Biocontrols, defensive symbiosis, and an unexpected tale of an uneasy alliance

CMB Seminar

13th February 2024

Collaborators

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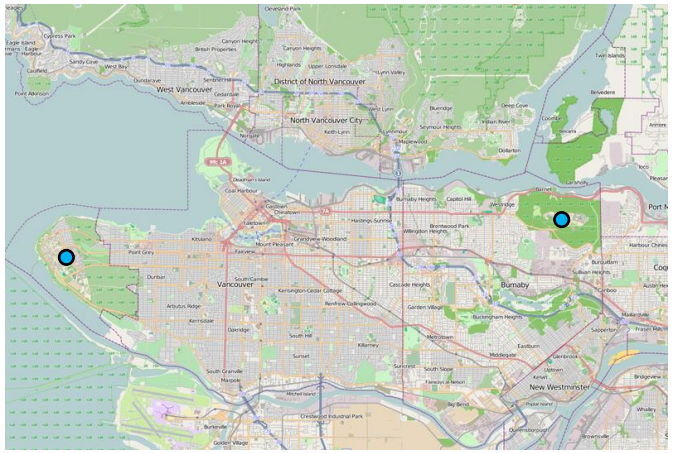

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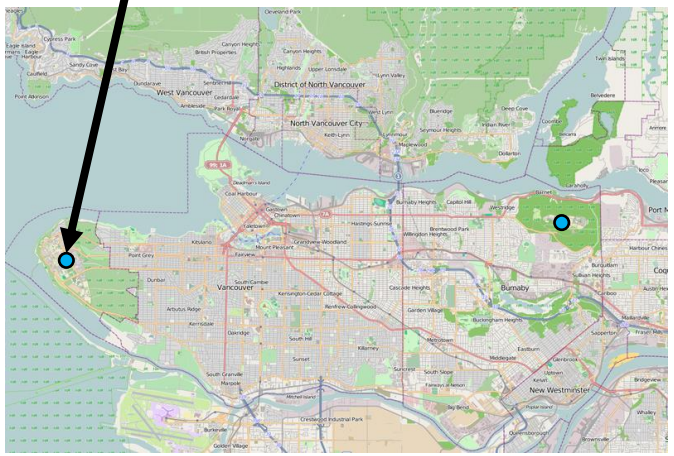

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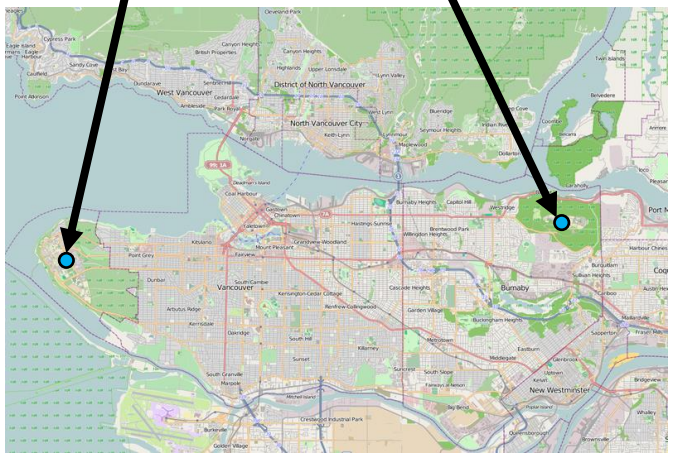

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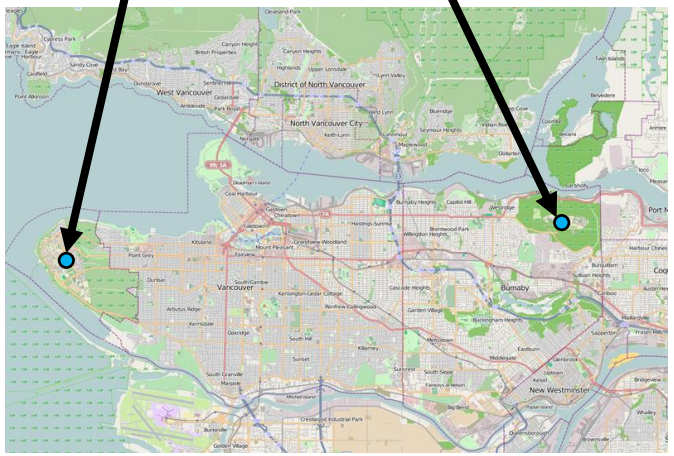

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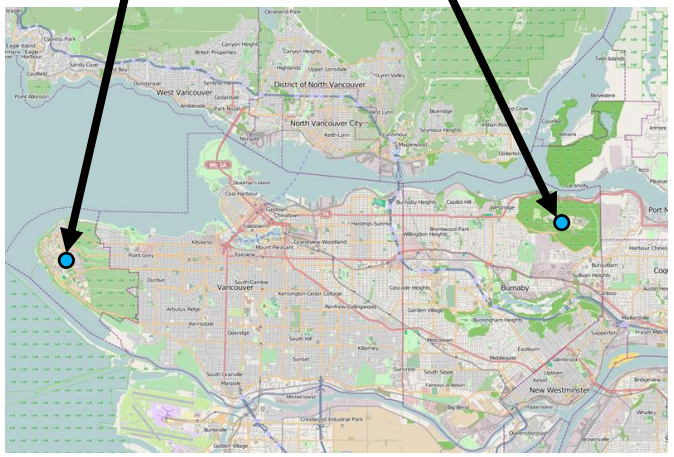

UNIVERSITY OF OXFORD

Outline

Background

Defence: Tolerance

Results

Defence: Resistance

Outline

Background

Biocontrols, defensive symbiosis, and an unexpected tale of an uneasy alliance

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Wolf spider

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Aphid parasitoid wasp

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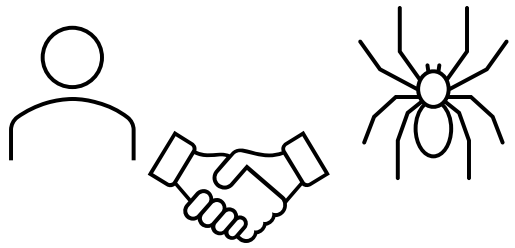
An organism that lives with(in) another organism in which **both gain** from the relationship (**mutualistic relationship**).



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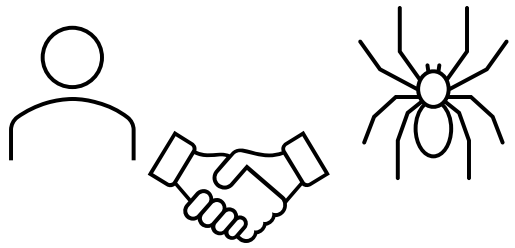
Defensive symbiosis:



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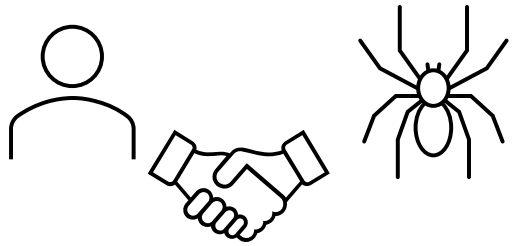
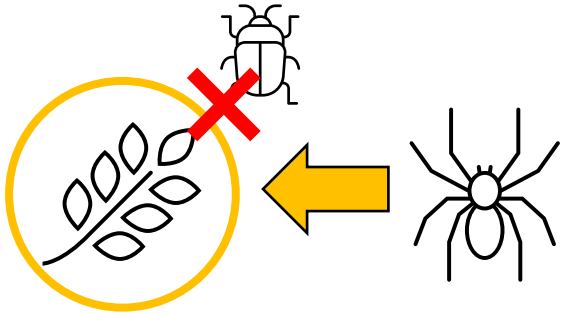
Defensive symbiosis:

One of these organisms gains a level of **defence** against a disease/pest.





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Aphid host

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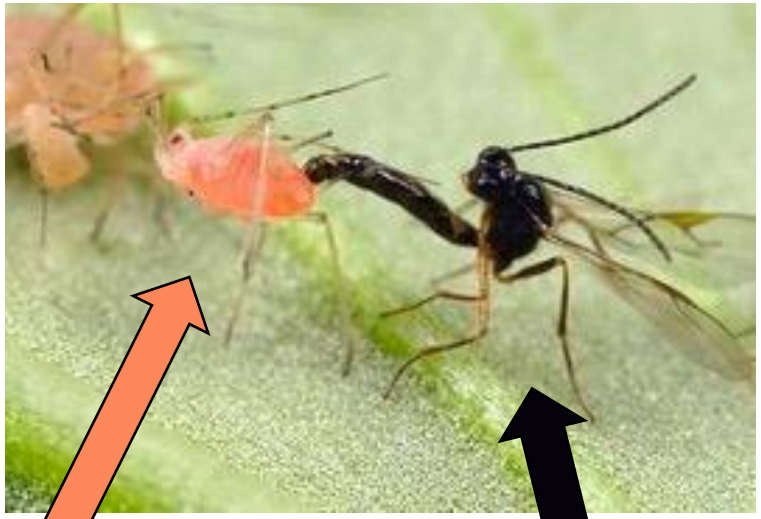

Aphid host

Parasitic wasp

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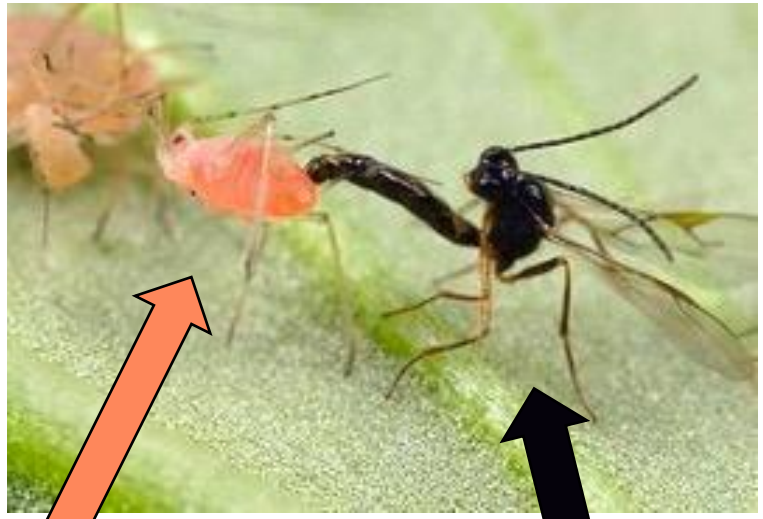

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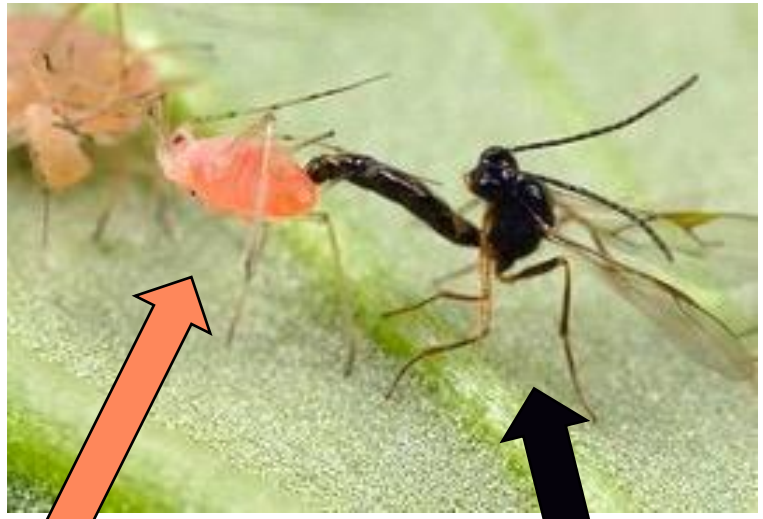

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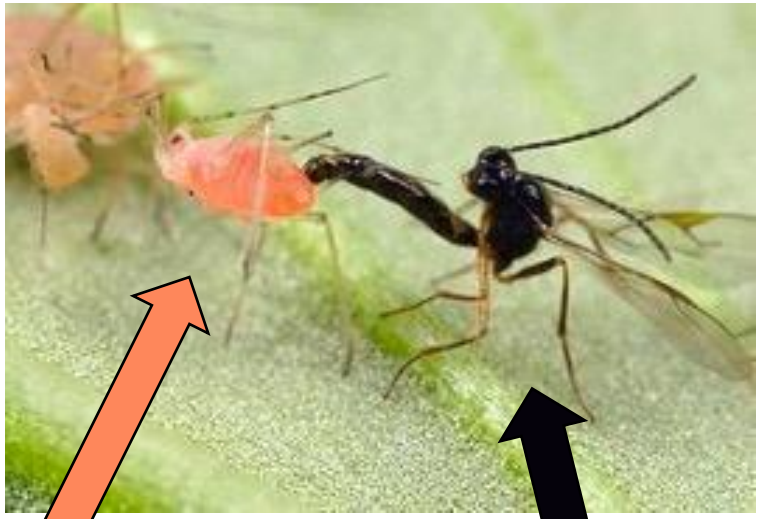

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Protective bacteria: *Hamiltonella defensa*

Defensive symbionts as biocontrols?

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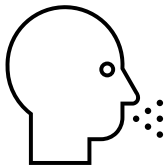

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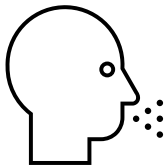

We will use a mathematical analysis to understand the viability of such a biocontrol in a host population

Types of defence

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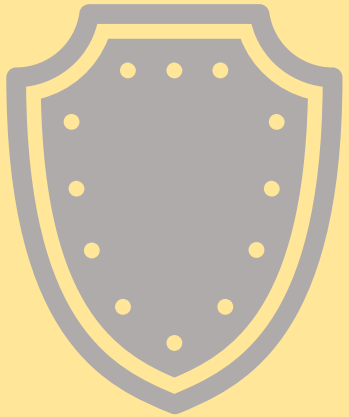

Tolerance

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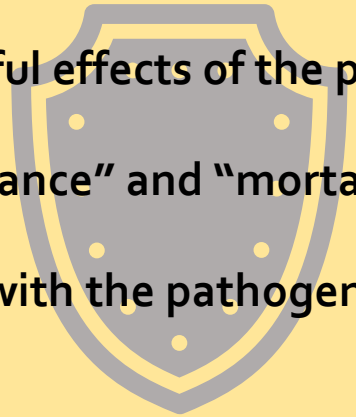

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Types of defence

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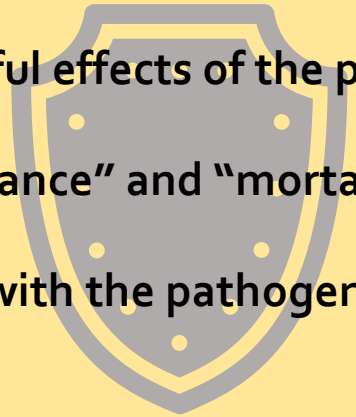

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Types of defence

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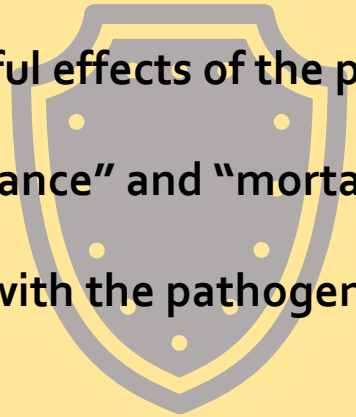

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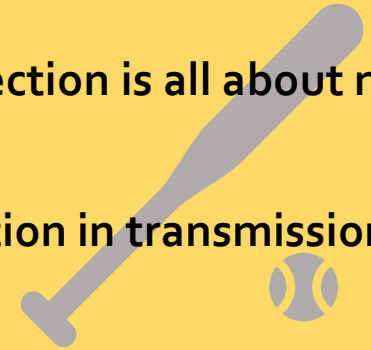

Resistance protection is all about making the host more resistant to infection

This may take the form of a reduction in transmission when harbouring the defensive symbiont compared to without

Modelling – a glossary

Phenotype: An observable trait (average height, virulence of pathogen)

Resident phenotype: The trait which sets the environment

Mutant phenotype: The trait trying to invade into an environment (shorter, more virulent)

Fitness: How good is the mutant at establishing into the resident environment?

Selection gradient: Derivative of the fitness (wrt mutant phenotype)

Mutation: A change to the phenotype (i.e. an observable change, average height increases)

Modelling

Adaptive dynamics – key points

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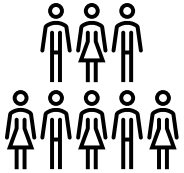

Incorporates population-level information (**Ecological dynamics**)

Modelling

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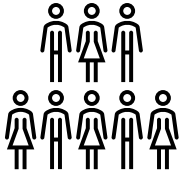

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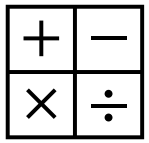

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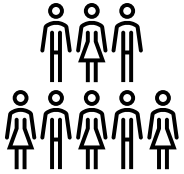

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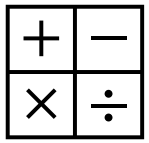

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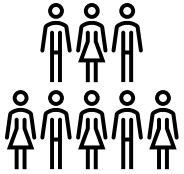

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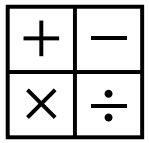

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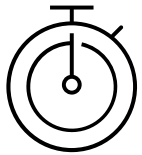

Mutations are rare (**Separation of timescales**)

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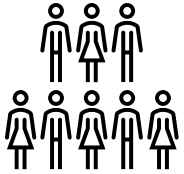

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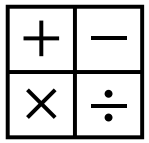

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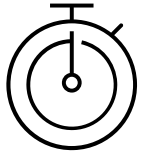

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Choose how our evolving parameter, say x, alters other ecological parameters.

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Ecological dynamics

Calculate the steady state number of individuals using x_r as a (resident) trait value using ODEs. We call this the resident population, $\boldsymbol{N}^*$.

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Invasion fitness

Calculate the invasion fitness, w, for a rare mutant, x_m, which is similar phenotypically to the resident at steady state. Calculate the selection gradient, s:

$$w \equiv w(x_m, x_r, \boldsymbol{N}^*),$$

$$s(x) = \left.\frac{\partial w}{\partial x_m}\right|_{x=x_m=x_r}.$$

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Stability analysis

Using higher order derivatives of the invasion fitness, we can determine the behaviour at singular strategies. For example:

$$\left.\frac{\partial^2 w}{\partial (x_m)^2}\right|_{x=x_m=x_r} < 0$$

denotes evolutionary stability.

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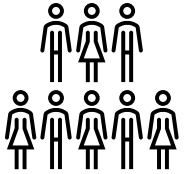
Adaptive dynamics – key points



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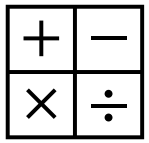
Numerical solution of ODEs



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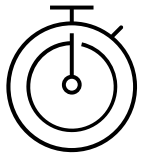

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Discretise the trait space

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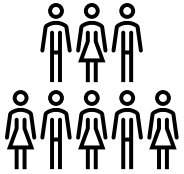

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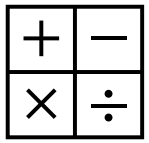

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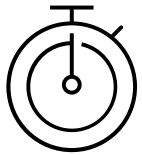

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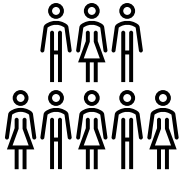

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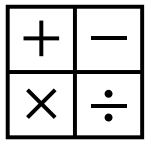

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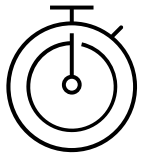


Mutations are rare (**Separation of timescales**)

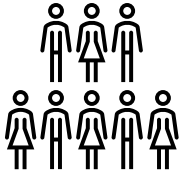
Run ecological dynamics for some length of time ~ steady state

Selection is weak (**mutations have small effects**)

Discretise the trait space

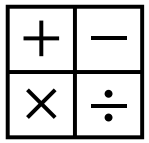
Modelling

Adaptive dynamics – key points



Incorporates population-level information (**Ecological dynamics**)

Numerical solution of ODEs



Calculate analytical expressions (**fitness** and **selection gradient**)

Computed "semi-analytically"

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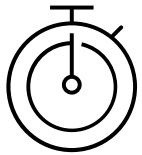

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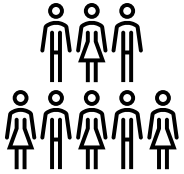

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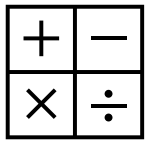

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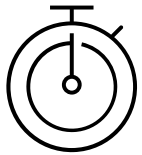

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Discretise the trait space

Outline

Background

Defence: Tolerance

Results

Defence: Resistance

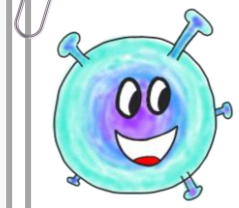
Outline

Defence: Tolerance

Meet the characters for today

Meet the characters for today

Pathogen registration form



Subject #796

Name:

TBC

Type:

DEFENSIVE SYMBIONT

Philosophy:

"PROTECC OR ATTACC, I'VE GOT YOUR BACK!"

Meet the characters for today

Pathogen registration form

Subject #796

Name:

TBC

Type:

DEFENSIVE SYMBIONT

Philosophy:

"PROTECC OR ATTACC, I'VE GOT YOUR BACK!"

Pathogen registration form

Subject #727

Name:

TBC

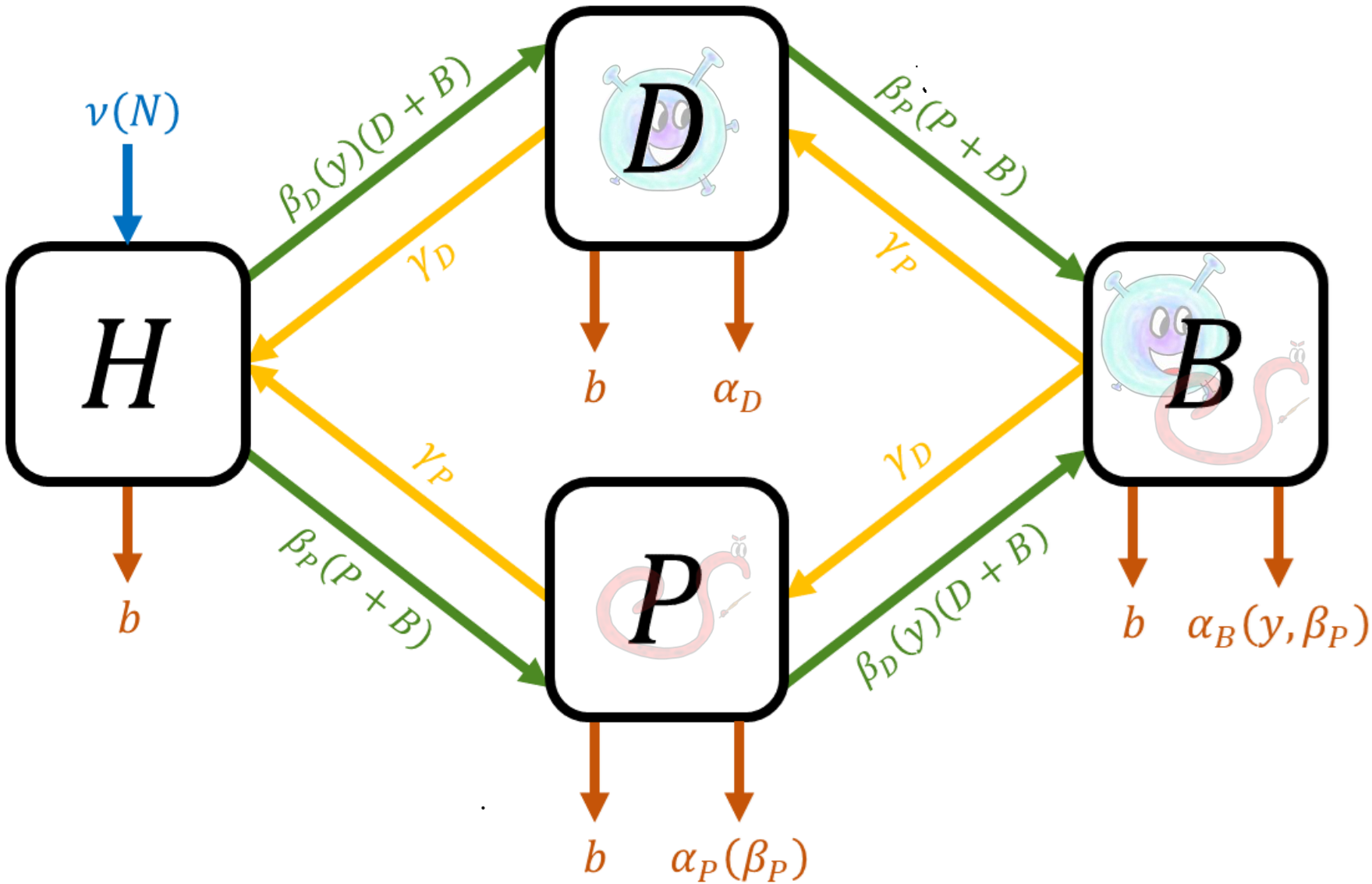
Type:

PARASITE

Philosophy:

"I HAVE A STICK AND I'M NOT AFRAID TO USE IT"

Ecological dynamics



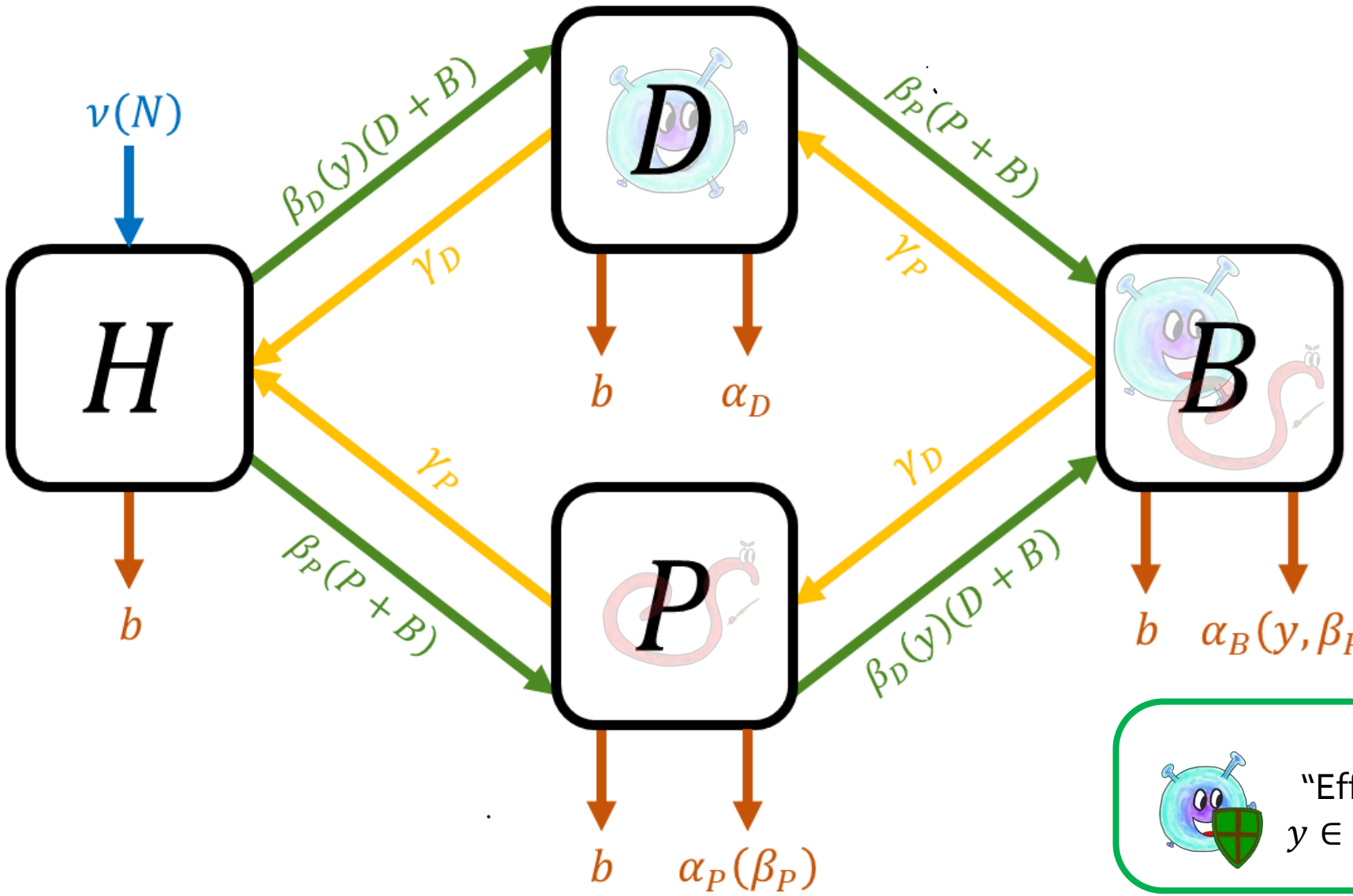
Blue: Births

Green: Transmission

Red: Deaths

Yellow: Recovery

Ecological dynamics



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Evolving parameters

"Effort"
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Transmissibility
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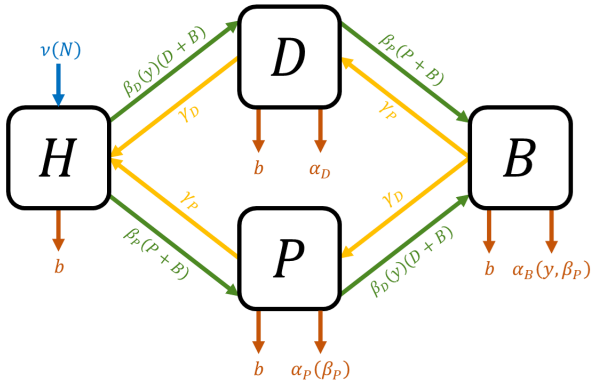


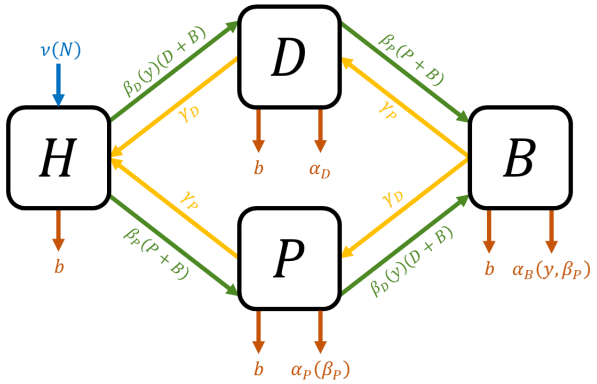
$$\dot{H} = \nu(N) - [b + \beta_D(y)(D + B) + \beta_P(P + B)]H + \gamma_D D + \gamma_P P$$

$$\dot{D} = \beta_D(y)H(D + B) - [b + \alpha_D + \gamma_D + \beta_P(P + B)]D + \gamma_P B$$

$$\dot{P} = \beta_P H(P + B) - [b + \alpha_P(\beta_P) + \gamma_P + \beta_D(y)(D + B)]P + \gamma_D B$$

$$\dot{B} = \beta_D(y)P(D + P) + \beta_P D(P + B) - [b + \alpha_D + (1 - y)\alpha_P(\beta_P) + \gamma_D + \gamma_P]B$$

Ecological dynamics



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$$\dot{P} = \beta_P H(P+B) - [b + \alpha_P(\beta_P) + \gamma_P + \beta_D(y)(D+B)]P + \gamma_D B$$

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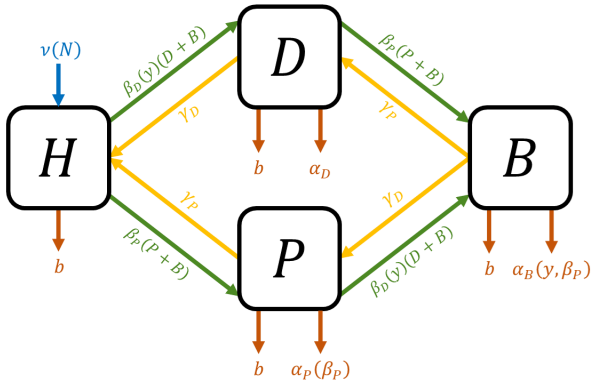
Fitness functions – how well can a mutant invade a resident population?

Ecological dynamics



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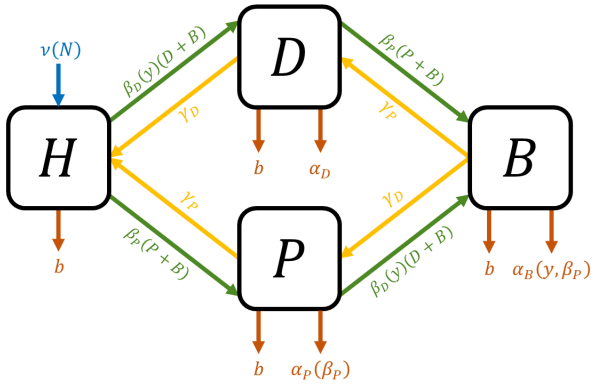
Fitness functions – how well can a mutant invade a resident population?

$w_D(y^m|y^r, \beta_P^r)$

$w_P(\beta_P^m|y^r, \beta_P^r)$

Ecological dynamics



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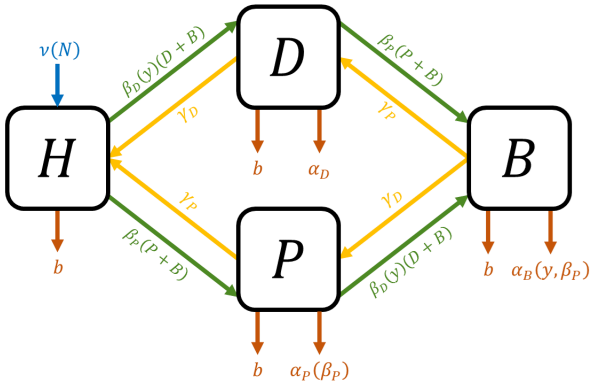
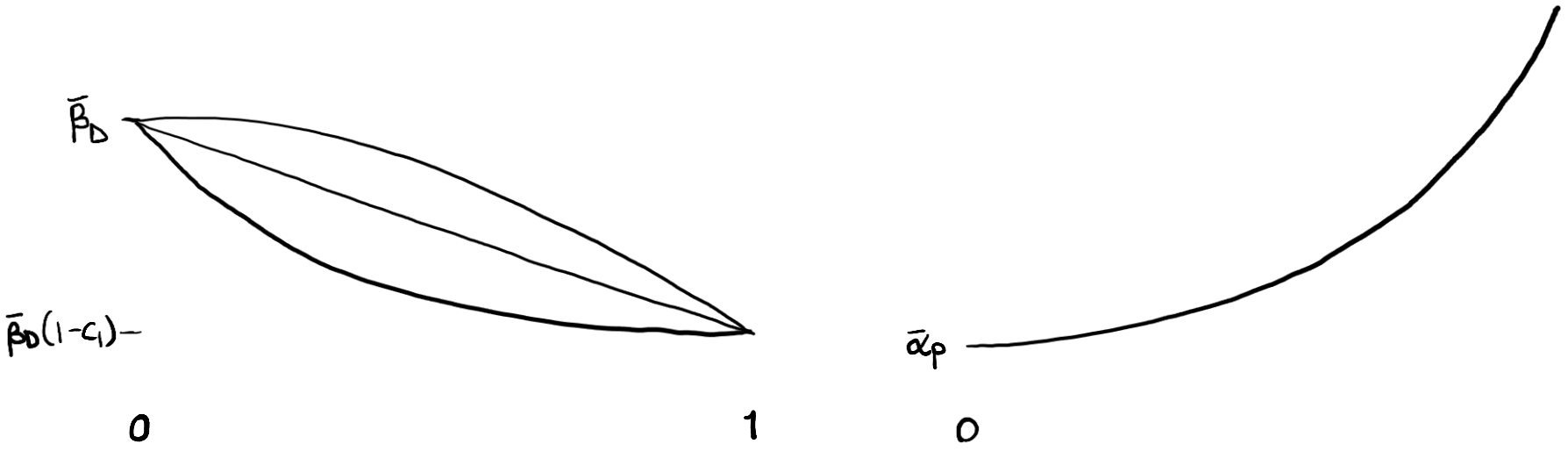
Fitness functions – how well can a mutant invade a resident population?

$$w_D(y^m|y^r,\beta_P^r) = \frac{\beta_D(y^m)\{H^*[b+\gamma_D+\gamma_P+\alpha_B(y^m,\beta_P^r)+\beta_P^r(P^*+B^*)]+P^*[b+\gamma_D+\gamma_P+\alpha_D+\beta_P^r(P^*+B^*)]\}}{\big(b+\gamma_D+\alpha_D+\beta_P^r(P^*+B^*)\big)(b+\alpha_B(y^m,\beta_P^r)+\gamma_D+\gamma_P)-\gamma_P\beta_P^r(P^*+B^*)} - 1$$

$$w_P(\beta_P^m|y^r,\beta_P^r) = \frac{\beta_P^m\{H^*[b+\gamma_D+\gamma_P+\alpha_B(y^r,\beta_P^m)+\beta_D(y^r)(D^*+B^*)]+D^*[b+\gamma_D+\gamma_P+\alpha_P(\beta_P^m)+\beta_D(y^r)(D^*+B^*)]\}}{\big(b+\gamma_P+\alpha_P(\beta_P^m)+\beta_D(y^r)(D^*+B^*)\big)(b+\alpha_B(y^r,\beta_P^m)+\gamma_D+\gamma_P)-\gamma_D\beta_D(y^r)(D^*+C^*)} - 1$$

Coevolution: Evolutionary dynamics





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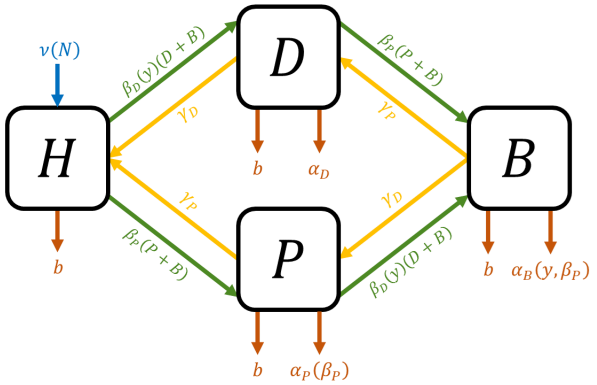
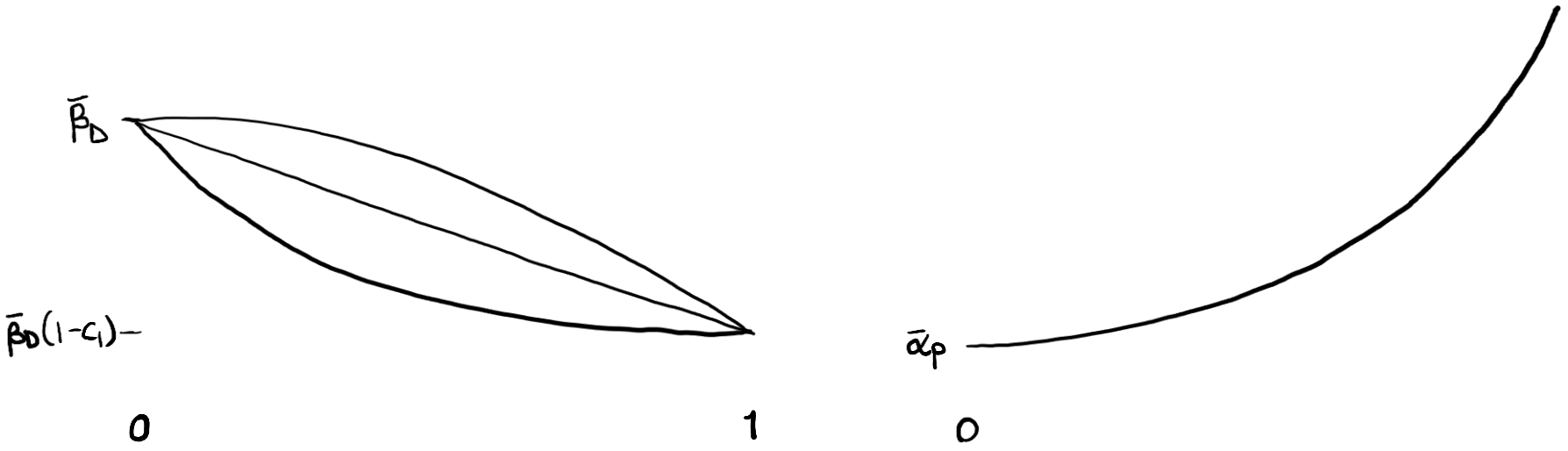


Evolving parameters

"Effort"
$y \in (0,1)$

Transmissibility
$\beta_P > 0$



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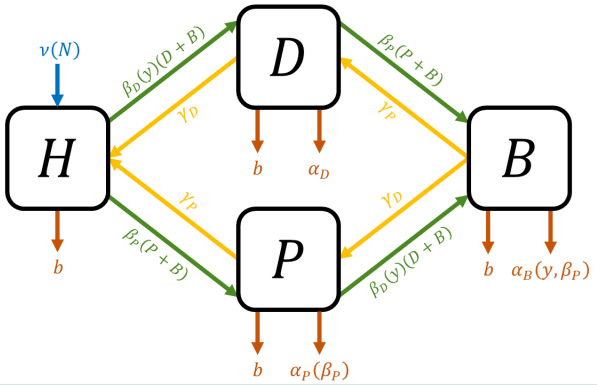

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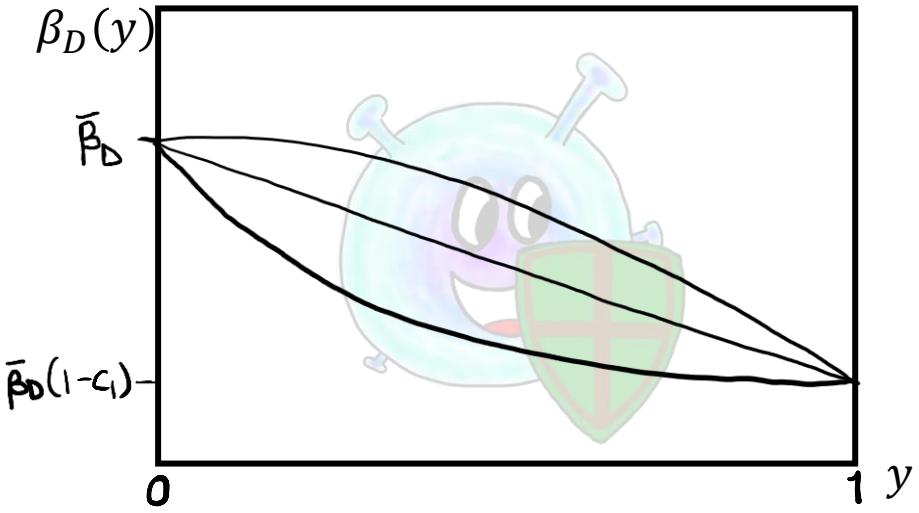

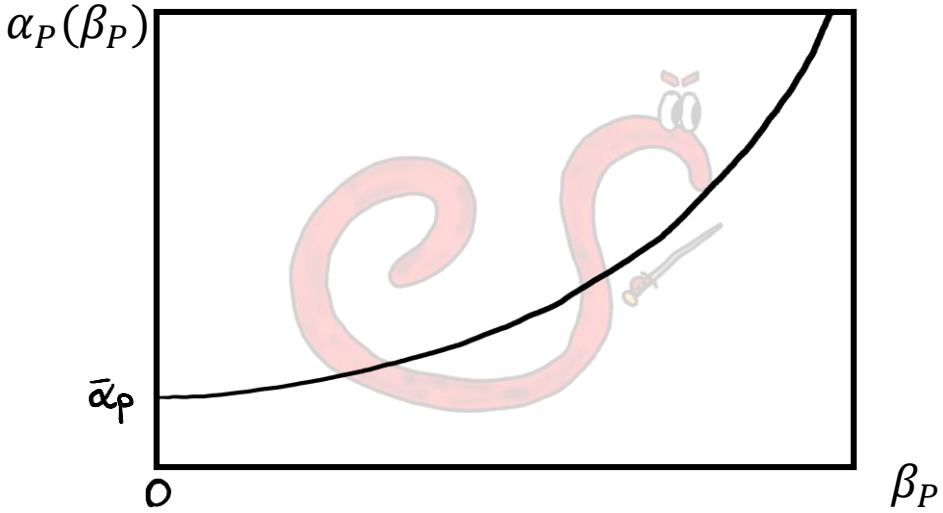

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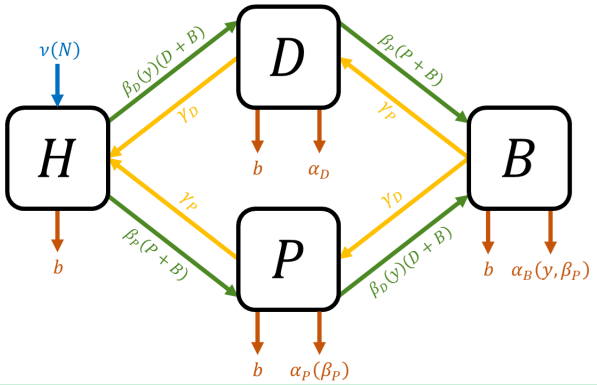

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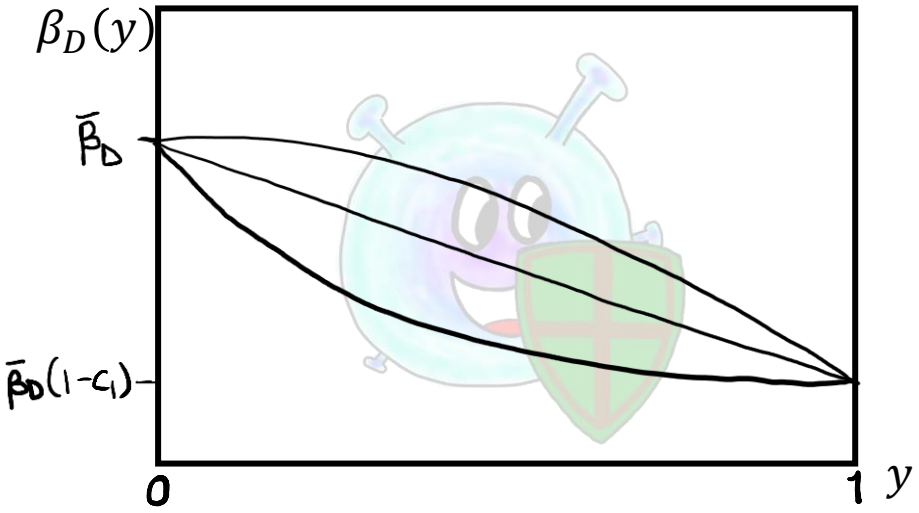

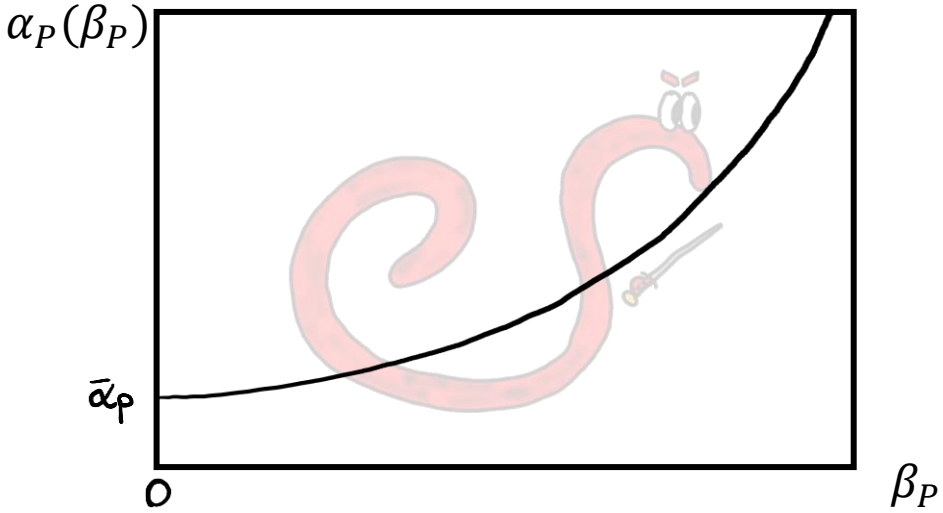

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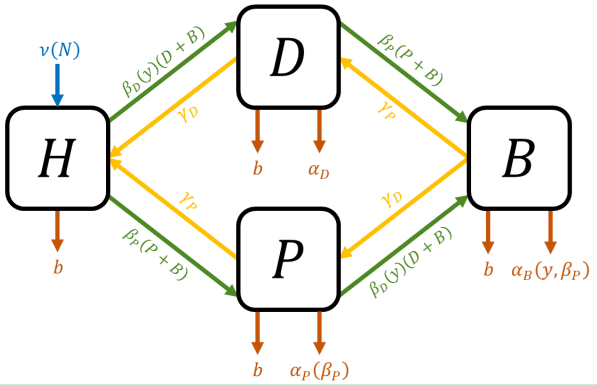

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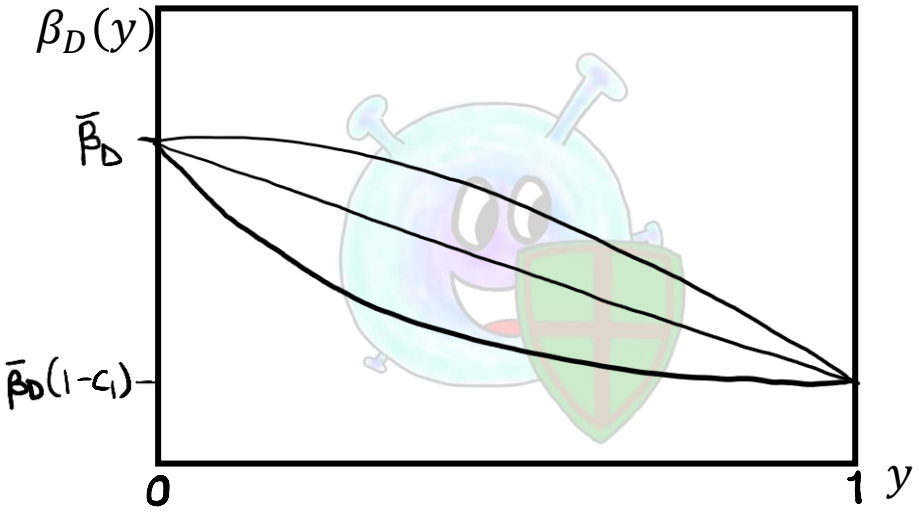

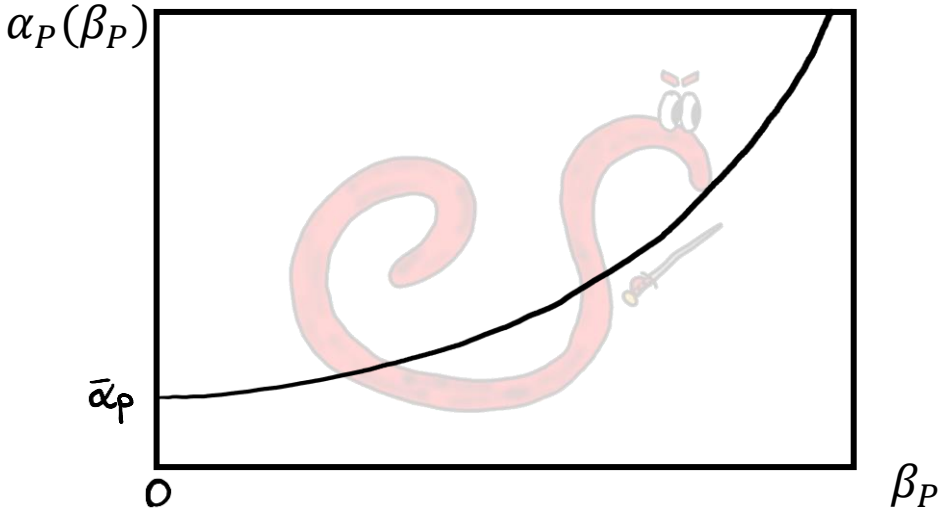

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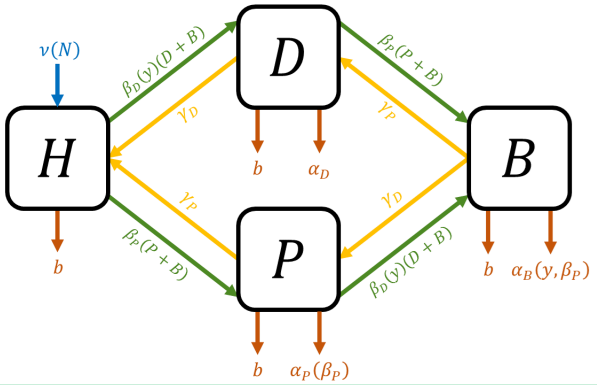

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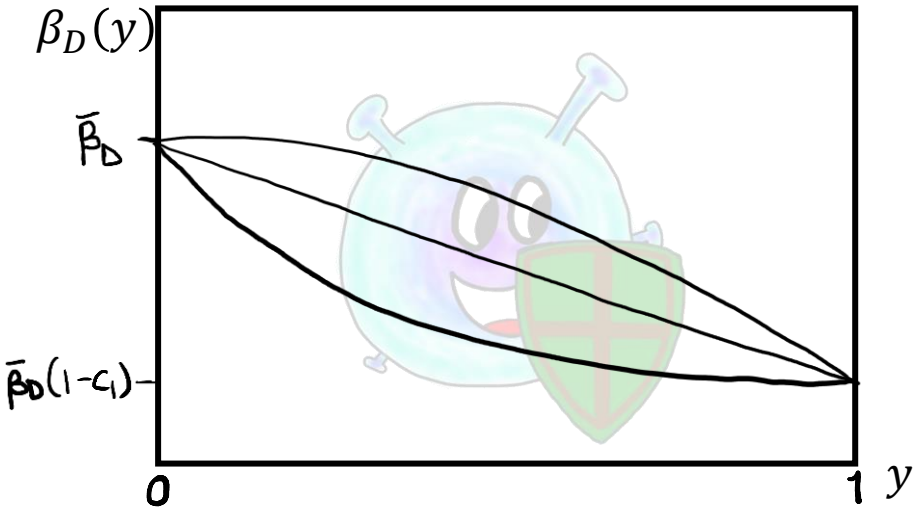

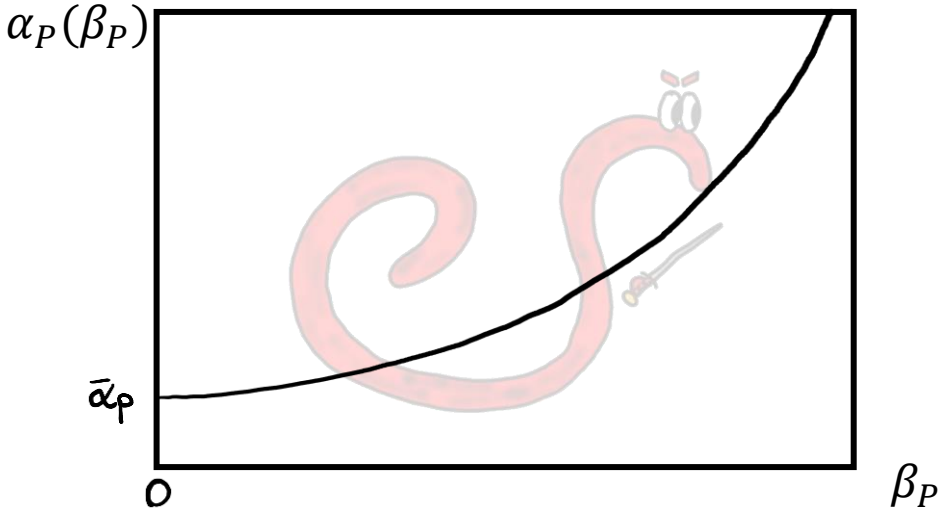

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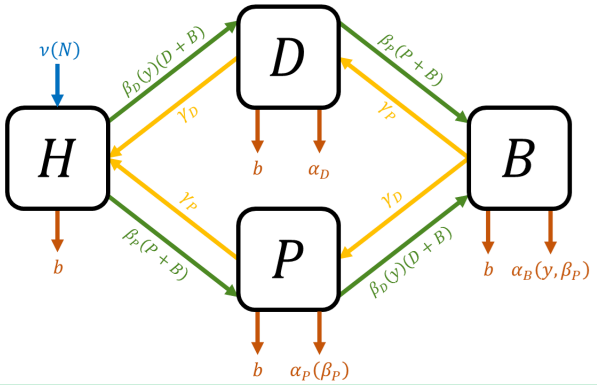

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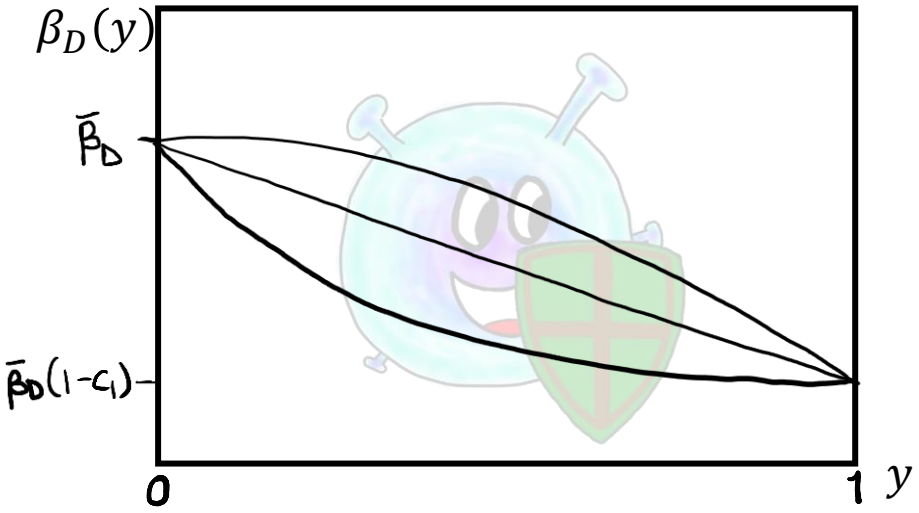

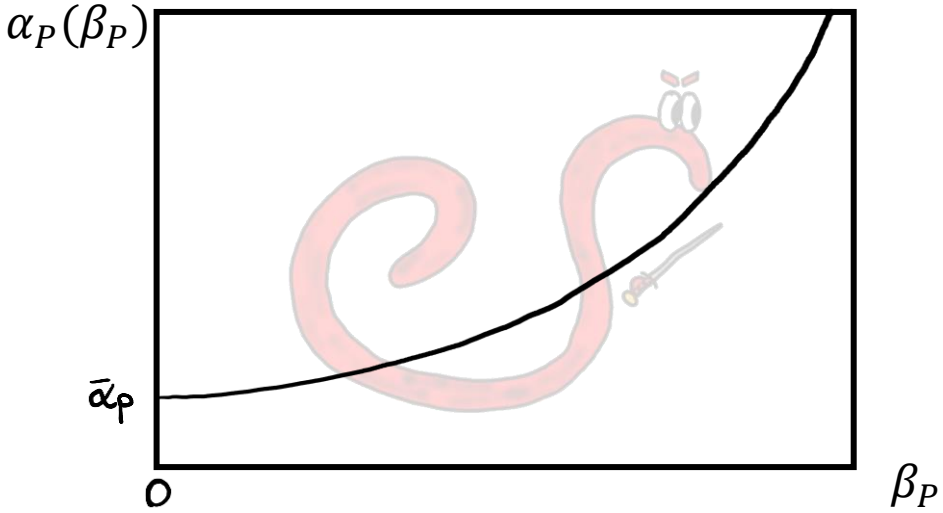

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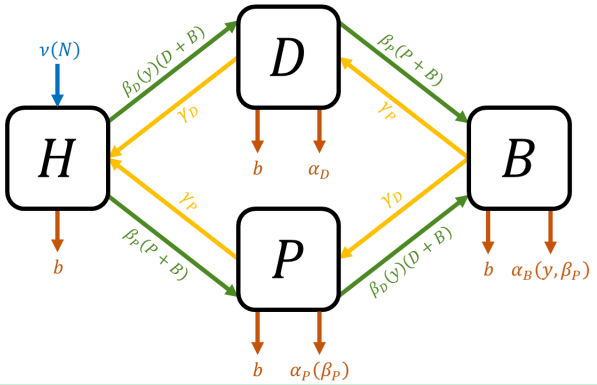

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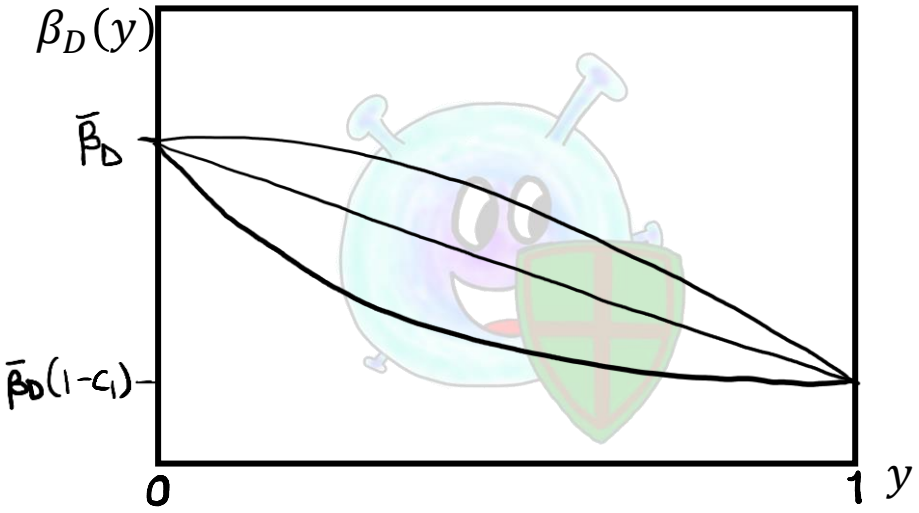

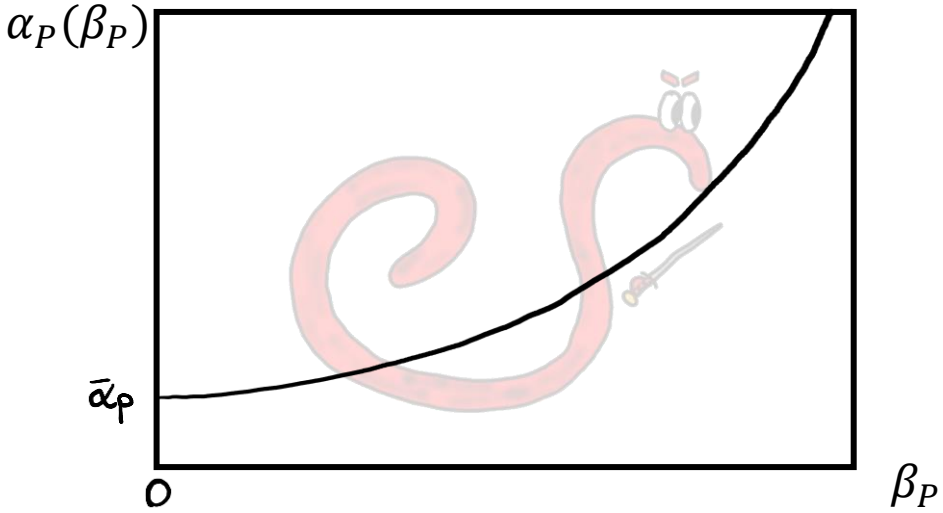

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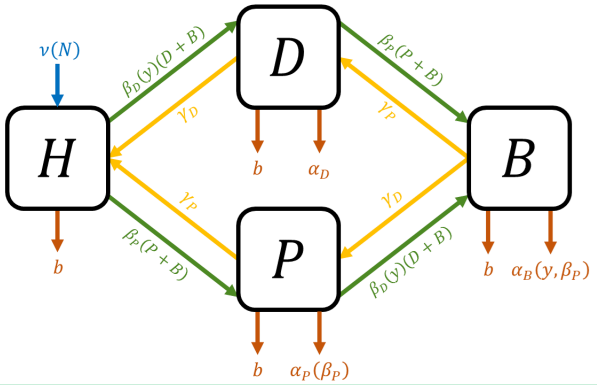

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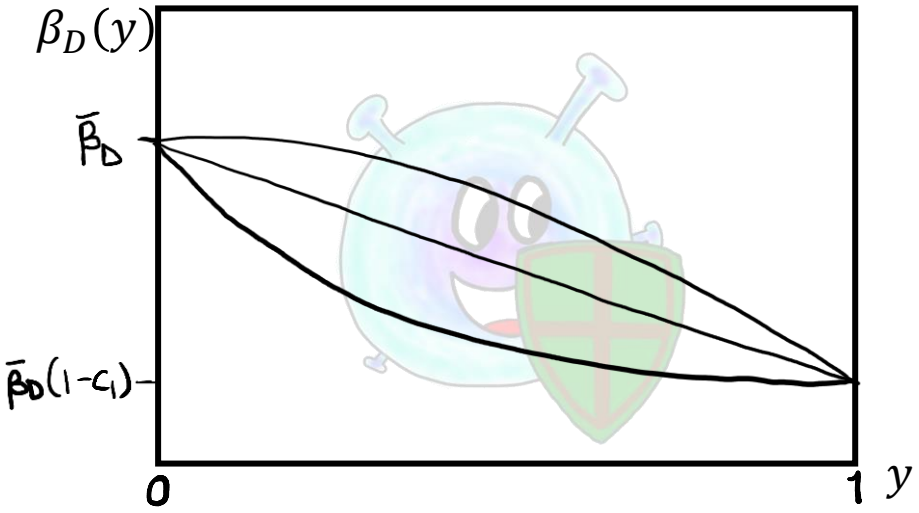

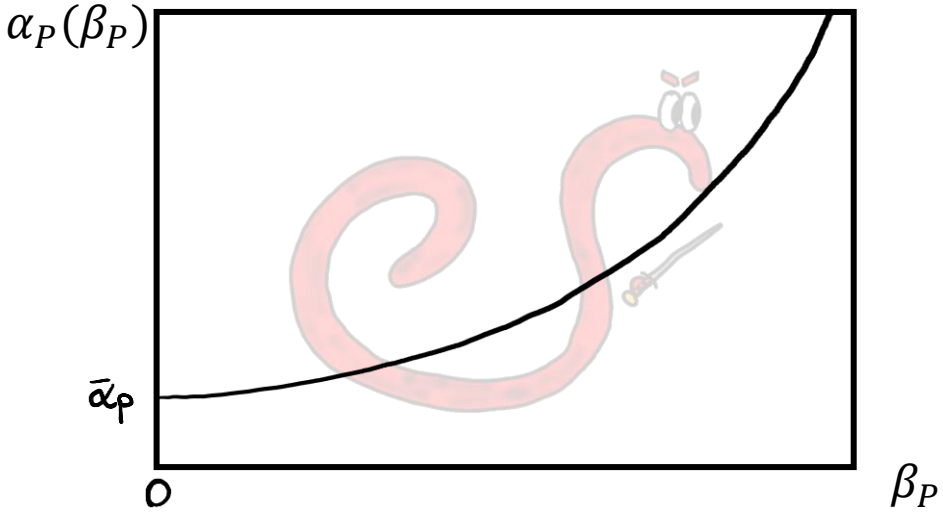

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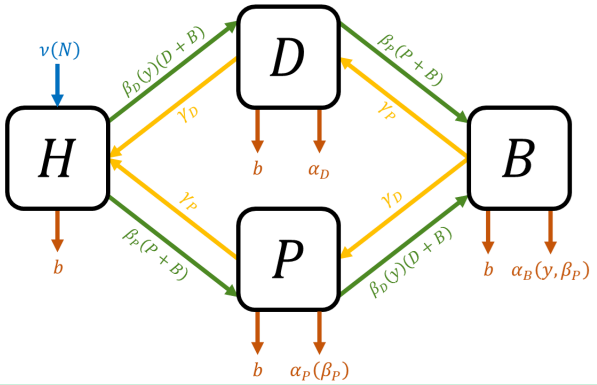

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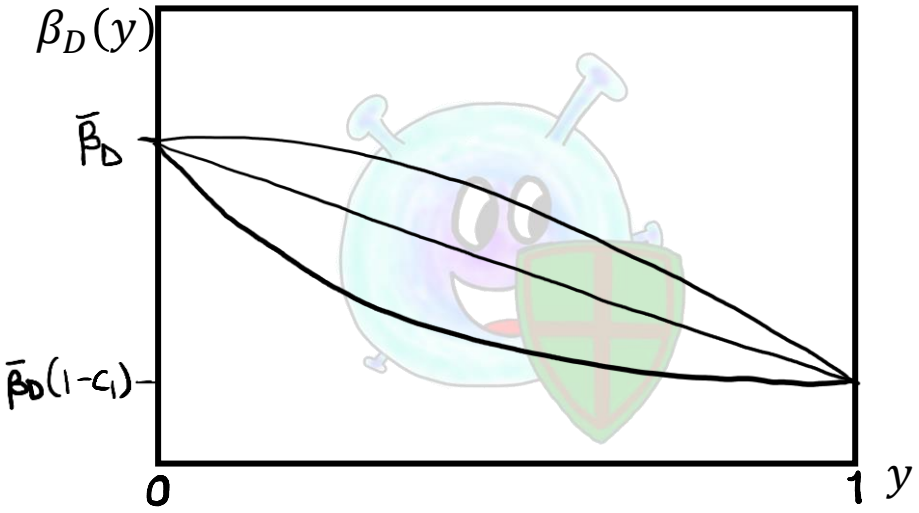

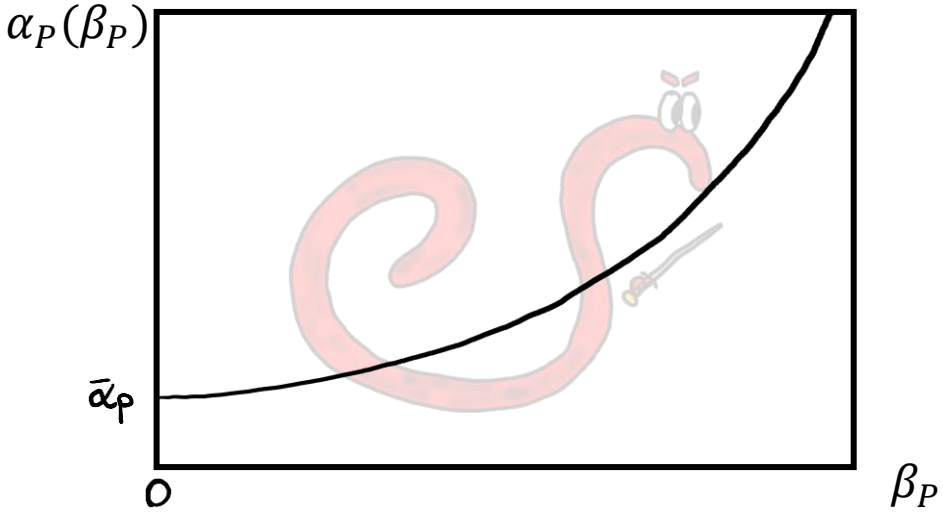

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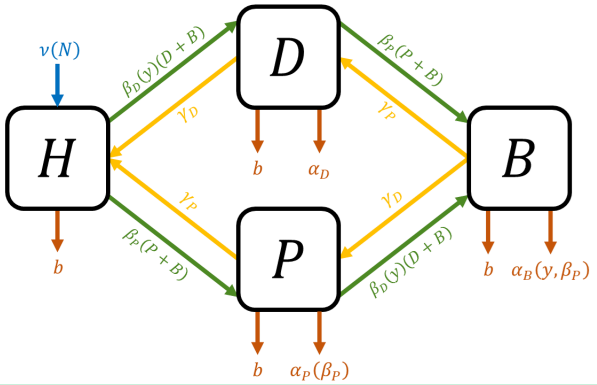

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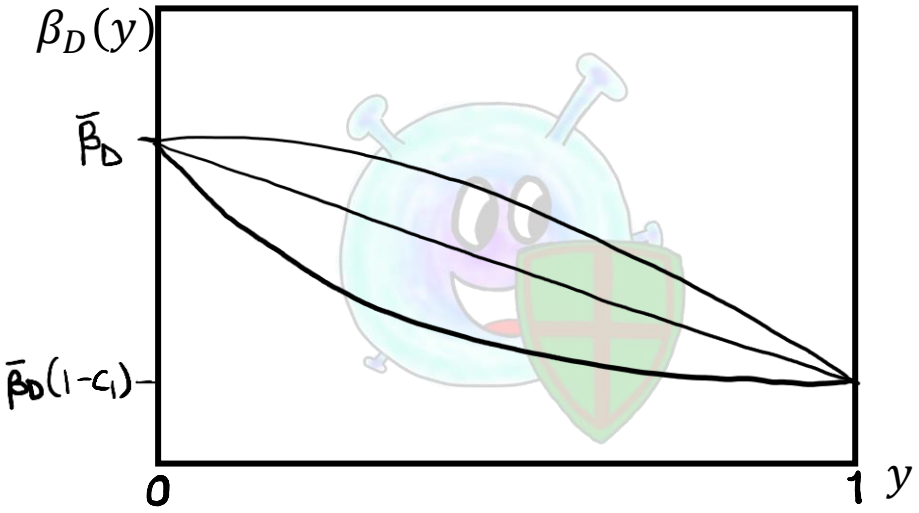
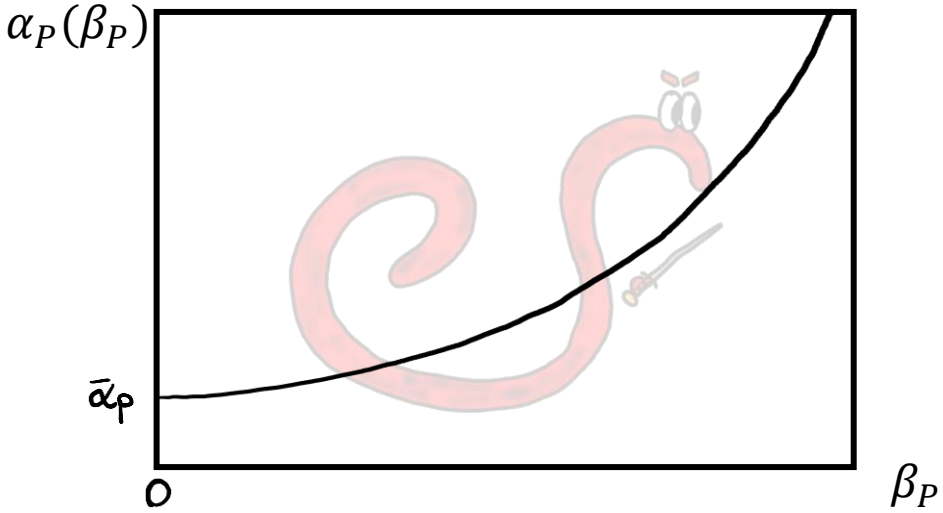
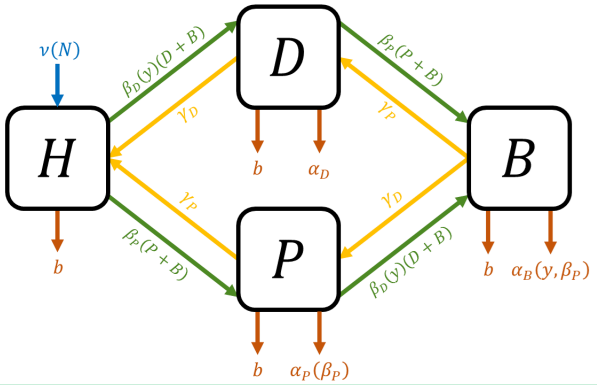




Coevolution: Evolutionary dynamics



Evolving parameters

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$y \in (0,1)$

Transmissibility
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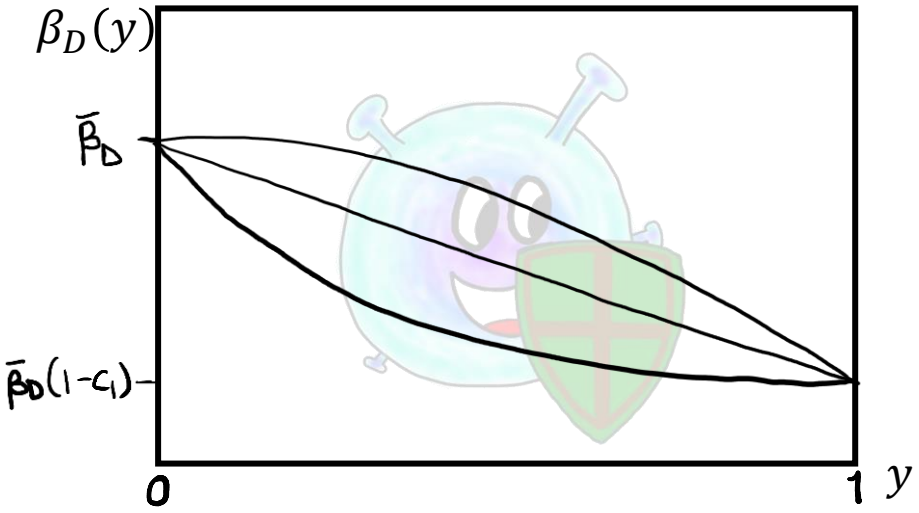

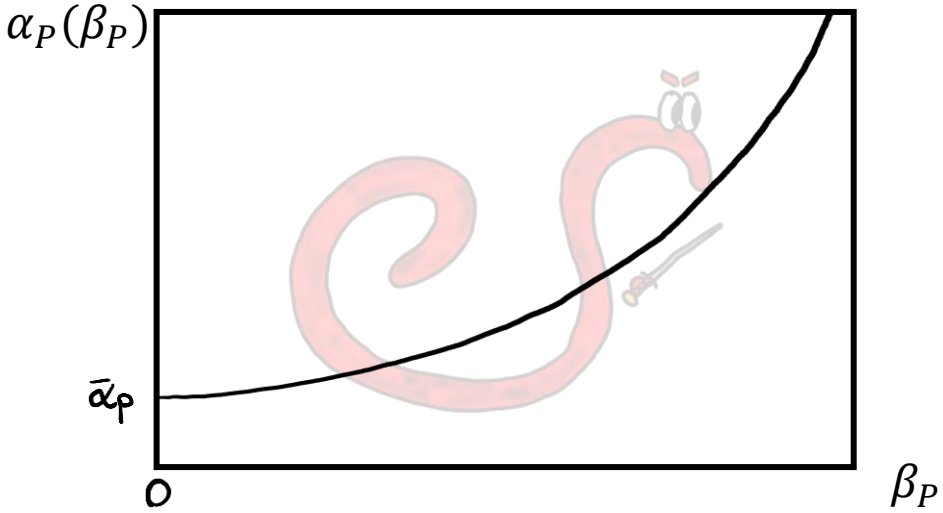

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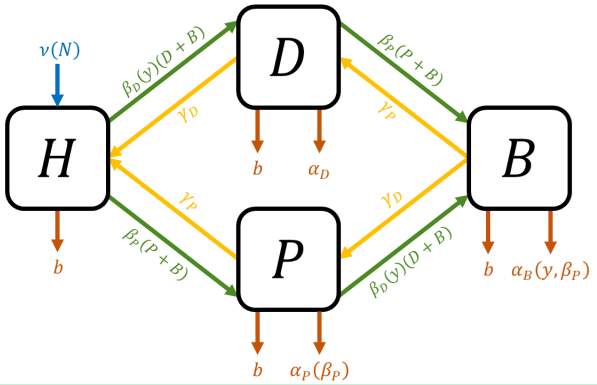

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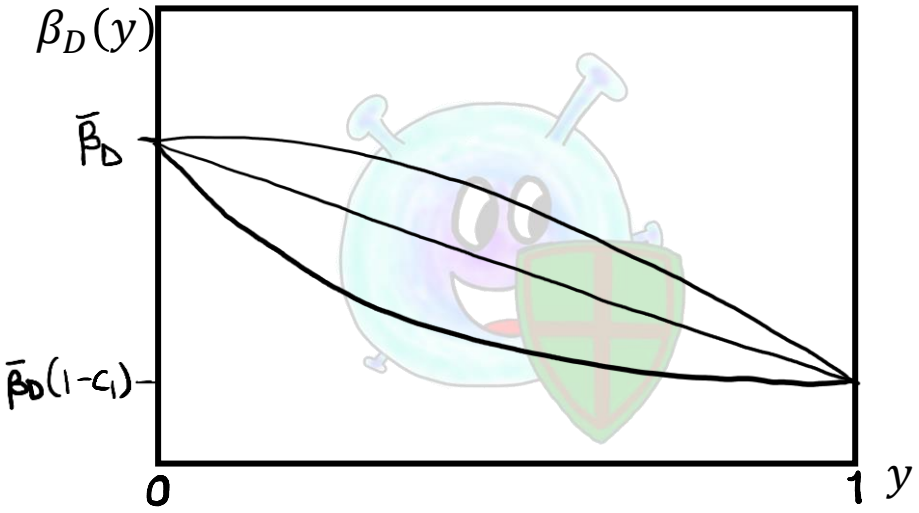

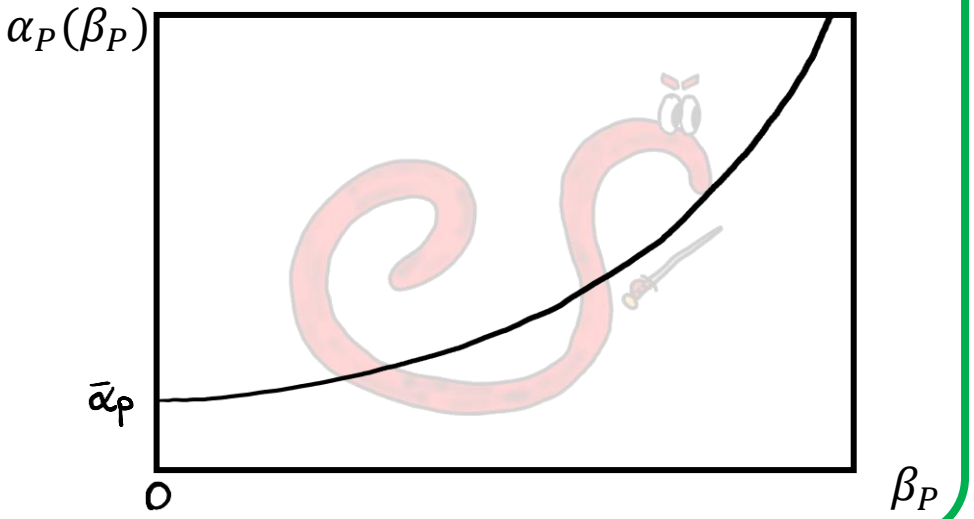

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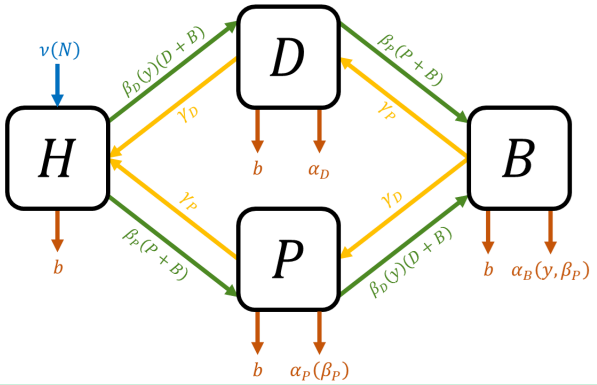

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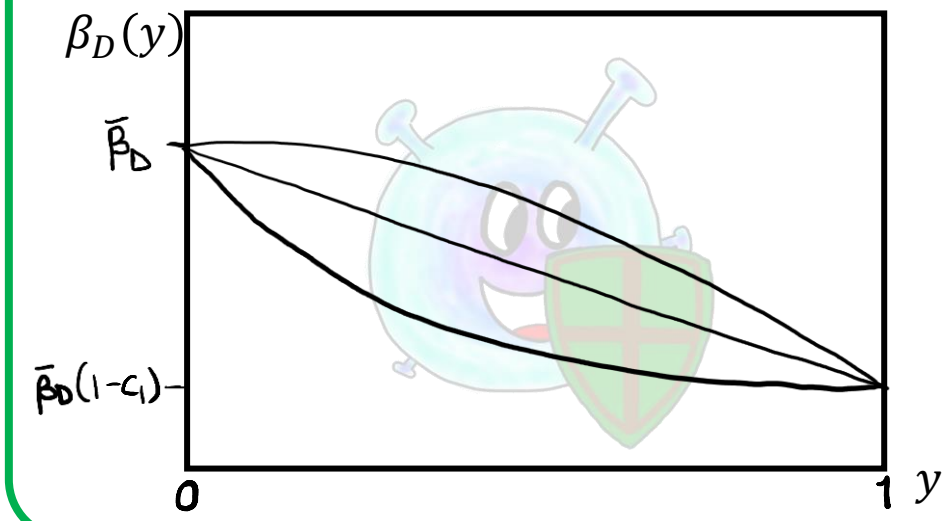
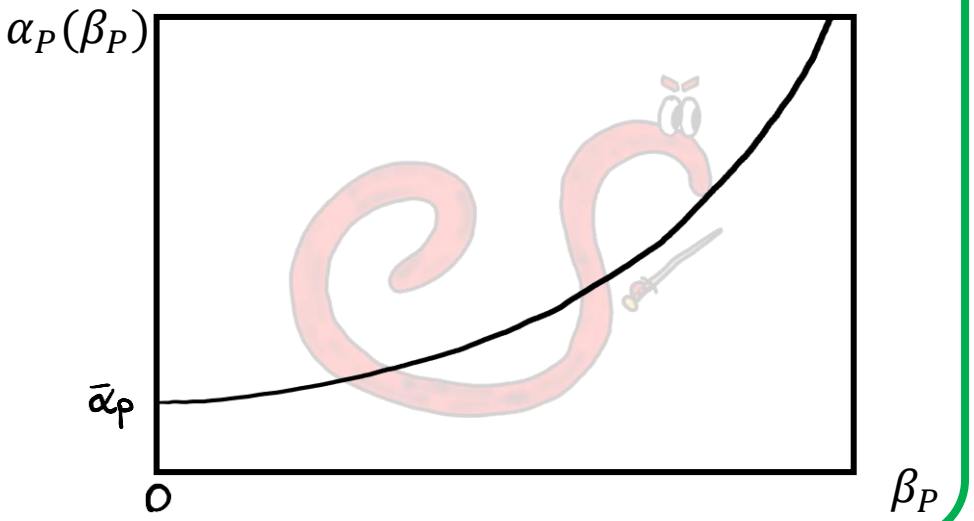
Mortality tolerance

Trade-offs





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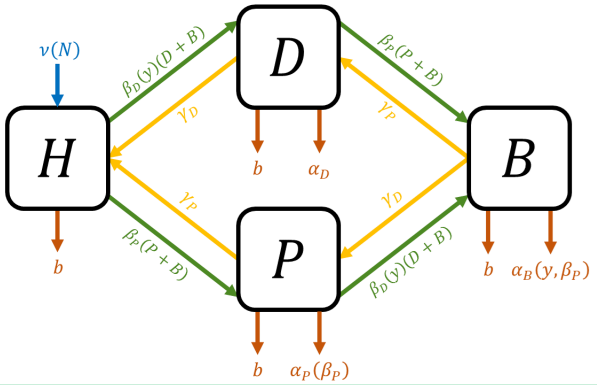

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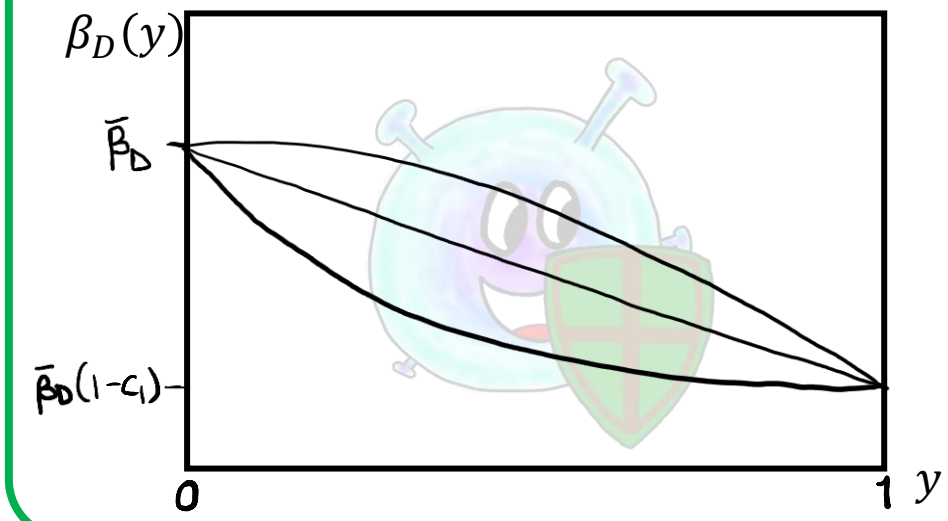

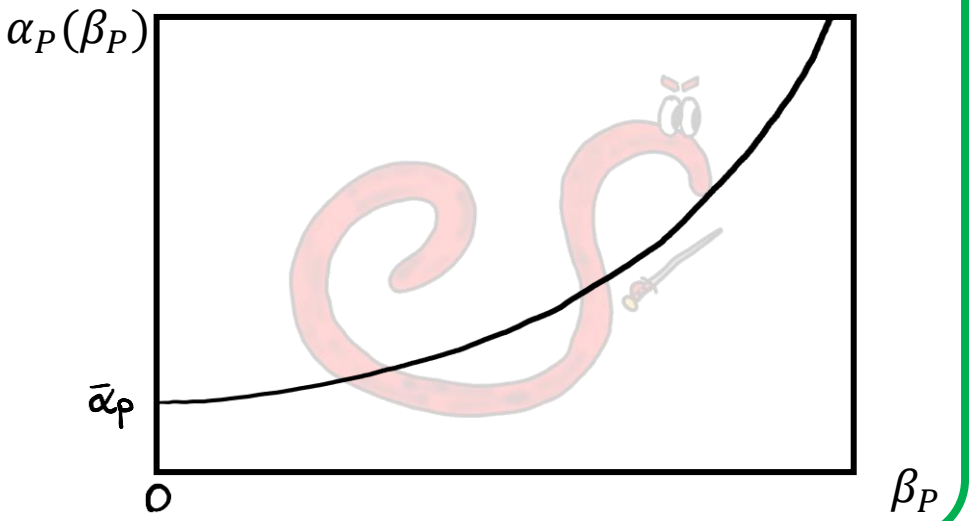

Protection

Mortality tolerance

$$\alpha_B(y,\beta_P) = \alpha_D + (1-y)\alpha_P(\beta_P)$$

Outline

Background

Defence: Tolerance

Results

Defence: Resistance

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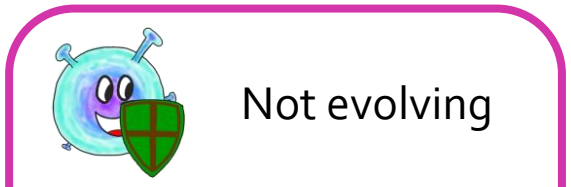

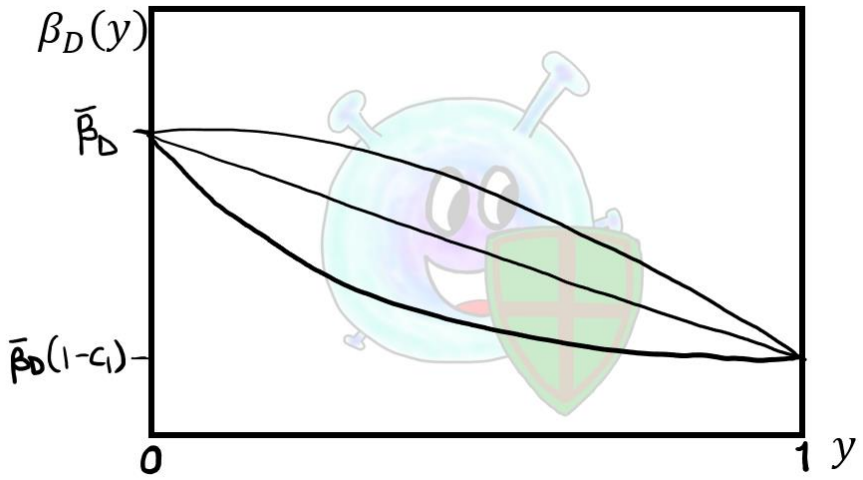

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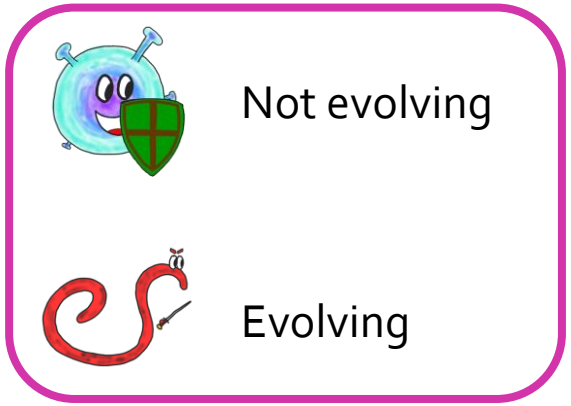

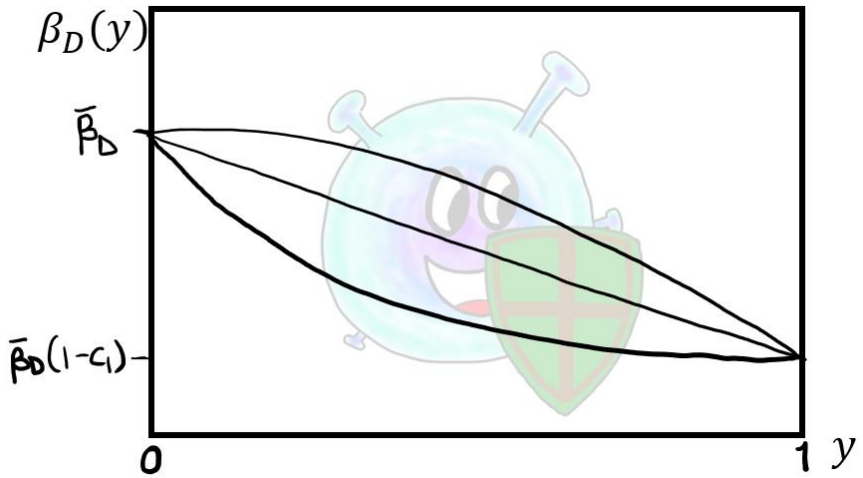

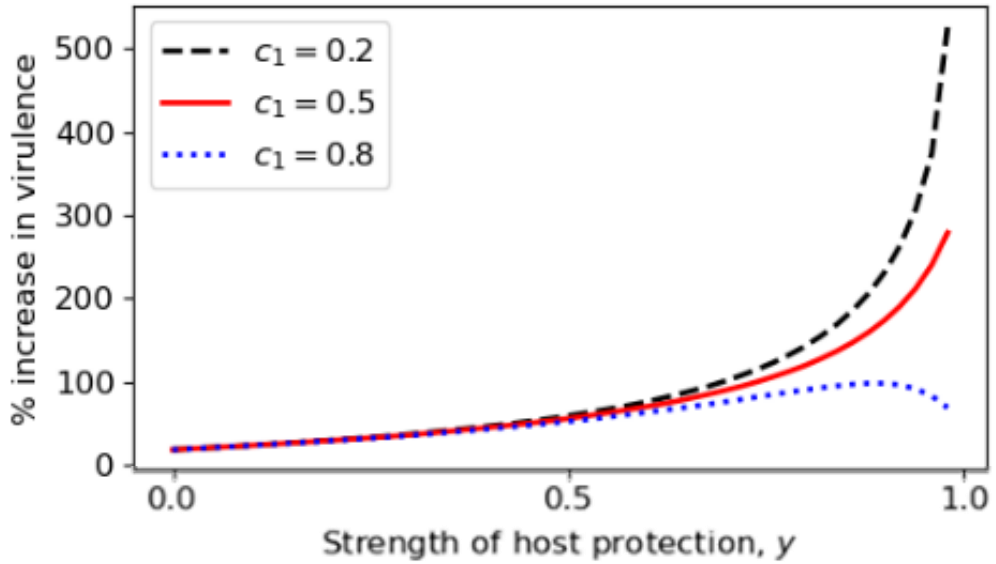

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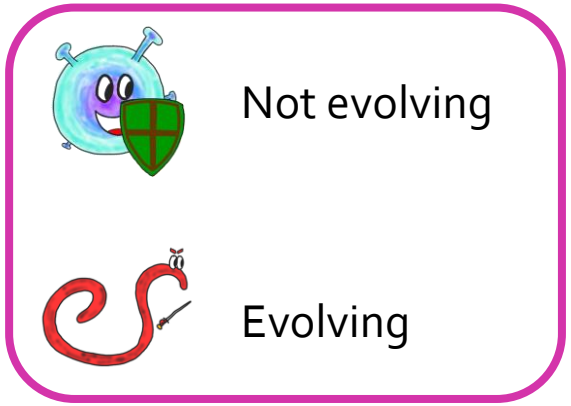

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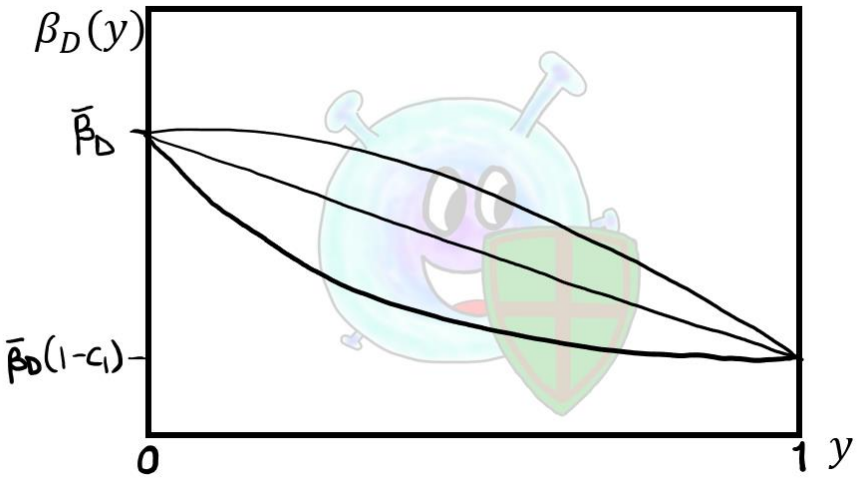

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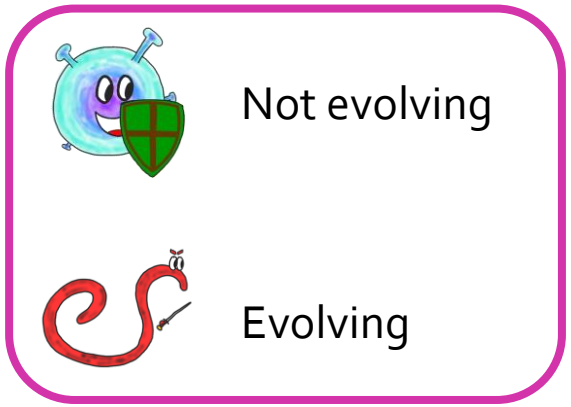

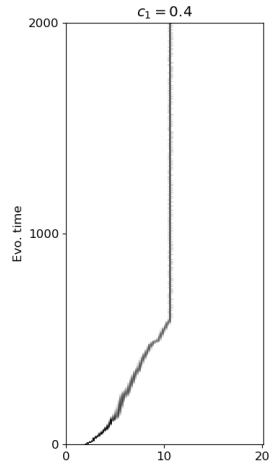

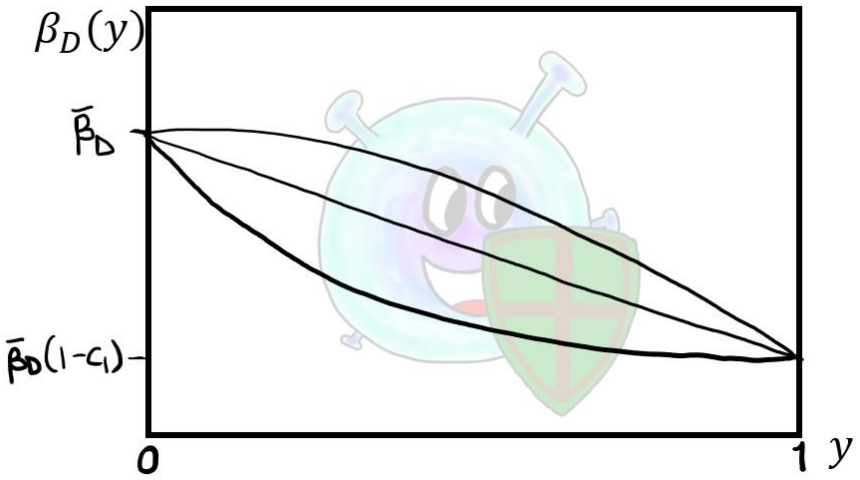

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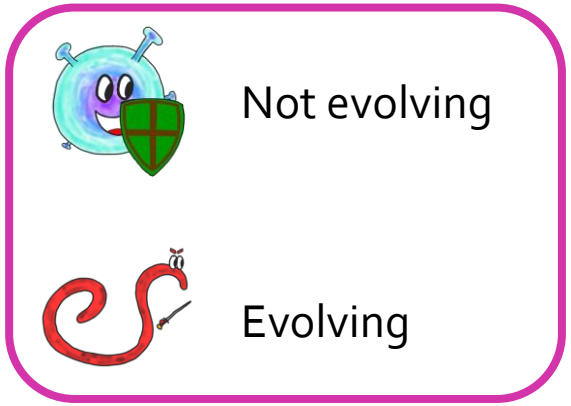

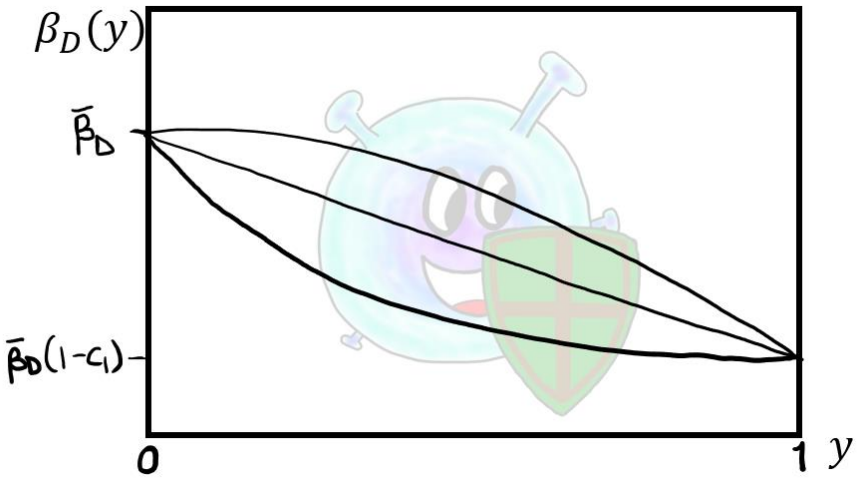

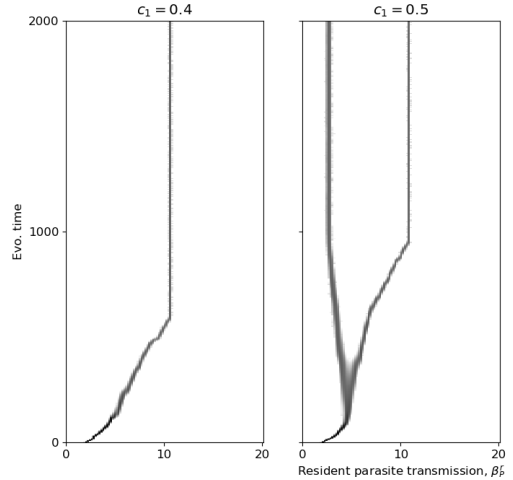

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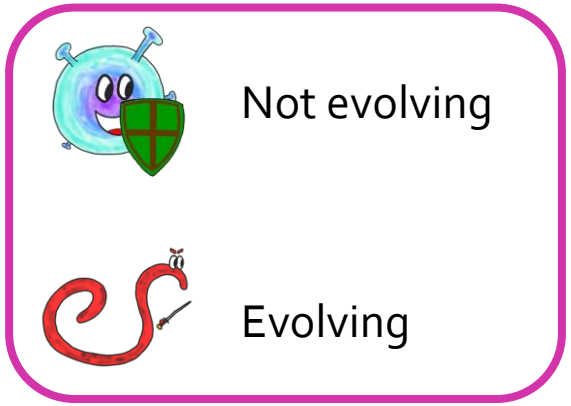

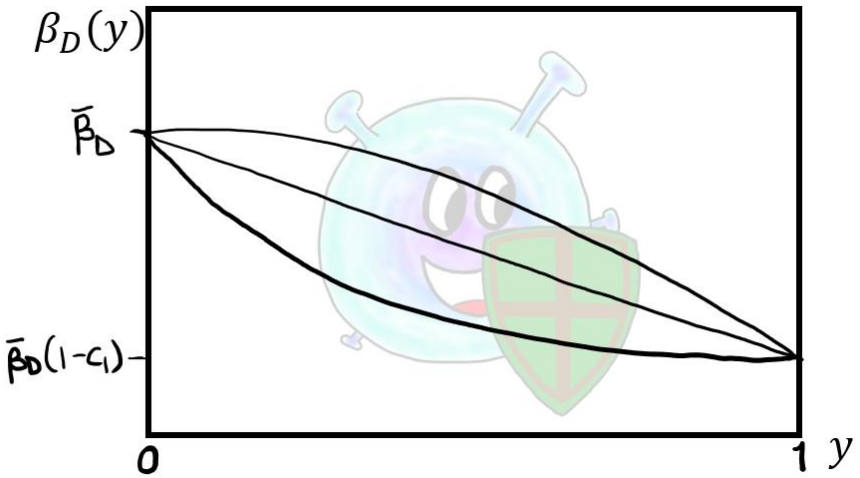

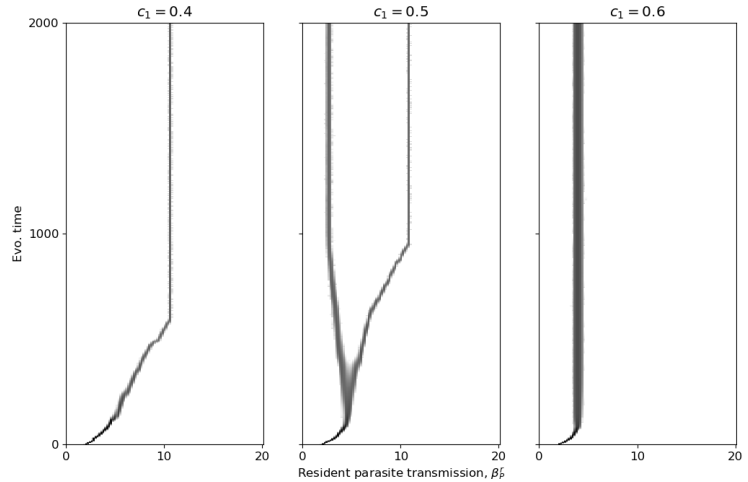

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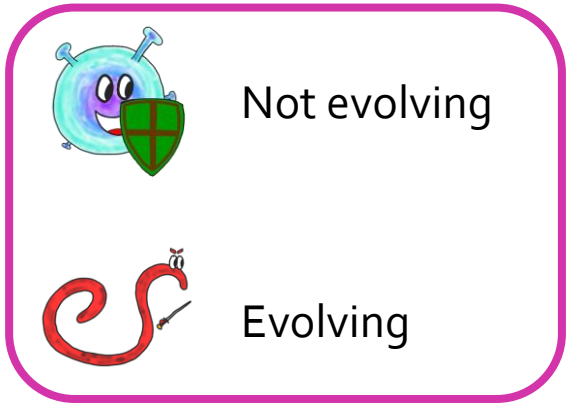

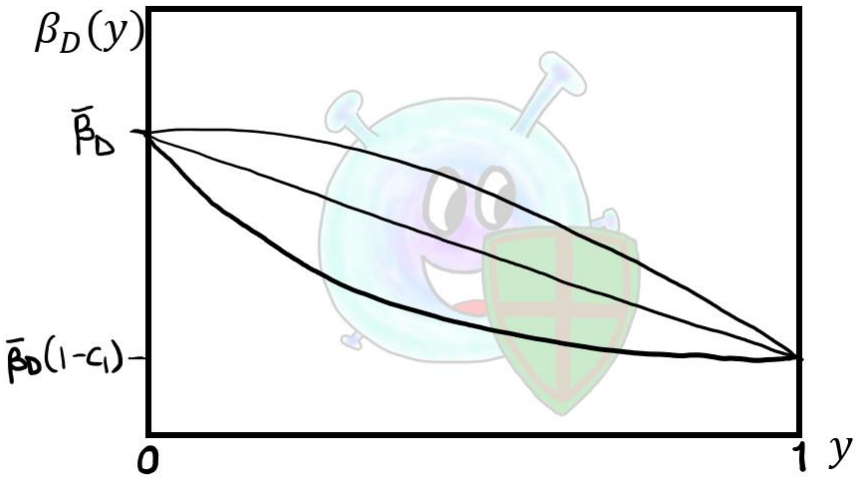

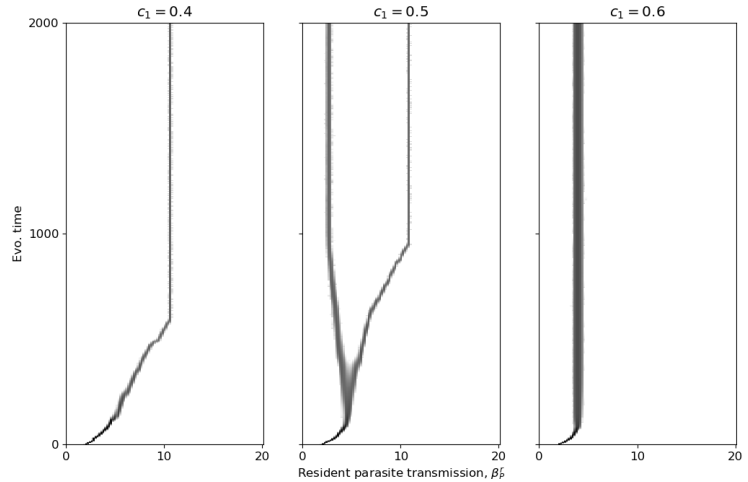

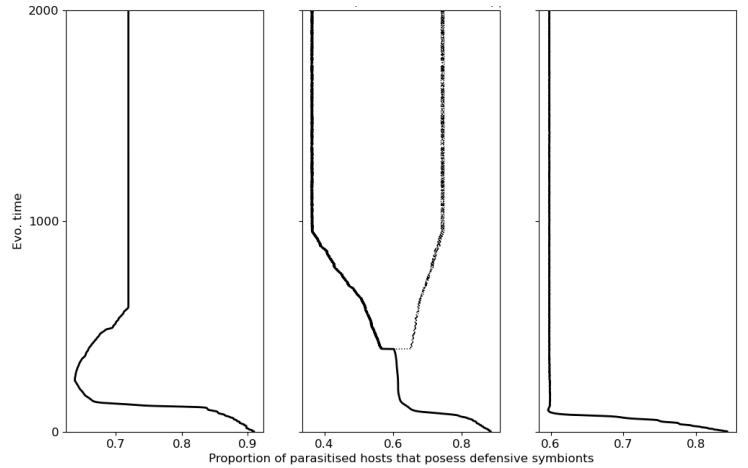

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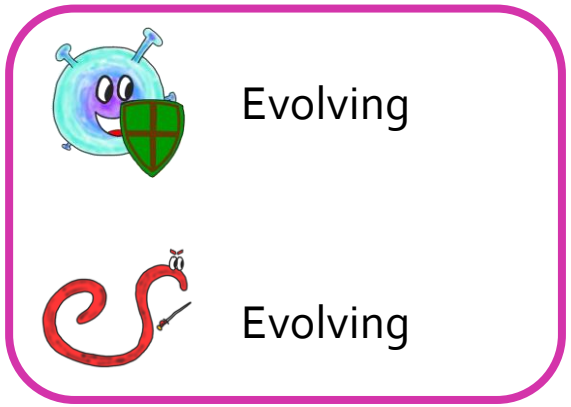

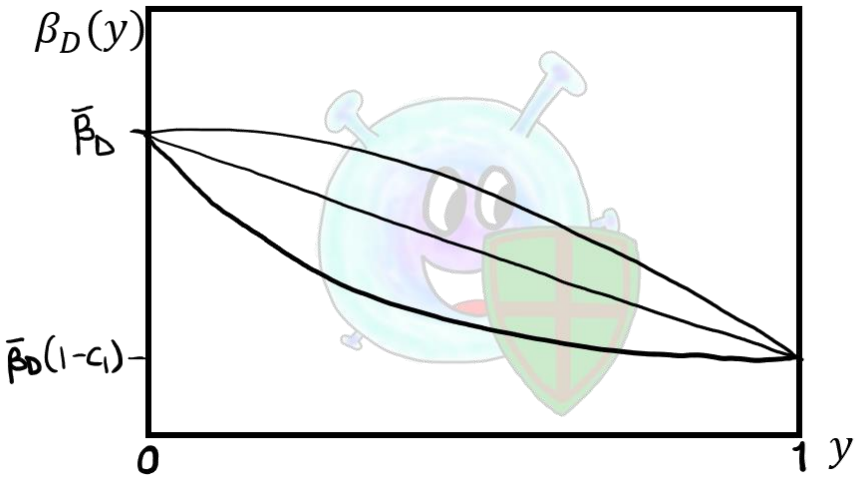

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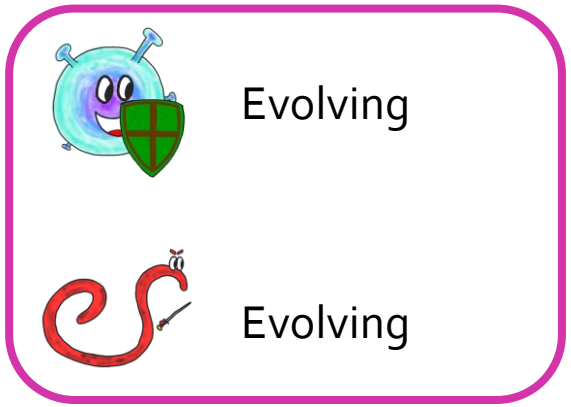

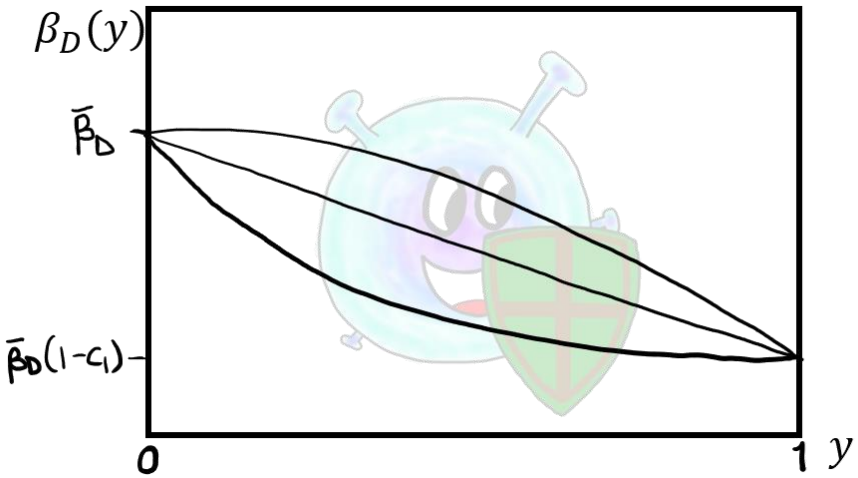

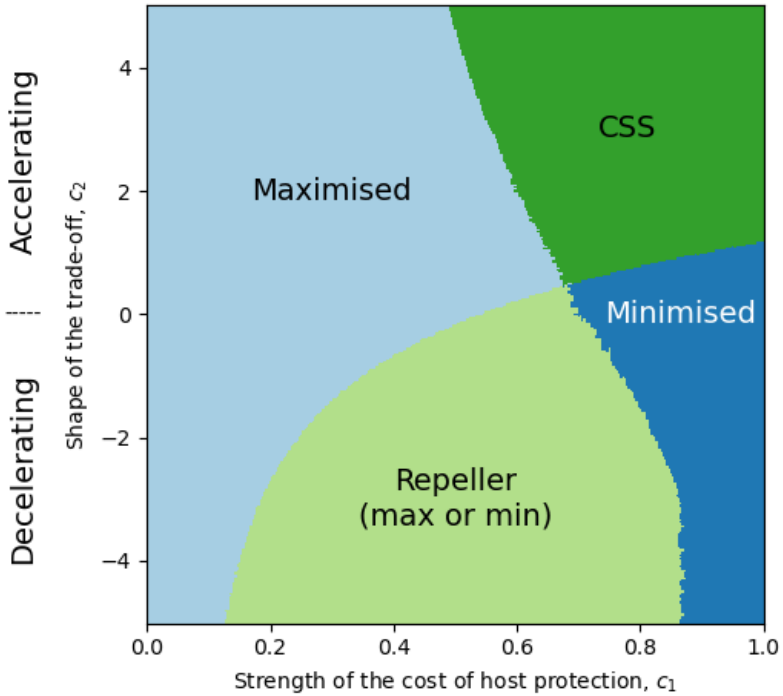

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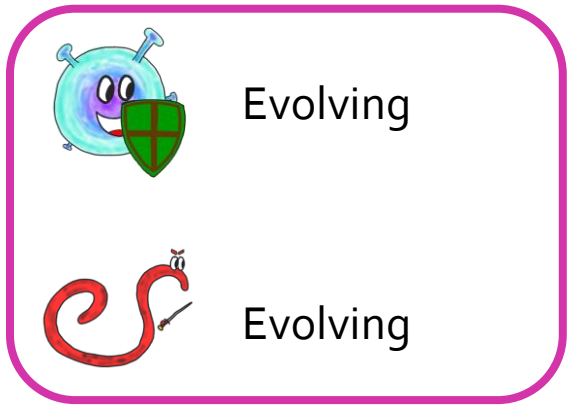

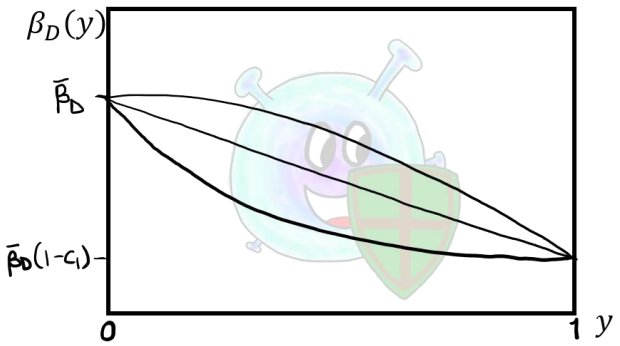

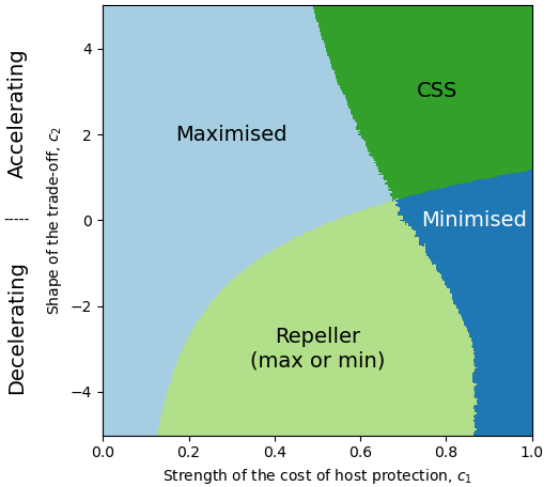

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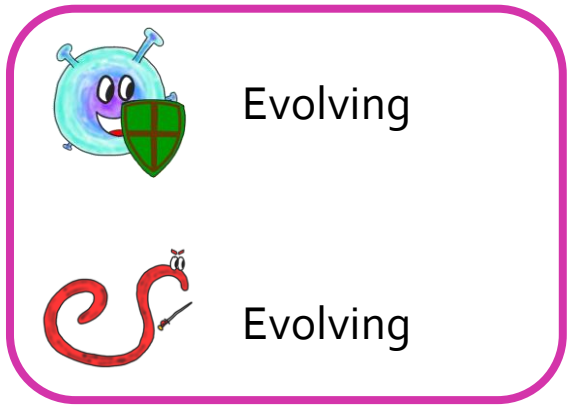

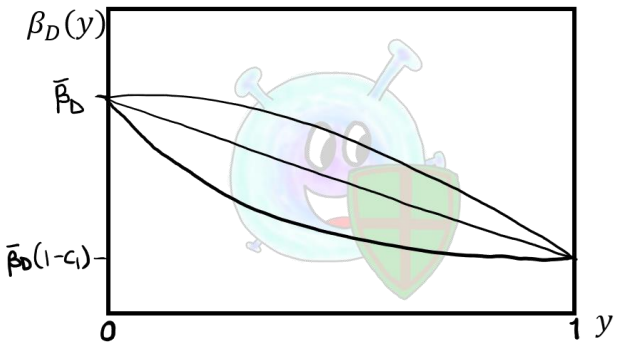

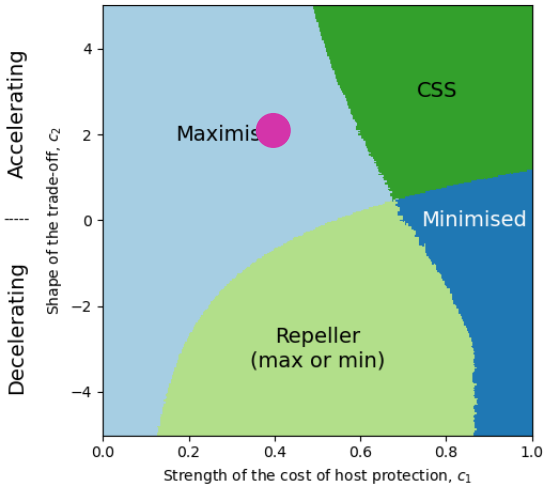

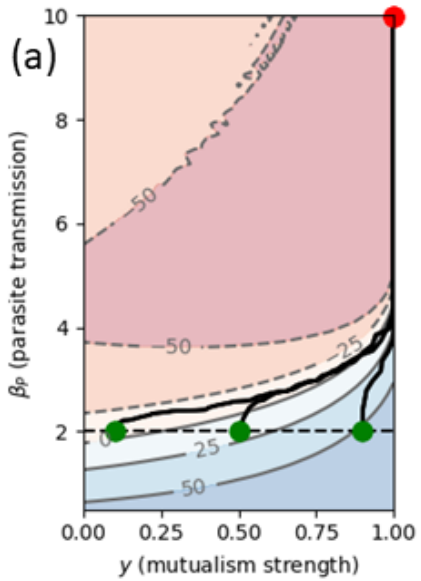

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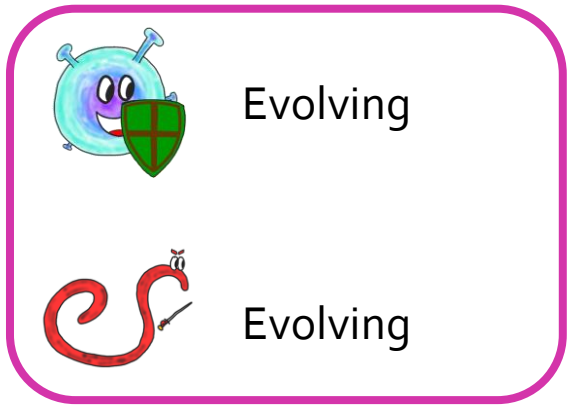

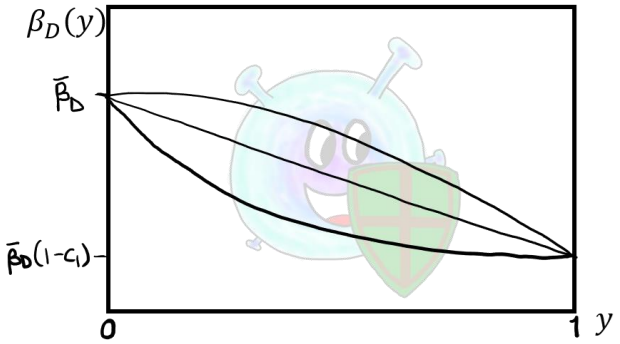

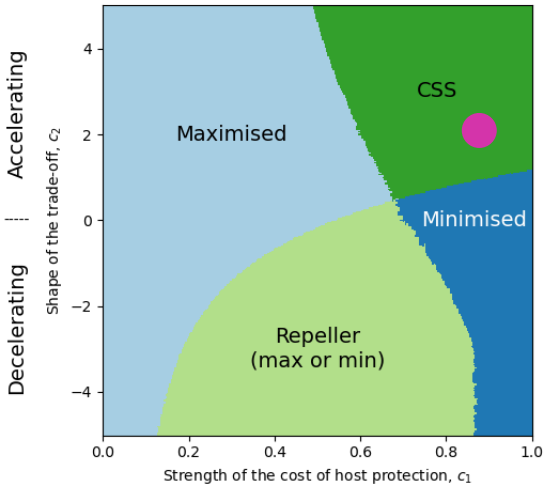

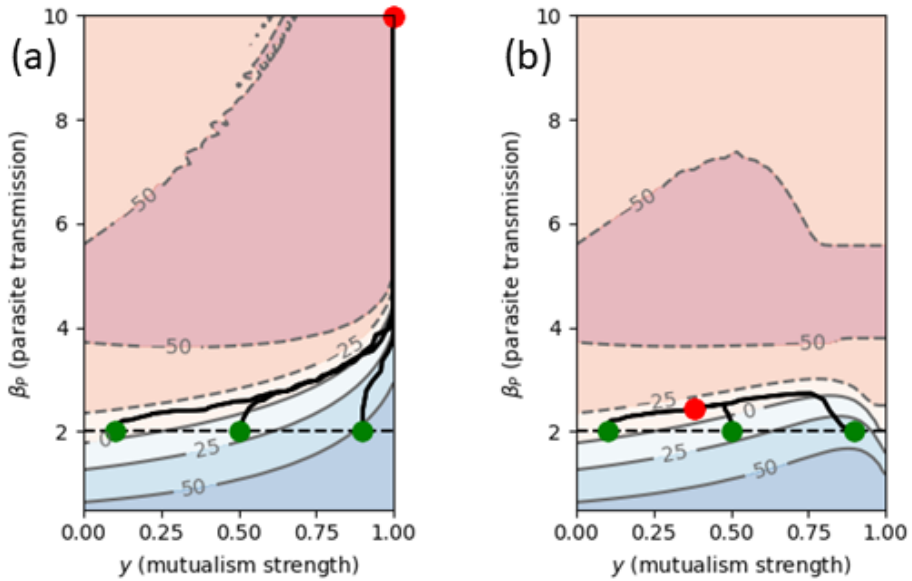

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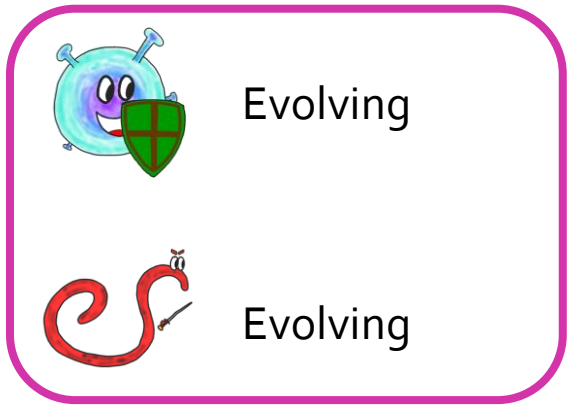

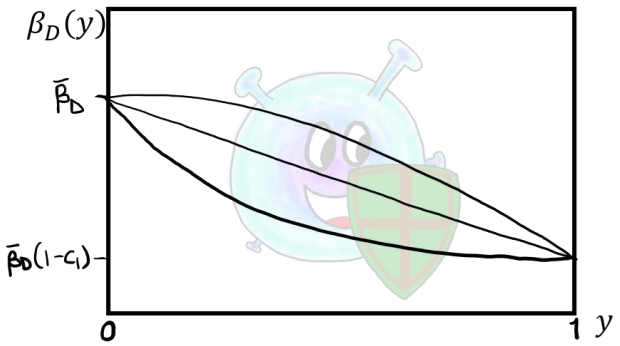

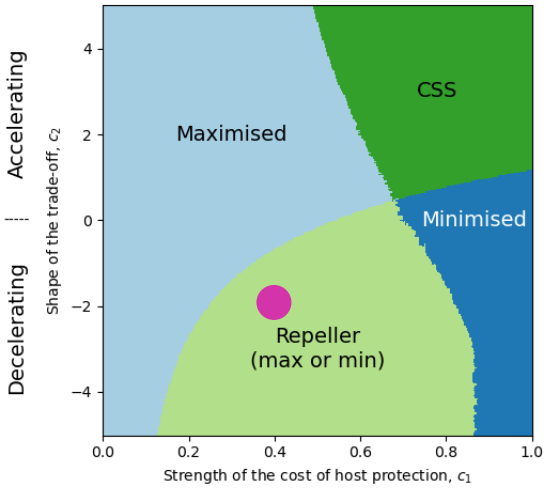

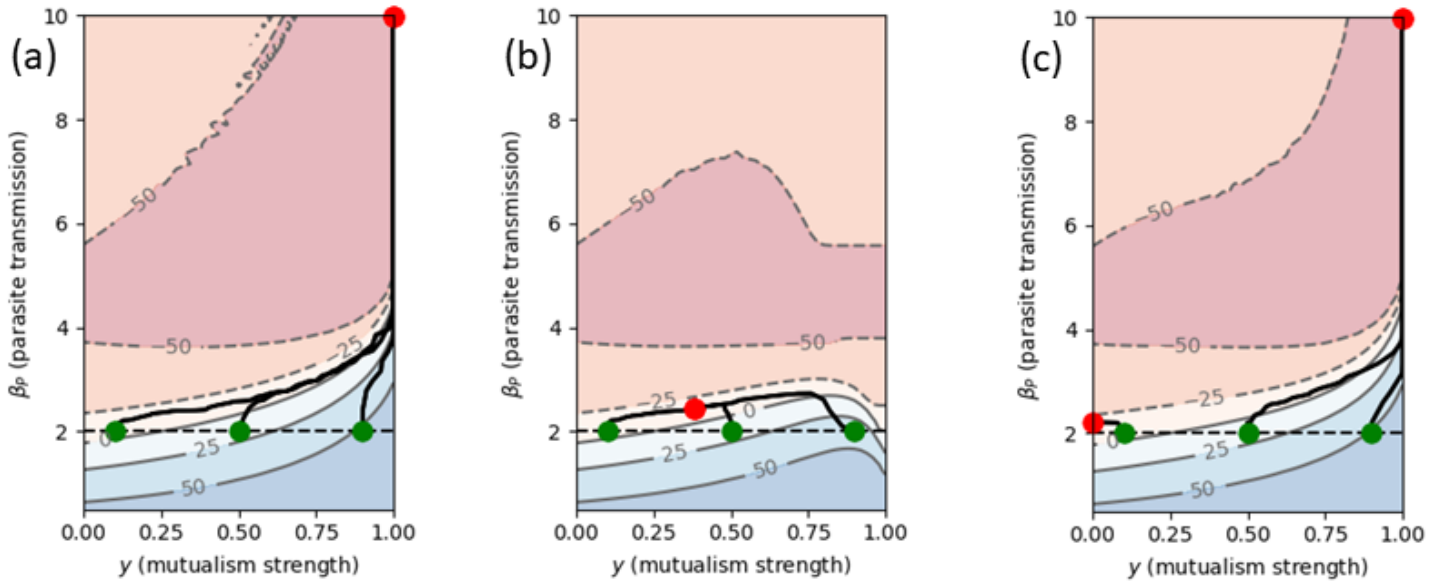

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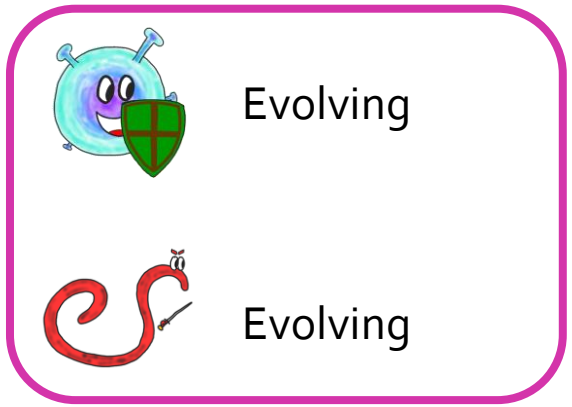
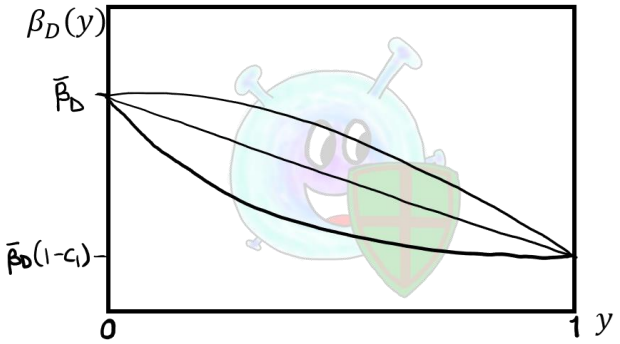
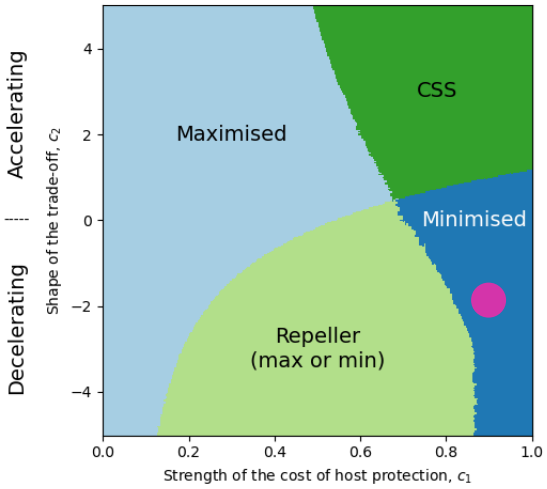
1. Defensive symbionts that confer tolerance always select for higher virulence.

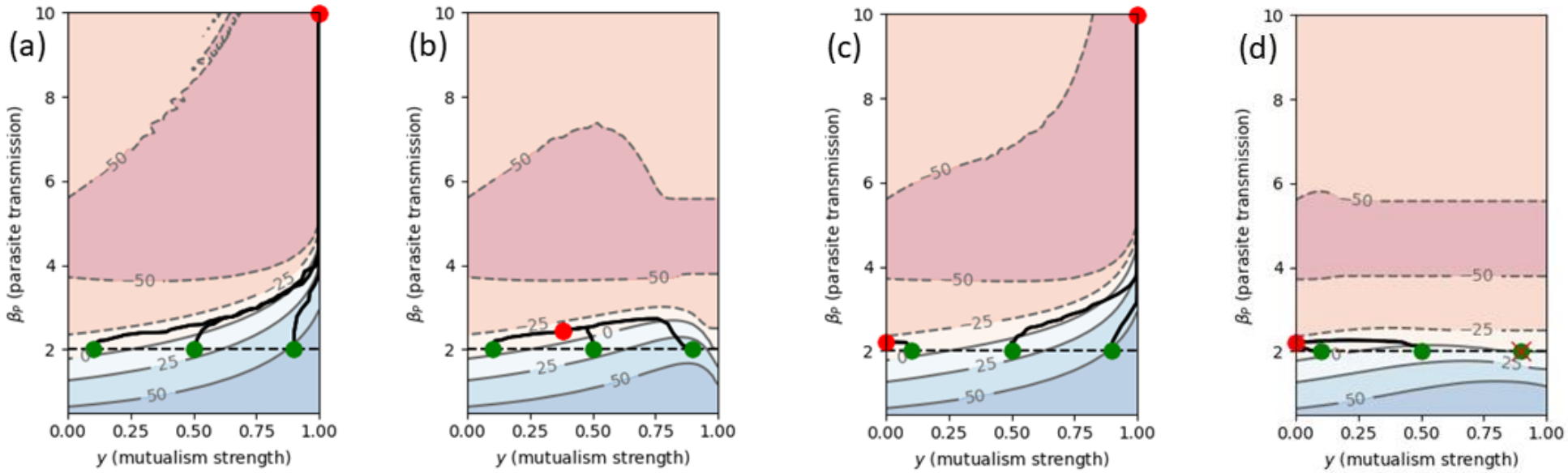
2. Defensive symbionts can drive parasite diversity.

3. Symbiont-parasite coevolution will be detrimental to the host population.









Outline

Background

Defence: Tolerance

Results

Defence: Resistance

Outline

Defence: Resistance

Other protection types

Tolerance

Tolerance shields the host from the harmful effects of the parasite.

Two forms of tolerance – "Fecundity tolerance" and "mortality tolerance".

Fecundity tolerance prevents new births with the parasite, mortality tolerance reduces virulence.

Other protection types

Resistance

Resistance protection is all about making the host more resistant to infection

This may take the form of a reduction in transmission when harbouring the defensive symbiont compared to without

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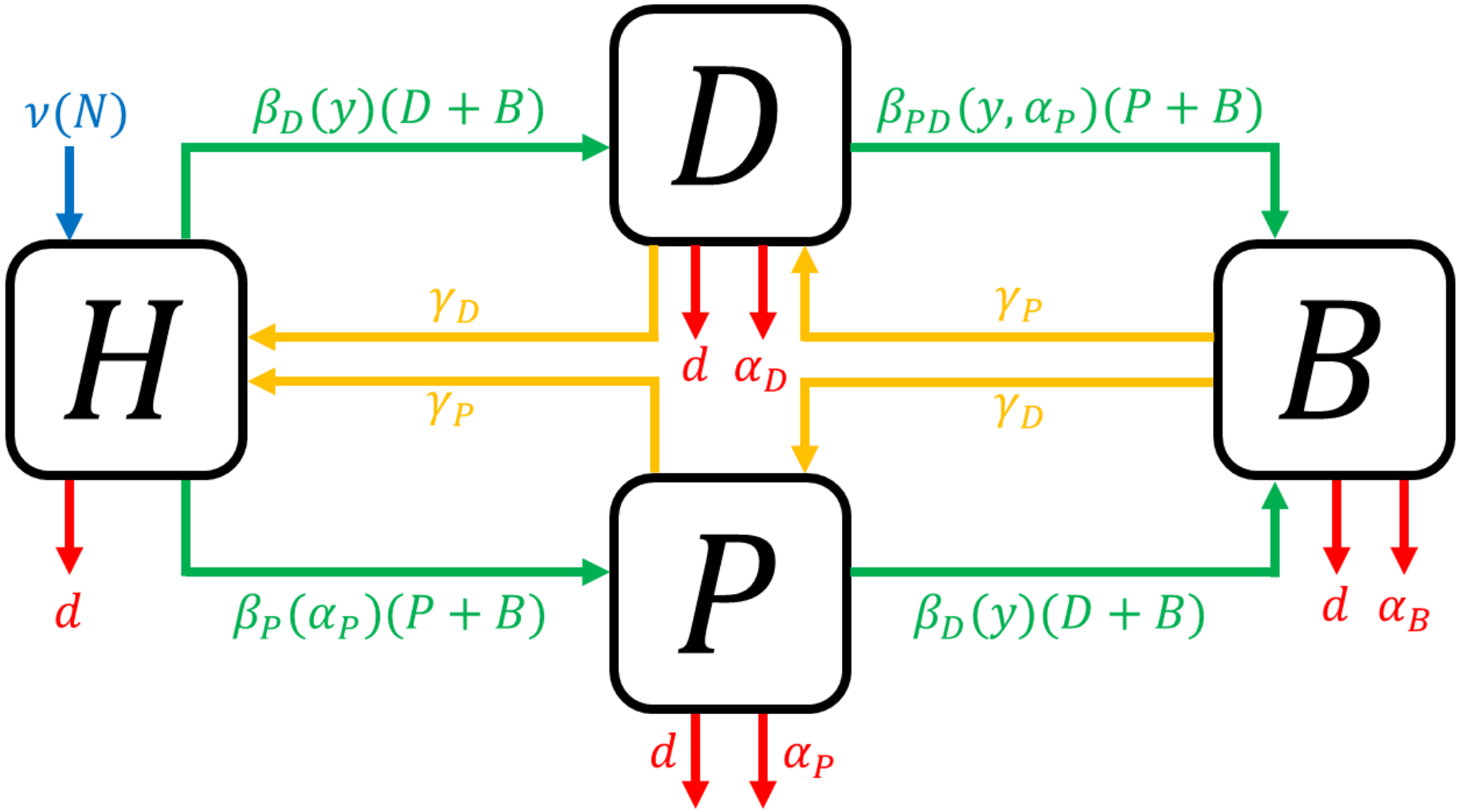

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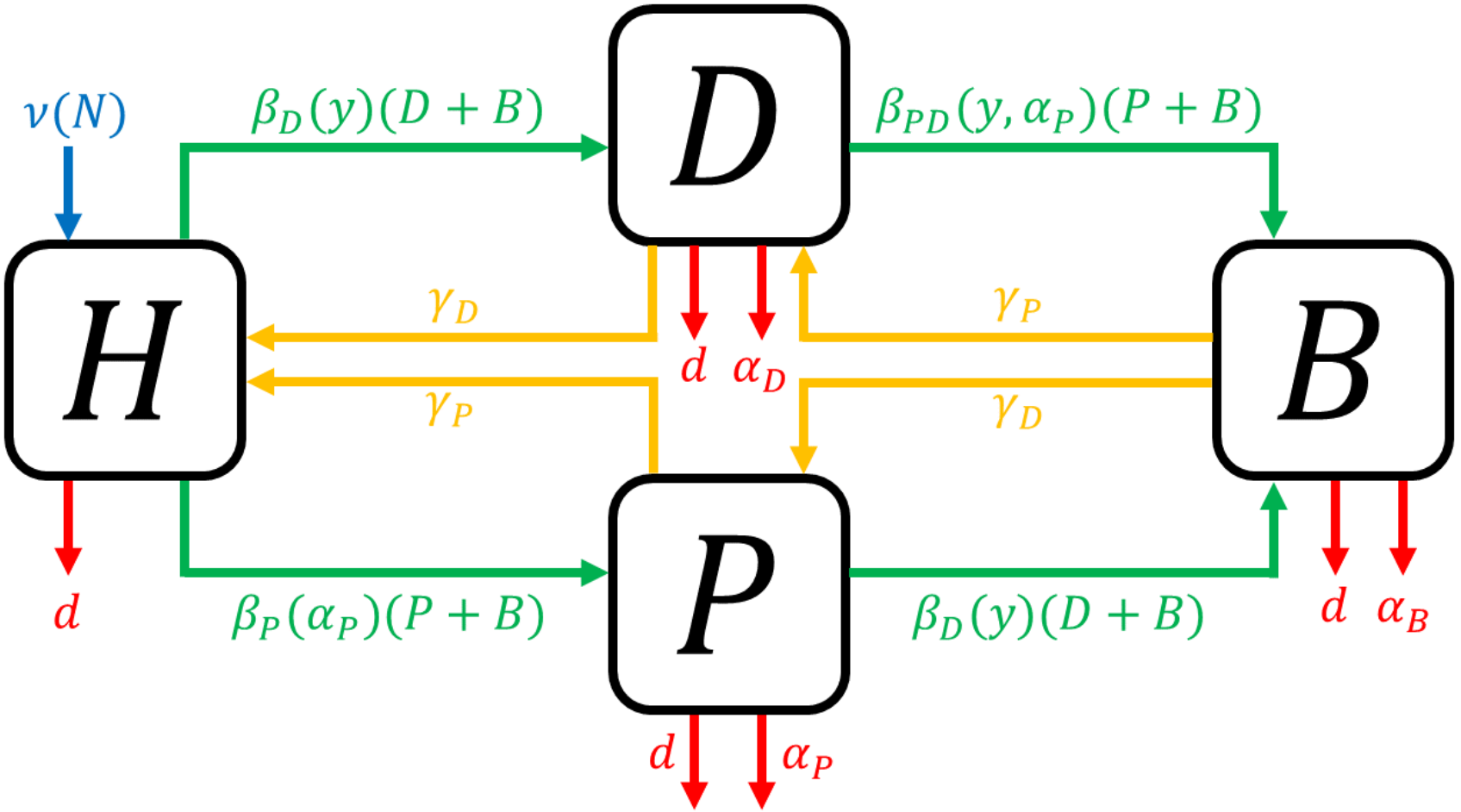

Differences from tolerance:

Combined virulence, α_B, is now constant

Transmission for D decreased by protection

Other protection types

1. Defensive symbionts that confer tolerance always select for higher virulence.

2. Defensive symbionts can drive parasite diversity.

3. Symbiont-parasite coevolution will be detrimental to the host population.

Other protection types

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1. Defensive symbionts that confer **resistance** always select for higher virulence.

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Other protection types

1. Defensive symbionts that confer **resistance** always select for higher virulence.

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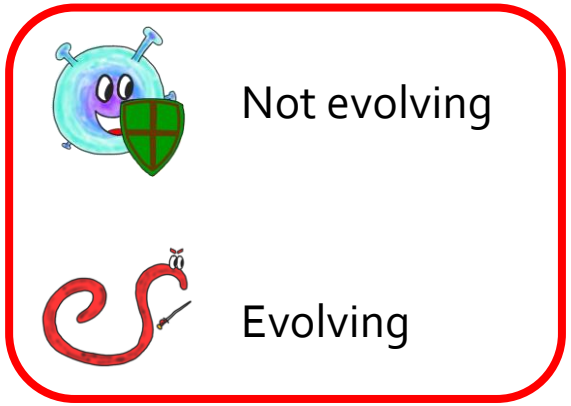

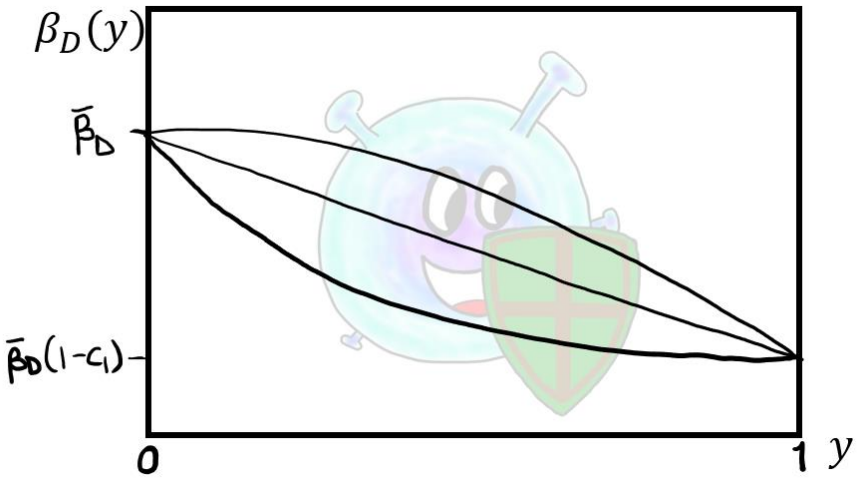

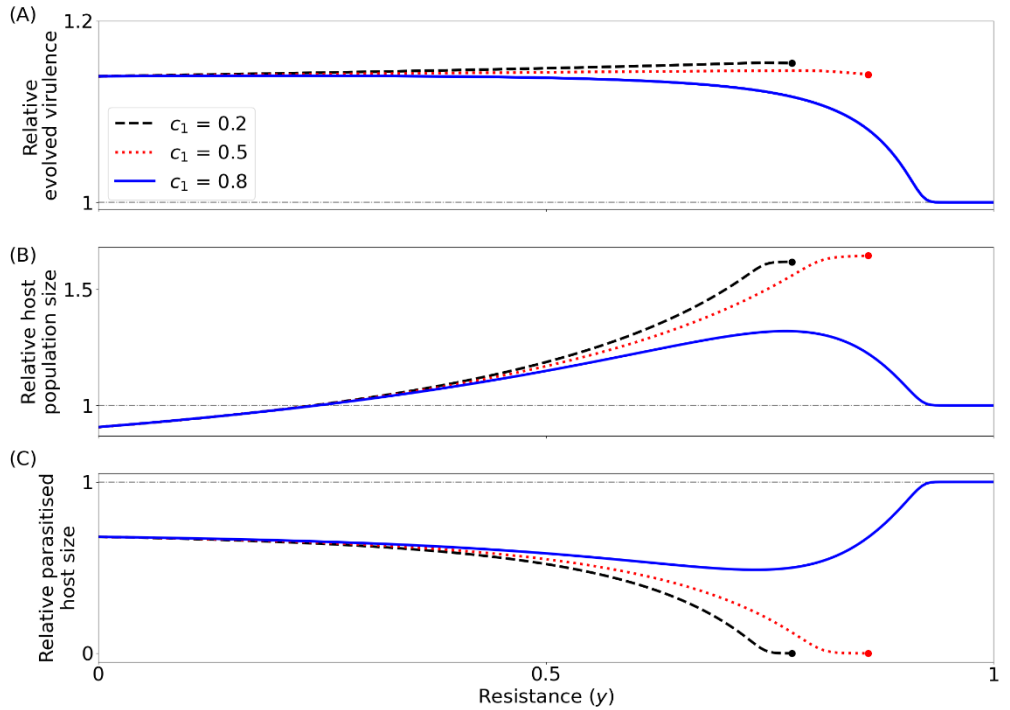

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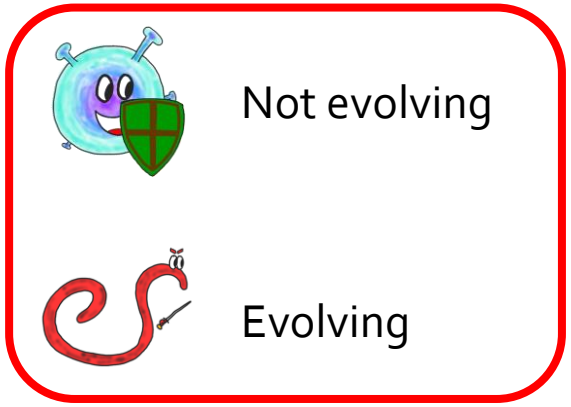

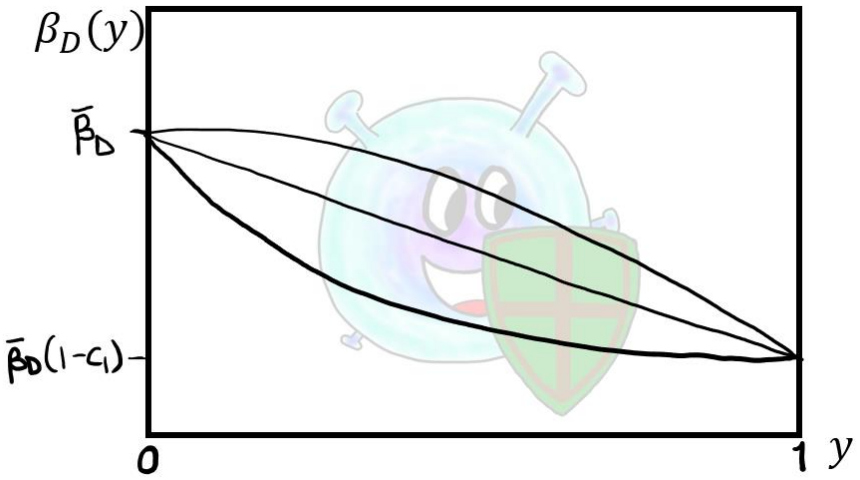

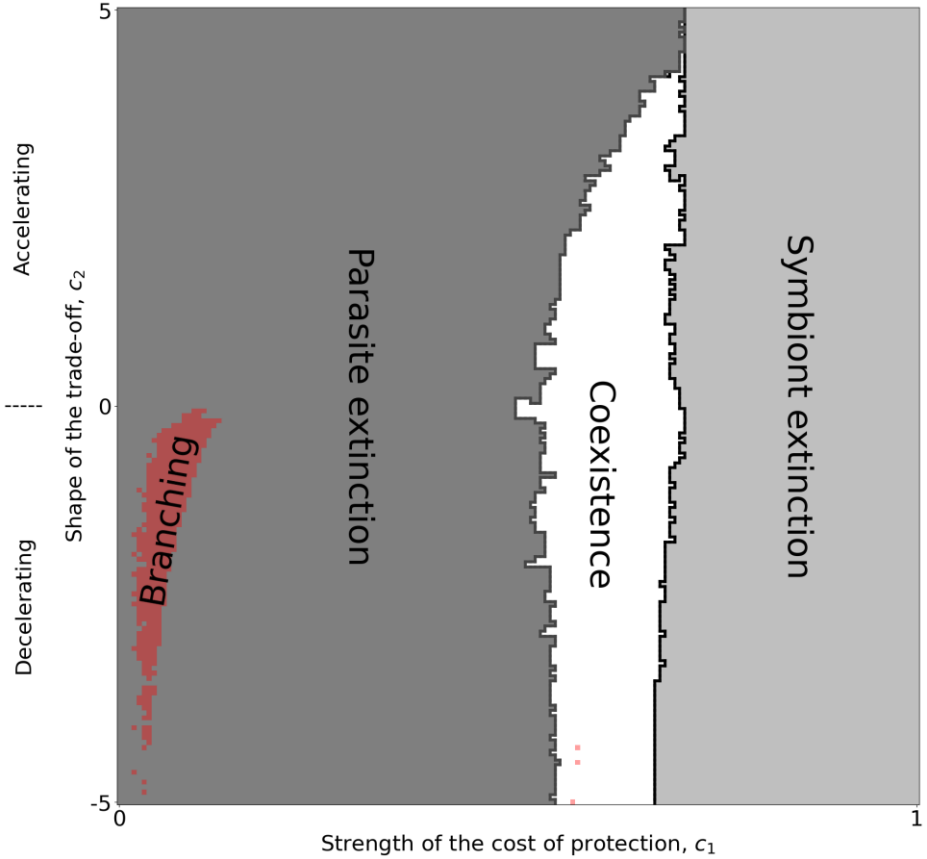

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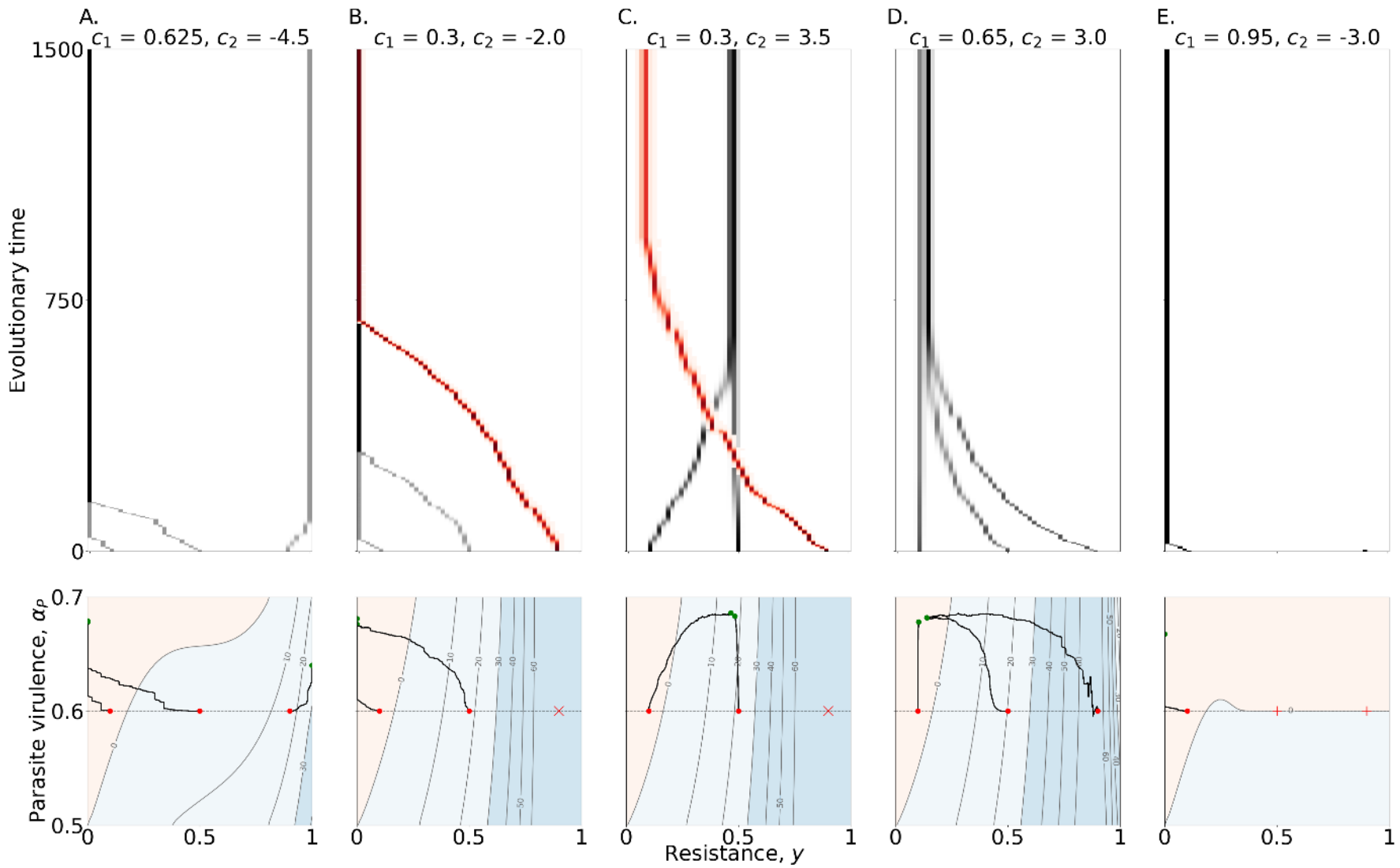

Conclusions

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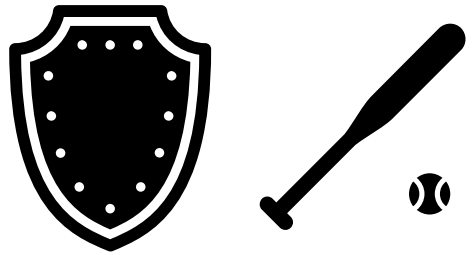

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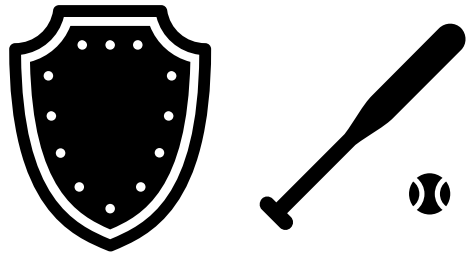

If you fancy becoming a cranberry farmer…

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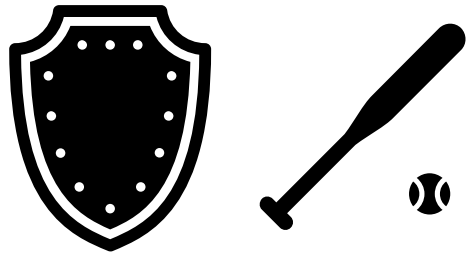


If you fancy becoming a cranberry farmer…

…you need to make friends with spiders!

Thank you for listening

Ben Ashby
Assoc. Professor

Dept. of Mathematics
Simon Fraser University

Kayla King
Professor

Dept. of Biology
University of British Columbia

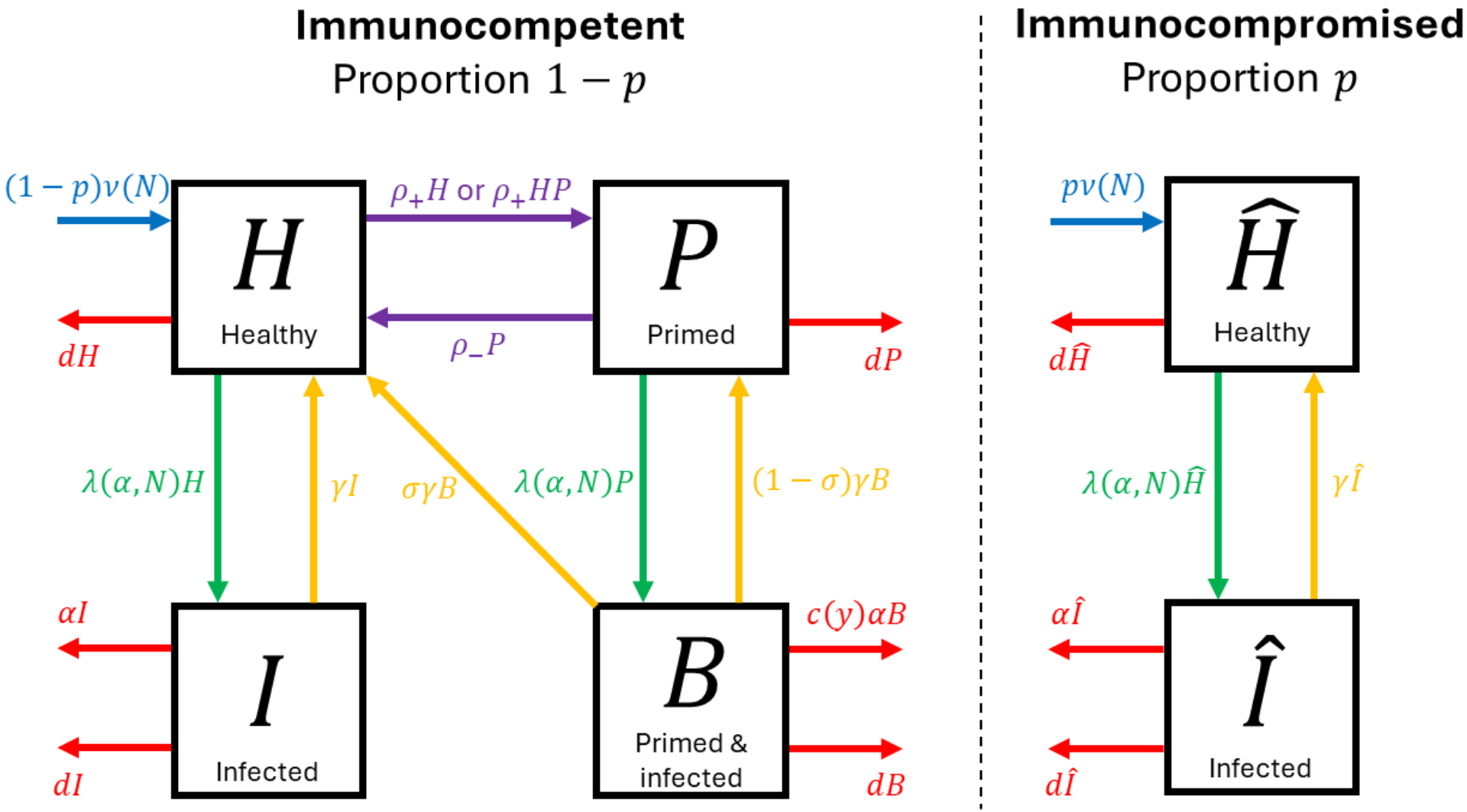
UNIVERSITY OF BATH

UNIVERSITY OF OXFORD

UKRI Natural Environment Research Council

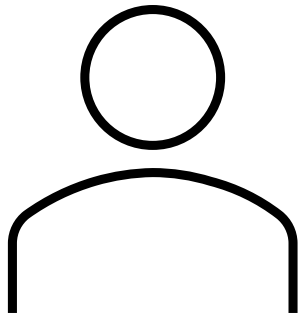
erc

Immune priming



Back to tolerance – with a twist

No protection



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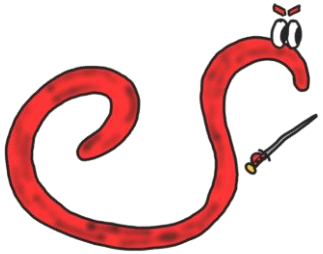

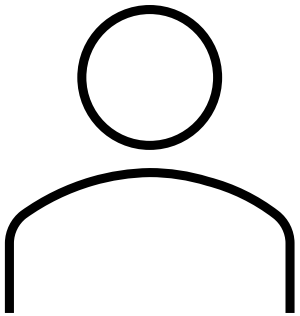

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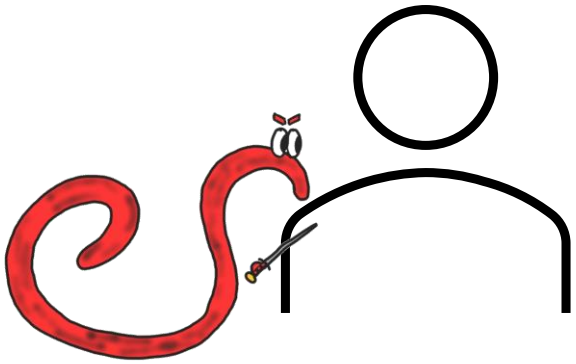

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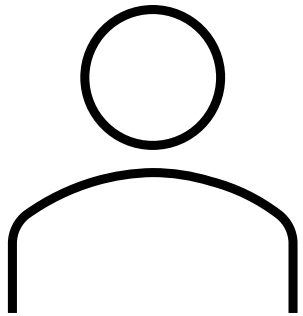

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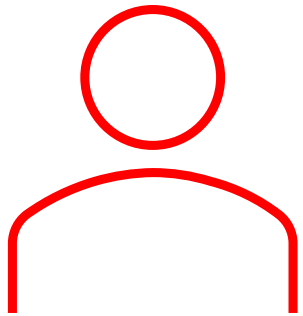

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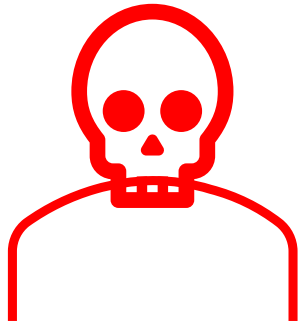

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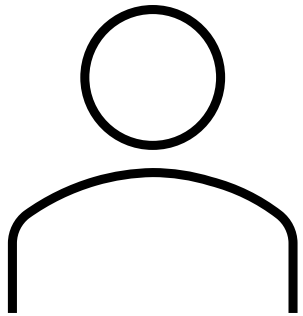

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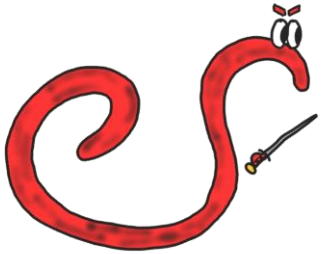

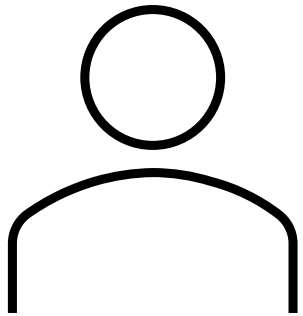

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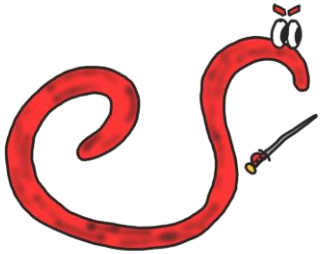

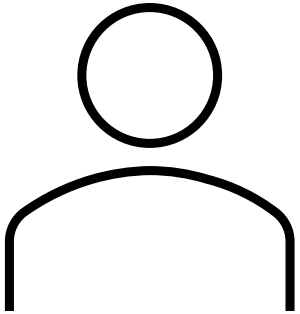

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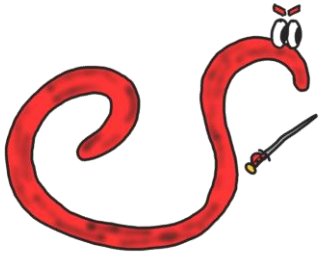

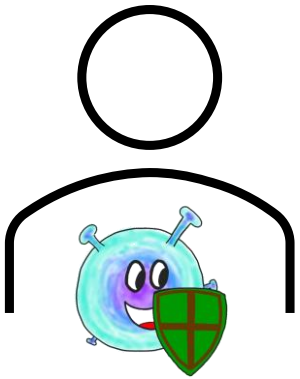

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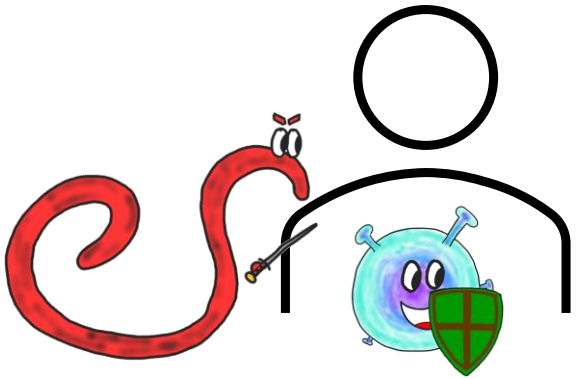

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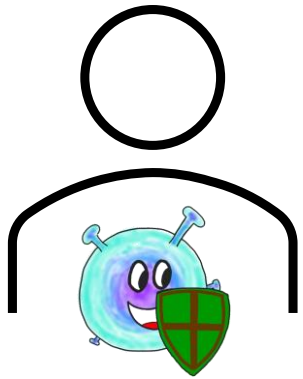

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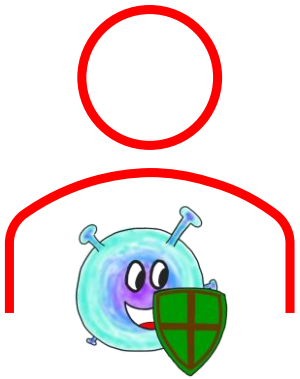

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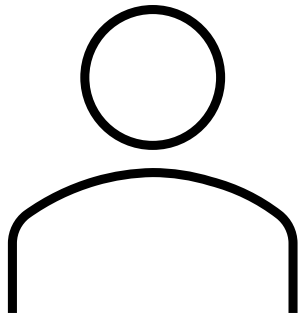
With indirect protection
"Immune priming"



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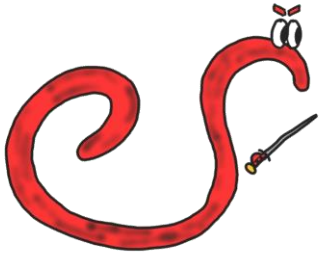

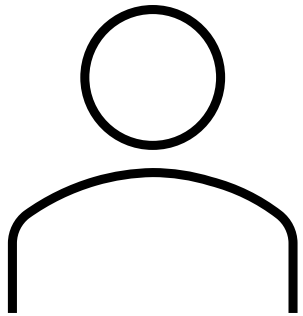

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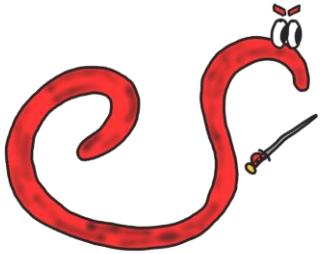

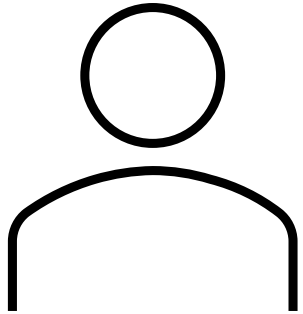

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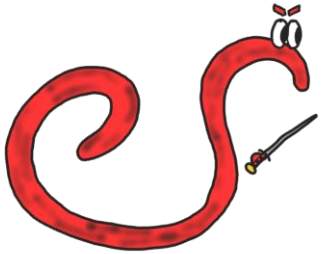

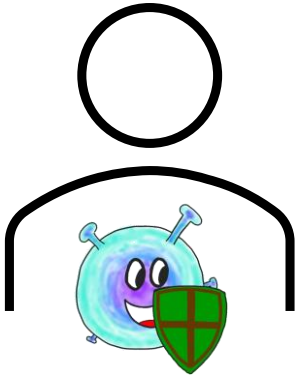

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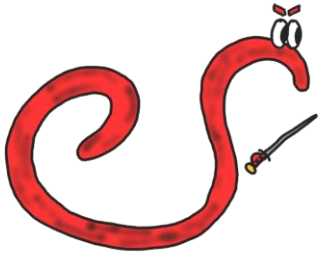
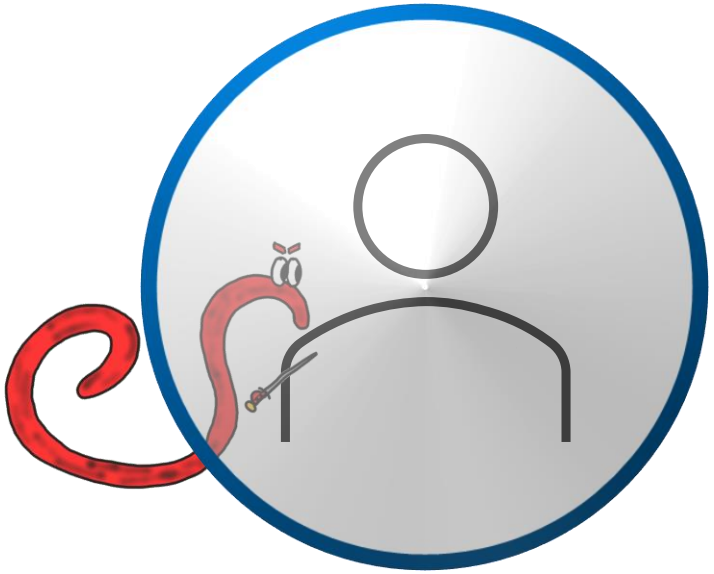


With indirect protection
"Immune priming"

Activation of immune pathways

Back to tolerance – with a twist

With indirect protection
"Immune priming"



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