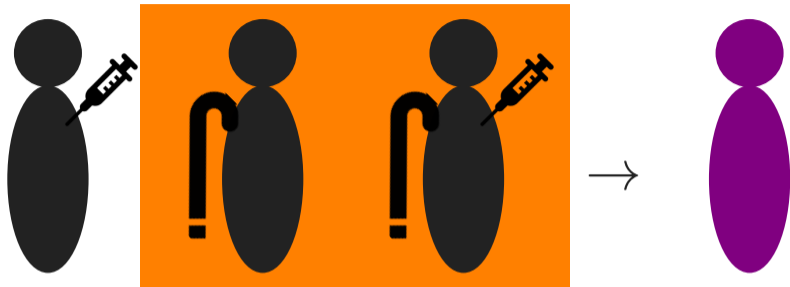
The equation shows the probability of a transition from a group of 5 black silhouettes to a group of 5 silhouettes where one is purple. This is modeled as the sum of a baseline black silhouette and three terms representing different interventions: a syringe, a curved arrow, and a combination of both, each weighted by the parameter θ_E .





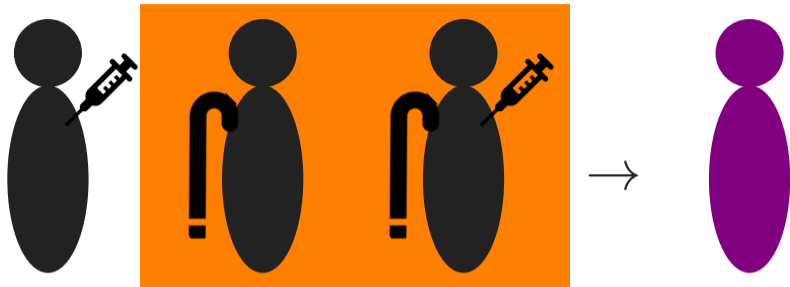




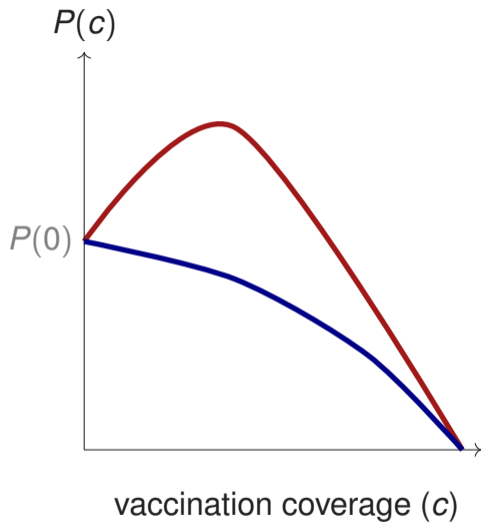


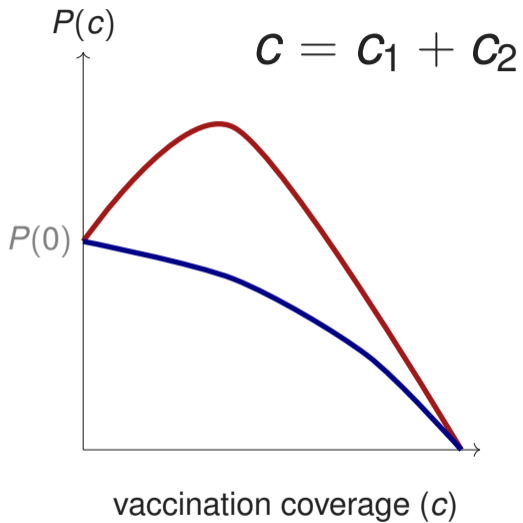
$$\mathbb{P} \left(\begin{array}{c} \text{[Group of 6 silhouettes: 4 black, 2 white]} \\ \text{---} \\ \text{[Group of 6 silhouettes: 4 black, 1 white, 1 purple]} \end{array} \right) = \text{[Black silhouette]} + \theta_E \text{[Black silhouette with syringe]}$$

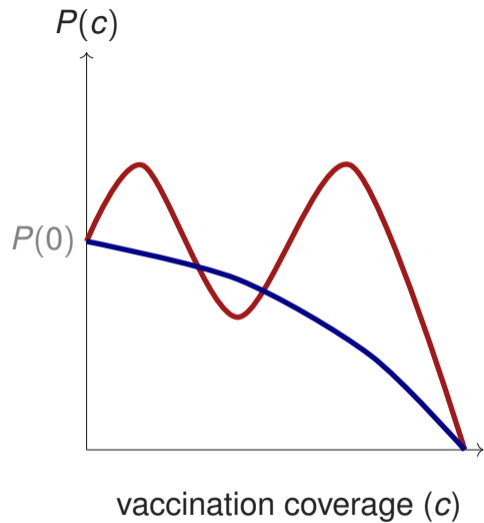
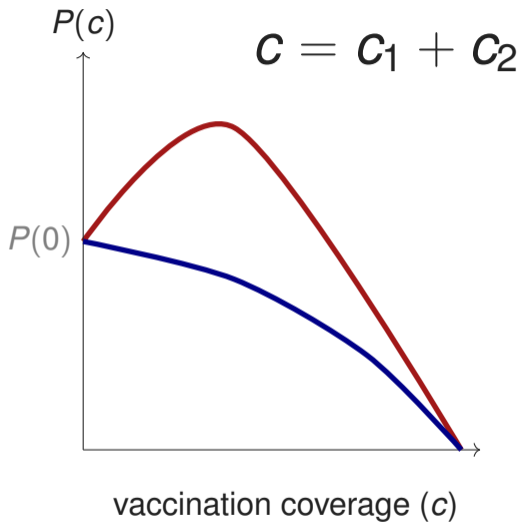
The equation shows a probability distribution over a group of 6 silhouettes. The left side shows a transition from a group of 6 silhouettes (4 black, 2 white) to a group of 6 silhouettes (4 black, 1 white, 1 purple). The right side shows the result as a black silhouette plus a term θ_E multiplied by a black silhouette with a syringe icon.



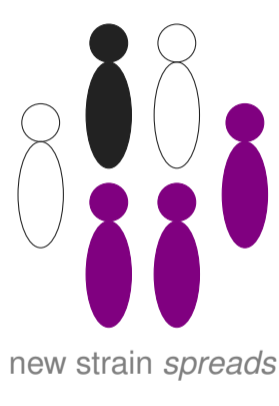
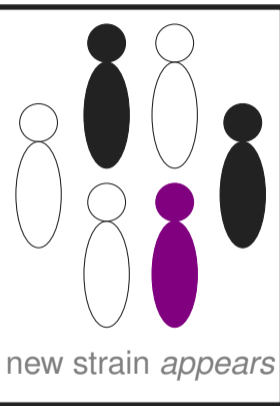
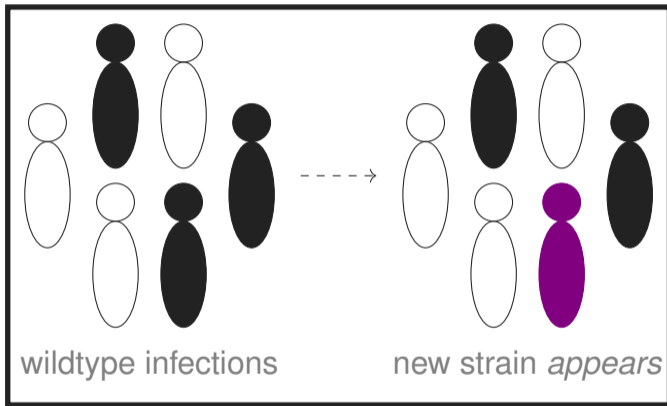
$$\mathbb{P} \left(\begin{array}{c} \text{[Group of 5 silhouettes: 2 black, 2 white, 1 black]} \\ \text{---} \\ \text{[Group of 5 silhouettes: 2 white, 1 black, 1 purple, 1 black]} \end{array} \right) = \text{[1 black silhouette]} + \theta_E \text{[1 black silhouette with syringe]} + p \text{[1 black silhouette with cane]} + p\theta_E \text{[1 black silhouette with cane and syringe]}$$

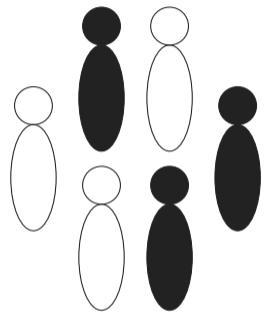




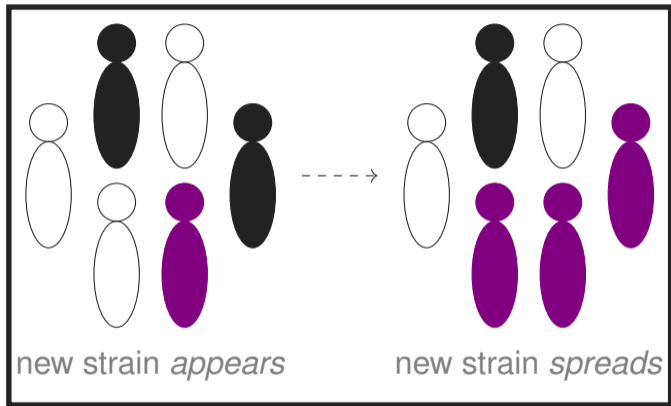






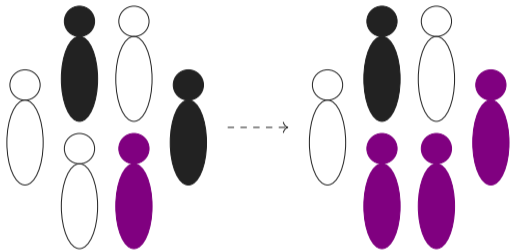


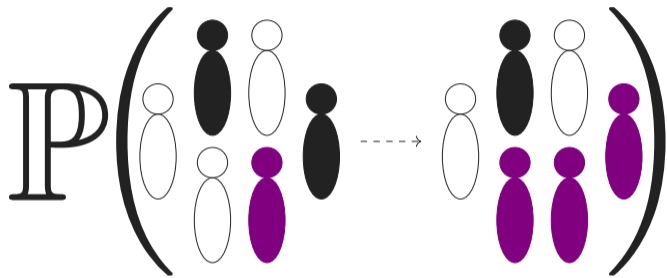
wildtype infections



new strain *appears*

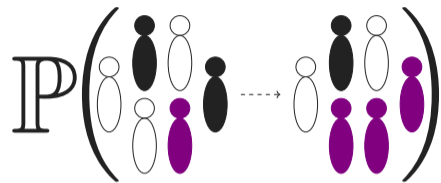
new strain *spreads*





$$\mathbb{P} \left(\begin{array}{c} \text{[Diagram showing a transition from a state with 4 individuals to a state with 5 individuals]} \end{array} \right) \neq 1 - \frac{1}{R(t)}$$

The diagram illustrates a transition between two states of a population. The initial state (left) contains four individuals: a white female, a black male, a white female, and a black male. A dashed arrow points to the final state (right), which contains five individuals: a white female, a black male, a white female, a purple female, and a purple female. The purple individuals represent a new genotype or state that has appeared in the population.



$$\mathbb{P}\left(\begin{array}{c} \text{[Diagram 1]} \\ \text{[Diagram 2]} \end{array}\right) \times \mathbb{P}\left(\begin{array}{c} \text{[Diagram 1]} \\ \text{[Diagram 2]} \end{array}\right) =$$

The image shows a mathematical equation involving two probability terms. Each term is a large 'P' followed by a large left parenthesis, a diagram, and a large right parenthesis. The diagrams are arranged in two rows and connected by a dashed arrow. The first diagram in each row shows a set of four figures: a white female, a black male, a white female, and a black male. The second diagram shows a white female, a black male, a purple female, and a purple female. The two terms are multiplied together, and the result is followed by an equals sign.

$$\mathbb{P}\left(\begin{array}{c} \text{Black} \\ \text{White} \\ \text{White} \\ \text{Purple} \\ \text{Black} \end{array} \rightarrow \begin{array}{c} \text{White} \\ \text{Black} \\ \text{White} \\ \text{Purple} \\ \text{Purple} \\ \text{Purple} \end{array}\right) \times \mathbb{P}\left(\begin{array}{c} \text{Black} \\ \text{White} \\ \text{White} \\ \text{Black} \\ \text{Black} \end{array} \rightarrow \begin{array}{c} \text{White} \\ \text{Black} \\ \text{White} \\ \text{Purple} \\ \text{Black} \end{array}\right) = \\
 \mathbb{P}\left(\begin{array}{c} \text{Black} \\ \text{White} \\ \text{White} \\ \text{Black} \\ \text{Black} \end{array} \rightarrow \begin{array}{c} \text{White} \\ \text{Black} \\ \text{White} \\ \text{Purple} \\ \text{Purple} \\ \text{Purple} \end{array}\right)$$

