On the evolutionary transitions from free-living organisms to obligate symbioses

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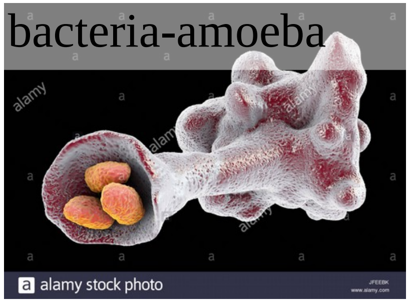
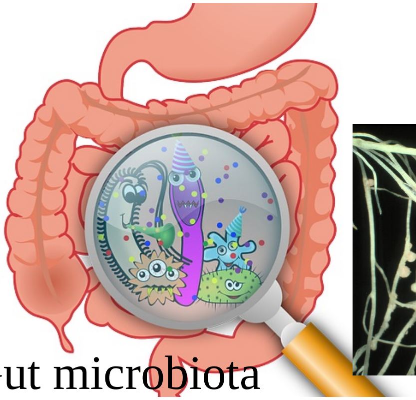
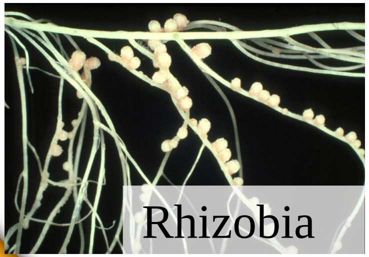
Minus van Baalen

MMEE – Lyon, July 2019

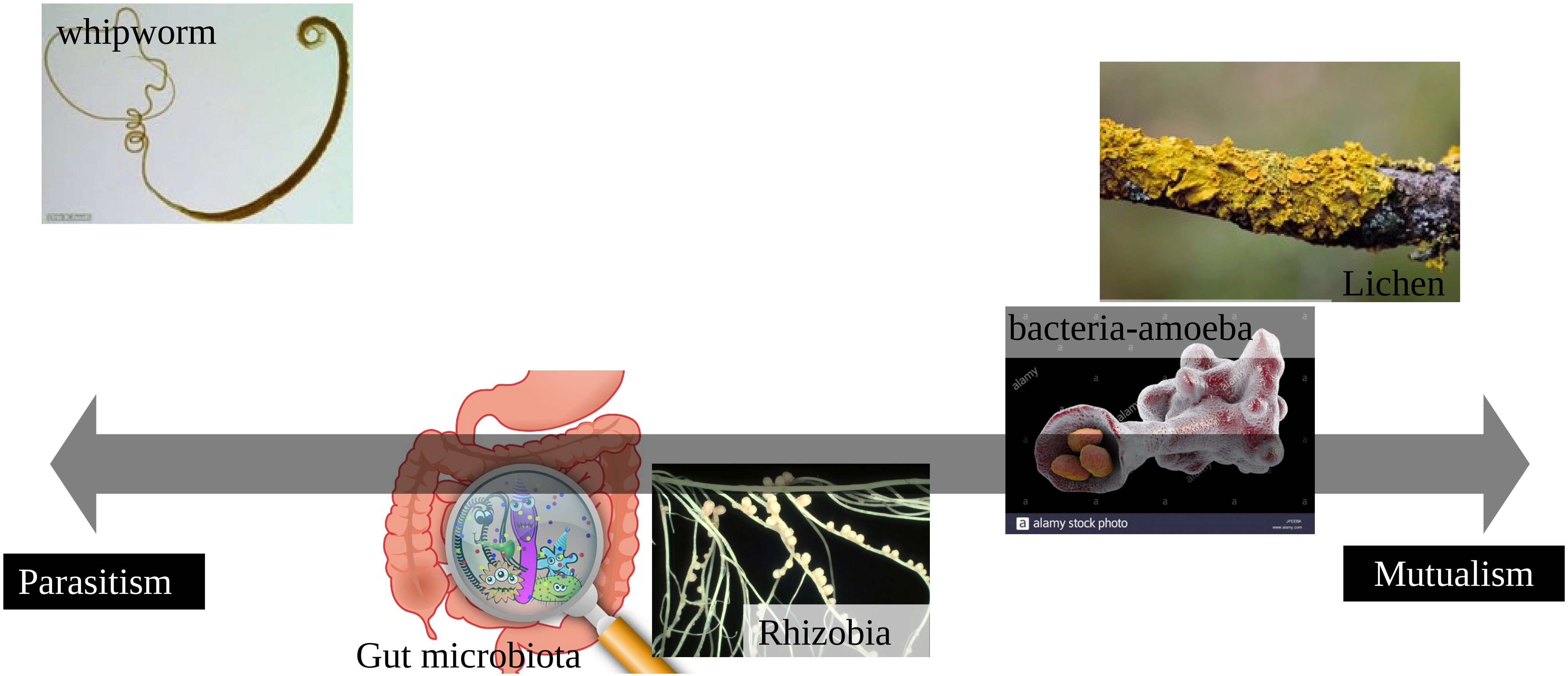
The diverse world of symbiosis



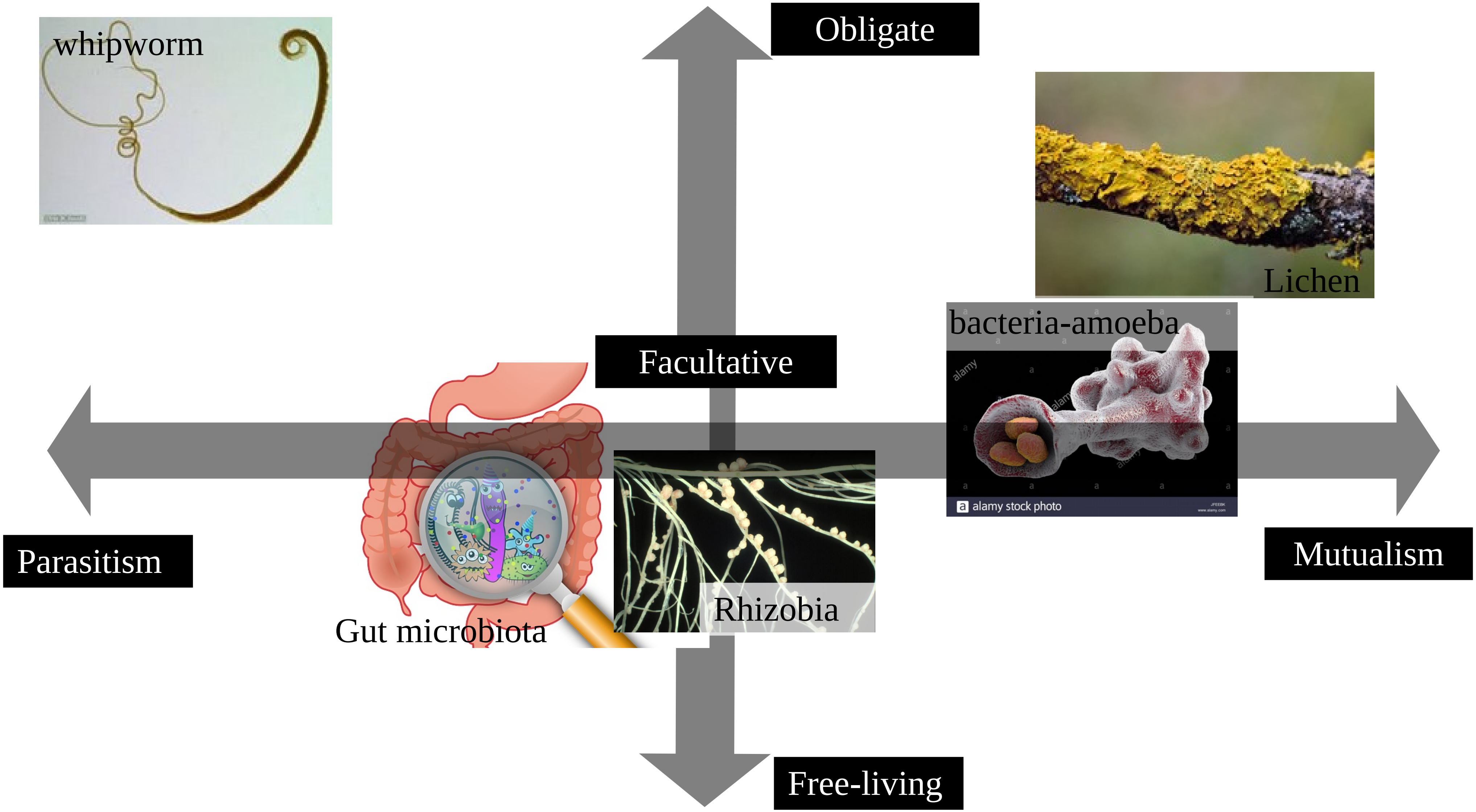




The diverse world of symbiosis

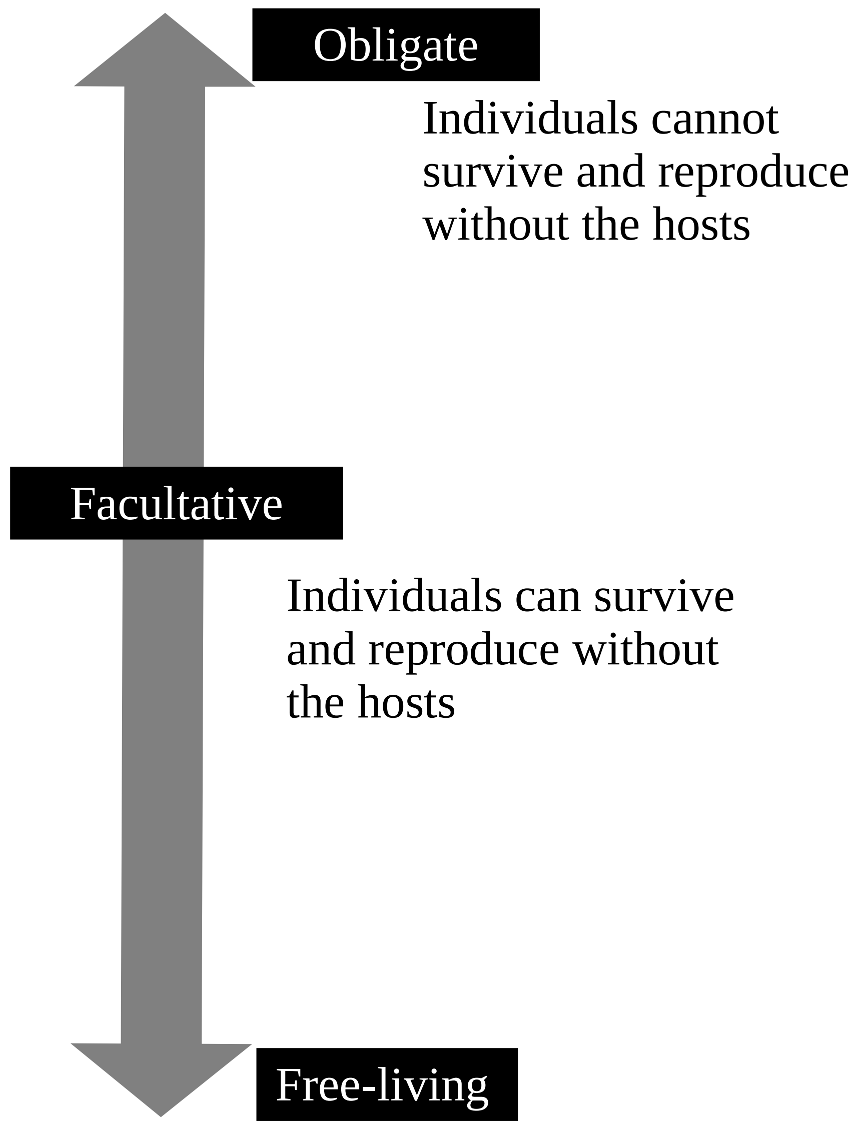


The diverse world of symbiosis

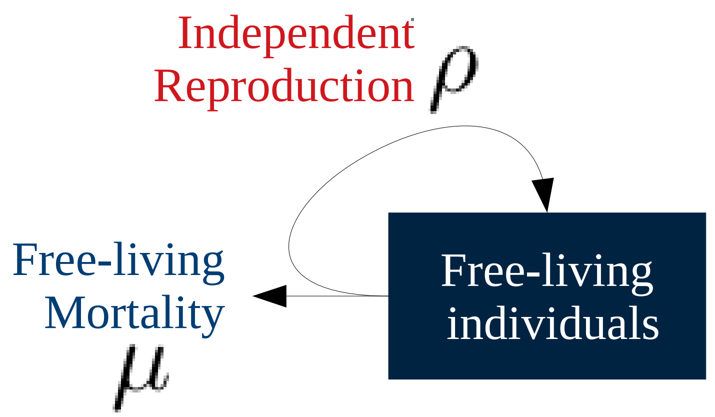


Transition from facultative to obligate symbiosis is an evolutionary riddle

- I will focus on the evolution of one partner (the SYMBIONT) given the ecological dynamics of the other partner (the HOST)
- I will use INDEPENDENT REPRODUCTION as indication of partner dependency



Ecological dynamics of a resident



$$\frac{d}{dt}\begin{pmatrix}\mathcal{F}\\ \mathcal{A}\\ \mathcal{H}\end{pmatrix} = \begin{pmatrix}\rho\ K(\mathcal{F}) - \mu - \beta\mathcal{H} & \tau & 0\\ \beta H & p\ r - \nu\ N(\mathcal{A},\mathcal{H}) & 0\\ -\beta\mathcal{H} & r(1-p) & r - d\ D(\mathcal{H},\mathcal{A})\end{pmatrix}\begin{pmatrix}\mathcal{F}\\ \mathcal{A}\\ \mathcal{H}\end{pmatrix}$$

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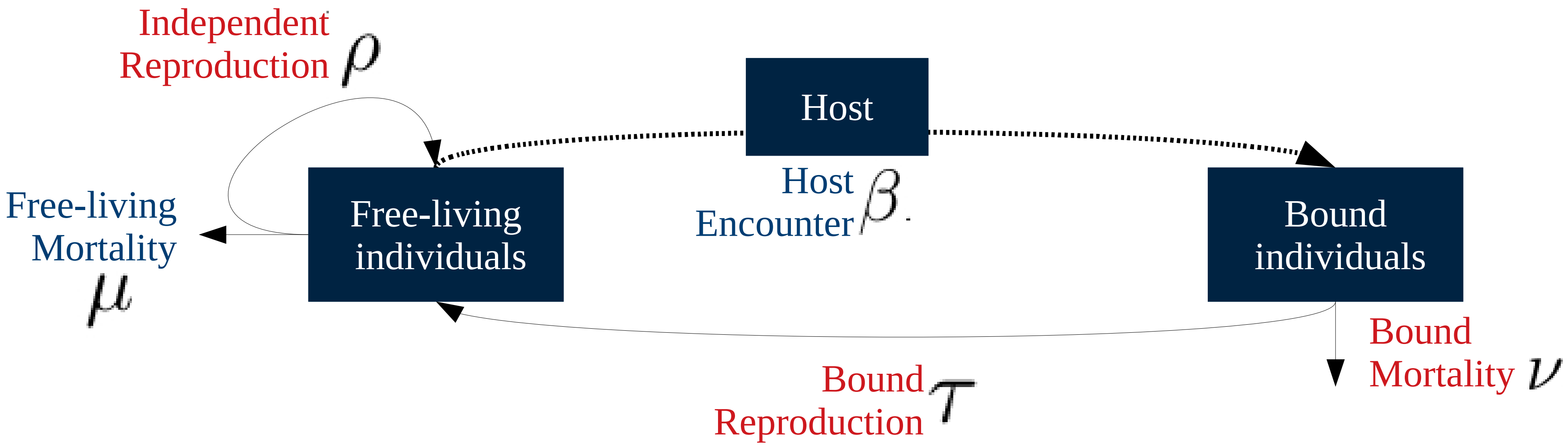

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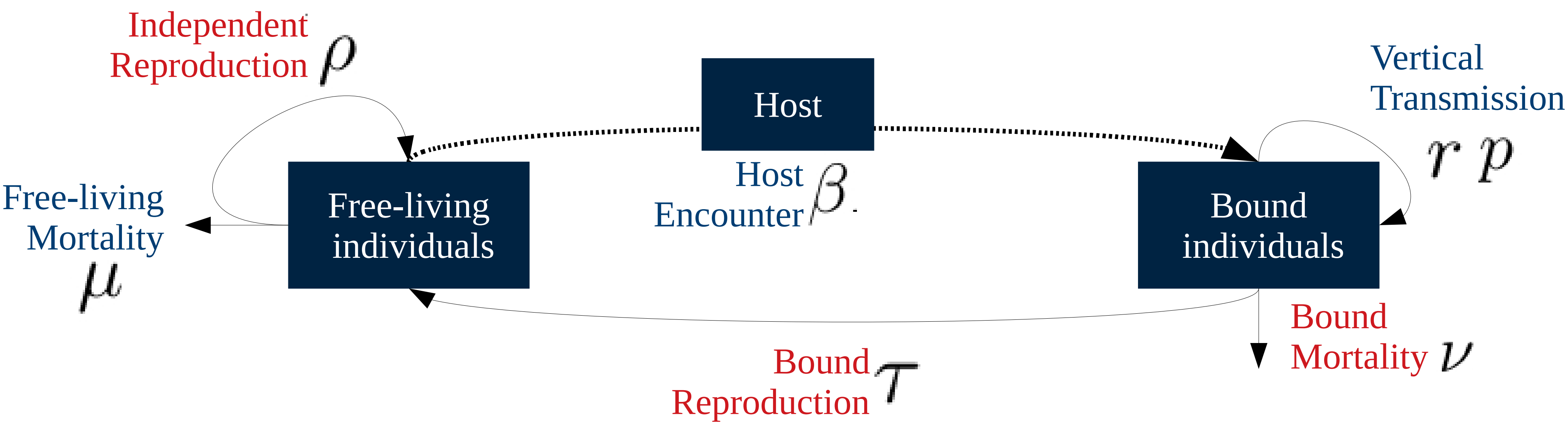

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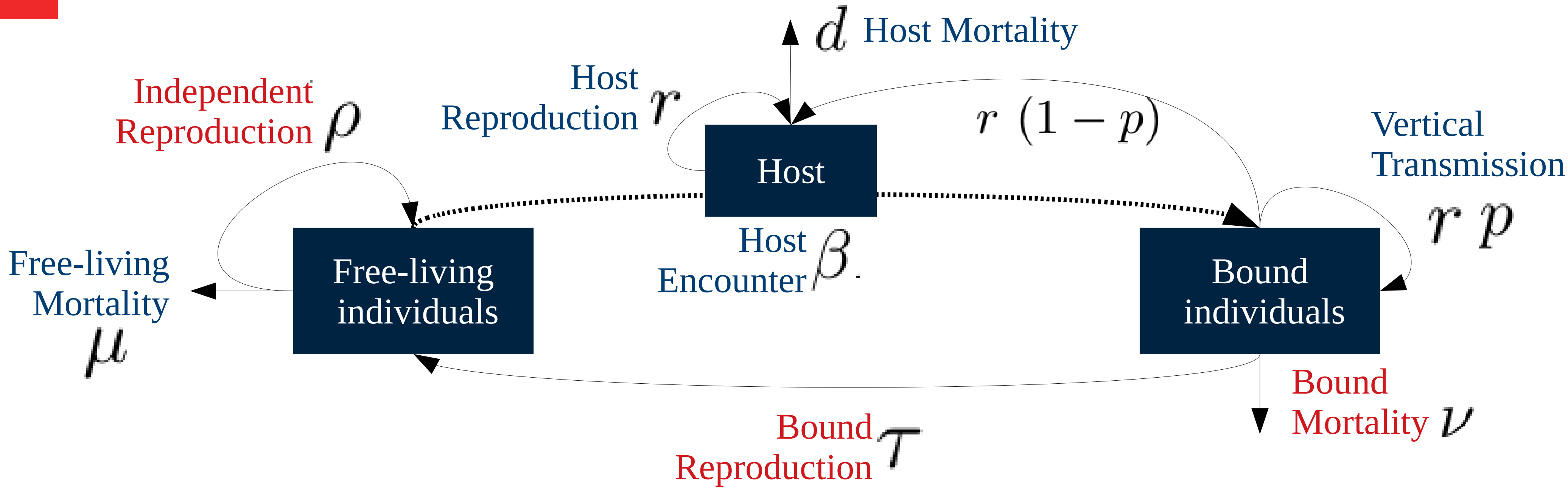

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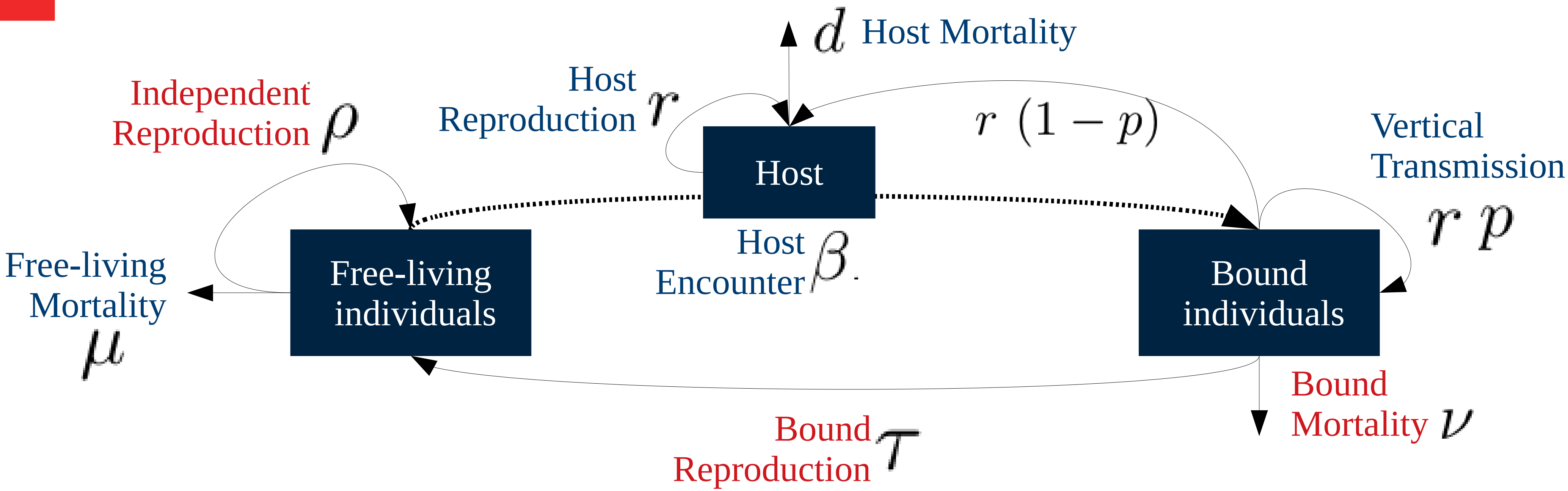
Invasion fitness of a mutant



$$\left(\boxed{\frac{\rho_m}{\mu}K(\hat{\mathcal{F}})}-1\right)\left(\boxed{\frac{p\quad r}{\nu_m}\,\frac{1}{N(\hat{\mathcal{A}},\hat{\mathcal{H}})}}-1\right)=\left(\boxed{\frac{p\quad r}{\nu_m}\,\frac{1}{N(\hat{\mathcal{A}},\hat{\mathcal{H}})}}+\boxed{\frac{\tau_m}{\nu_m}\,\frac{1}{N(\hat{\mathcal{A}},\hat{\mathcal{H}})}}-1\right)\left(\boxed{\frac{\beta}{\mu}\,\hat{\mathcal{H}}}\right) < 0$$

R_{ff}
Free-living reproduction ratio

R_{aa}
Bound reproduction ratio (vertical transmission)

R_{af}
Bound reproduction ratio (horizontal transmission)

$\mathcal{T}$
Effective host encounters

Trade-off among bound reproduction, independent reproduction and bound mortality rate

$$\tau = \theta - \rho^h + \eta(\nu - \nu_0)^g$$

Adaptation to the symbiotic lifestyle imposes a cost on the independent reproduction

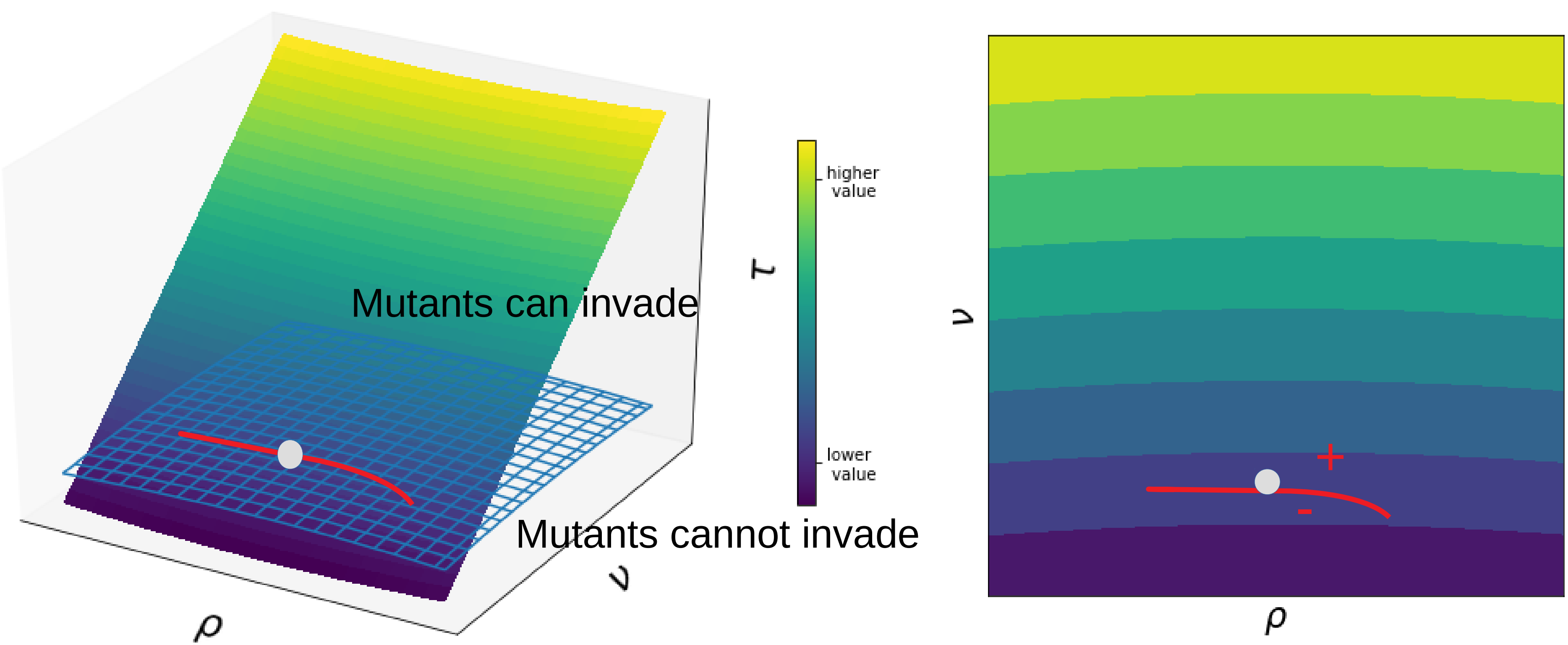
$\eta > 0$: The adaptation increases host mortality rate (parasitic relationship)

$\eta < 0$: The adaptation reduce host mortality rate
(mutualistic relationship via host protection)

Trade-off and invasion fitness can be represented as manifolds

$$\tau = \theta - \rho^h + \eta(\nu - \nu_0)^g$$

$$\tau_m > \frac{N(\hat{\mathcal{A}}, \hat{\mathcal{H}})\nu_m - pr}{\beta\hat{\mathcal{H}}}\left(\beta\hat{\mathcal{H}} + \mu - K(\hat{\mathcal{F}})\rho_m\right)$$



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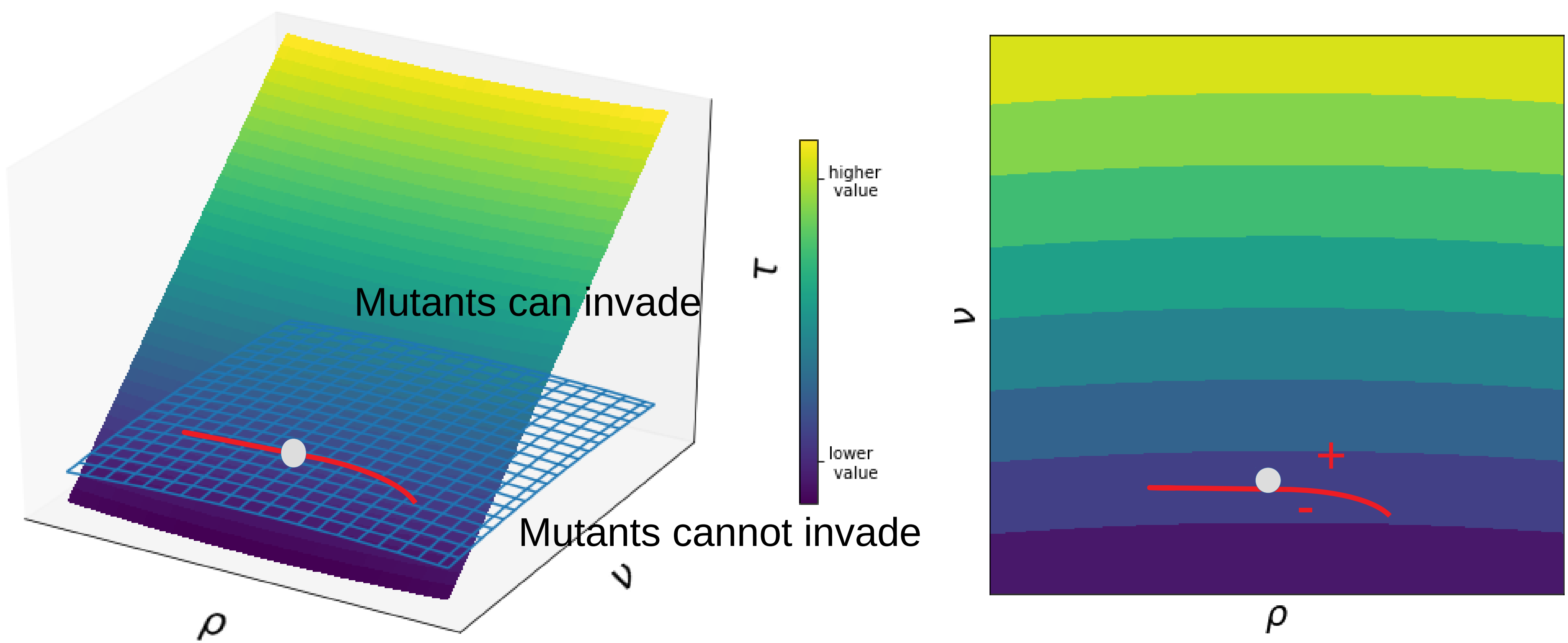
Invasion boundary



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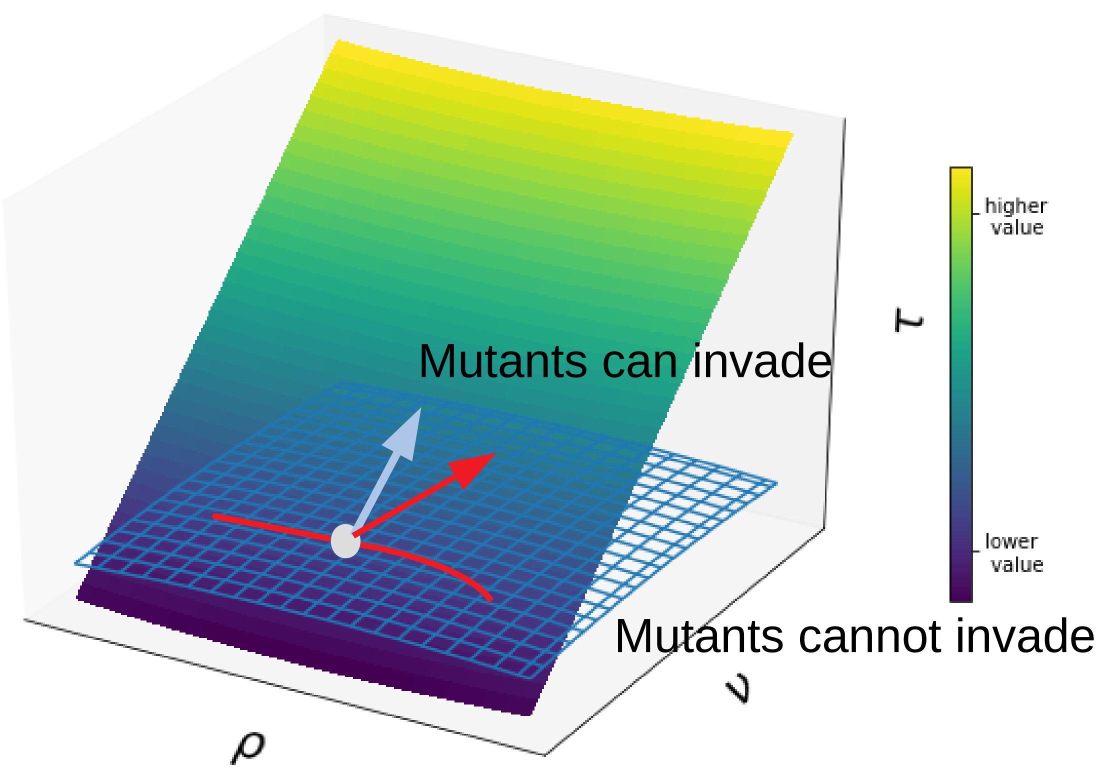
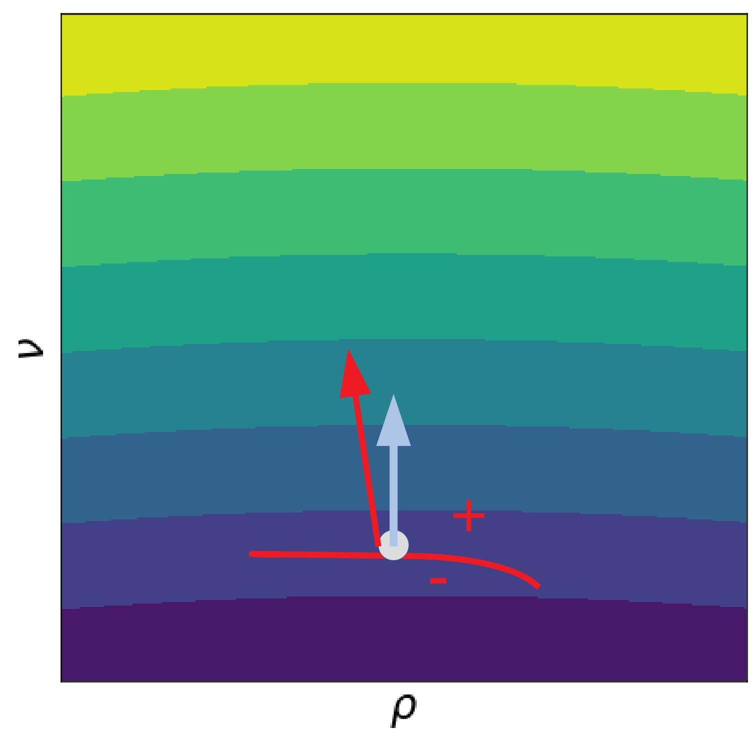
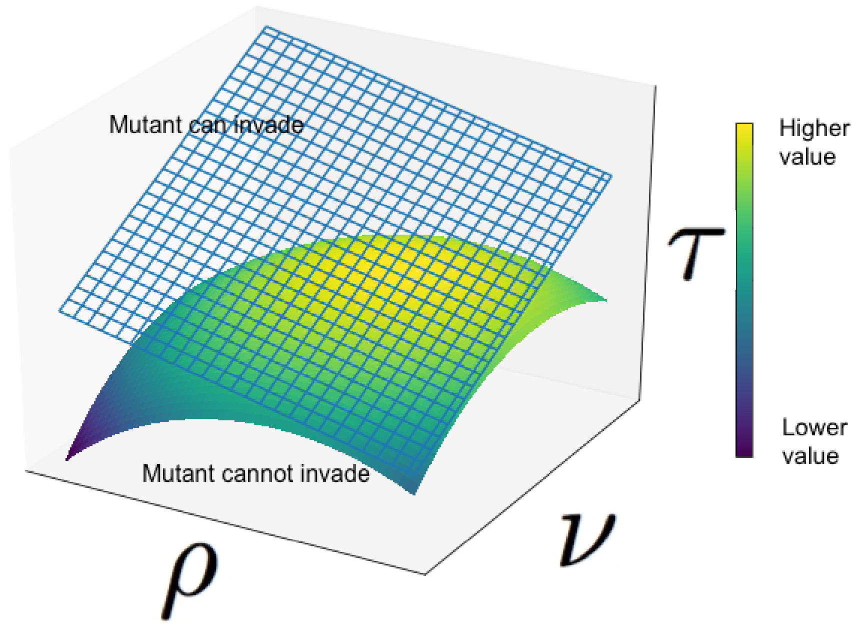
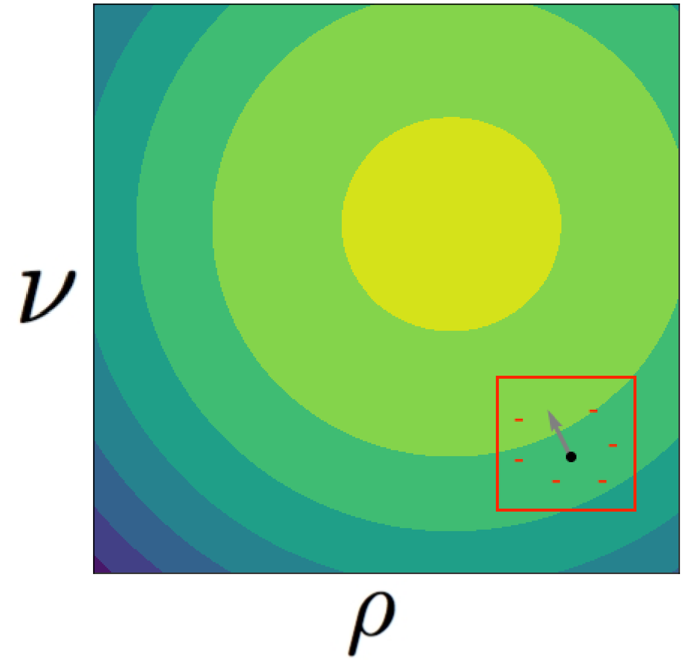
Invasion boundary | Steepest ascent of tradeoff surface | Steepest ascent of invasion surface



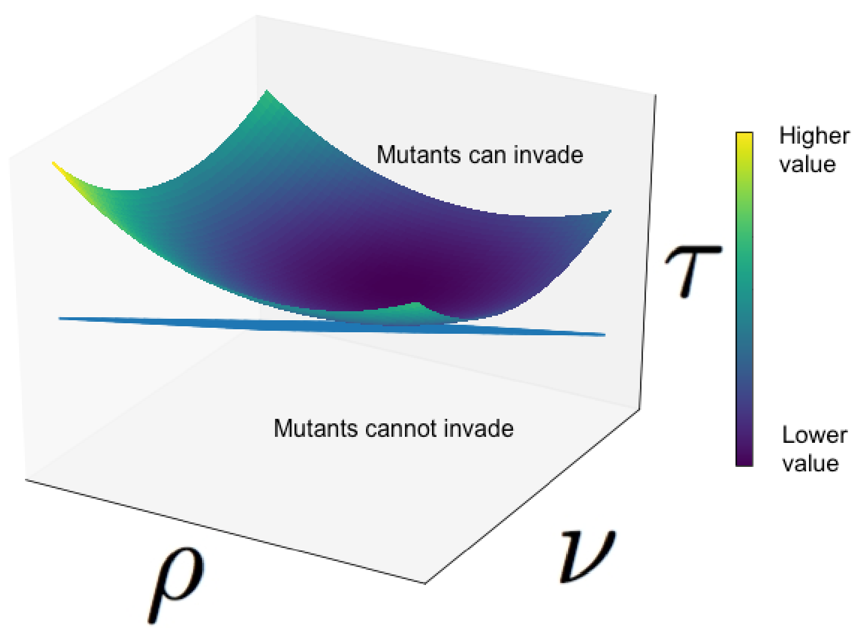


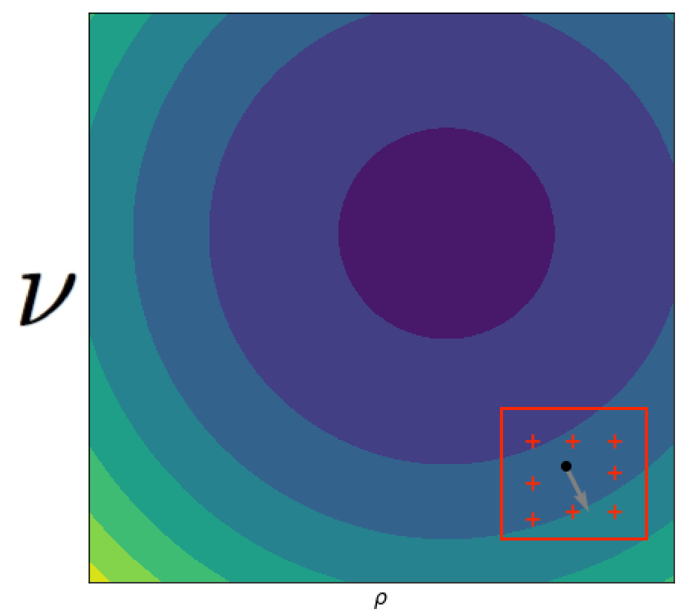
Singular strategy is the tangent point of the two manifolds





Evolutionarily Stable Strategy (ESS)

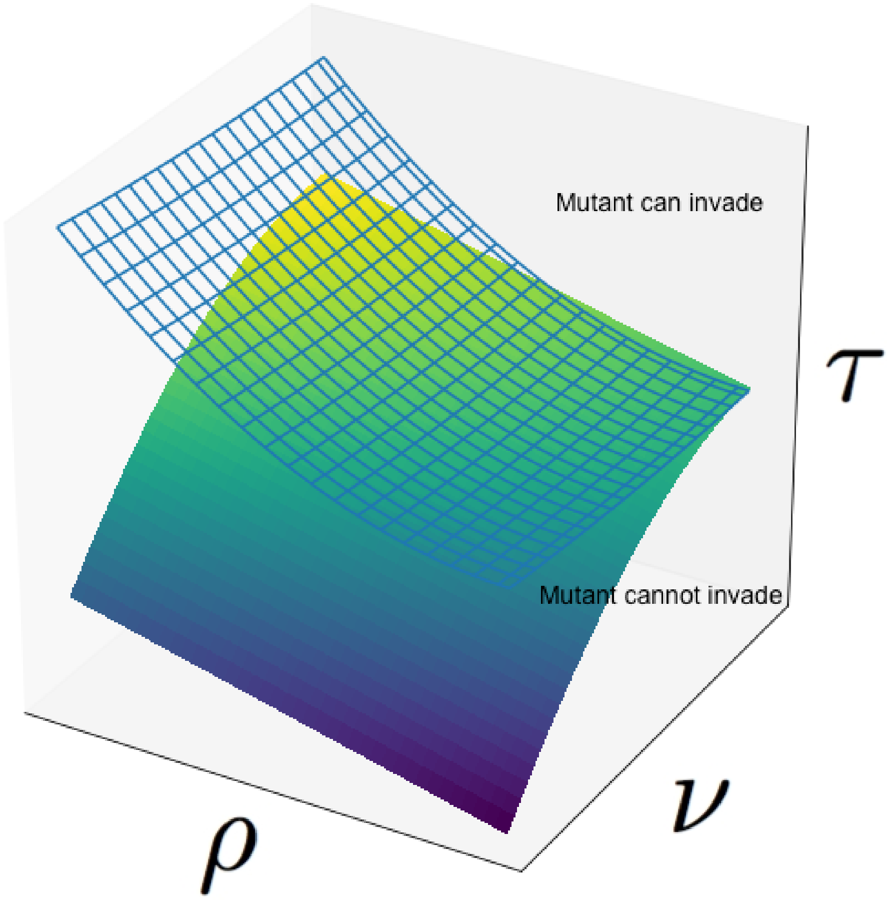


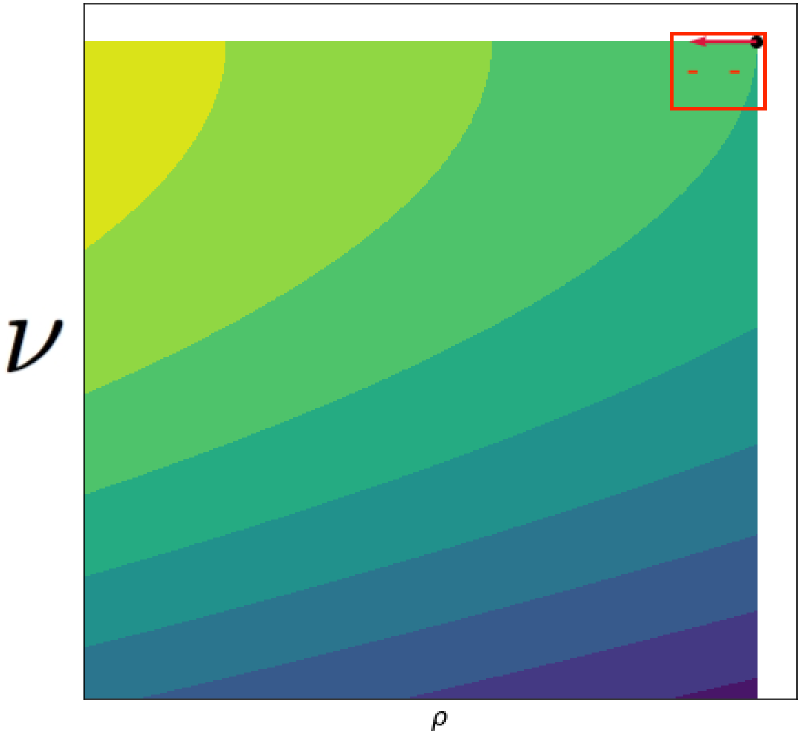


Minimum

Boundary ESS

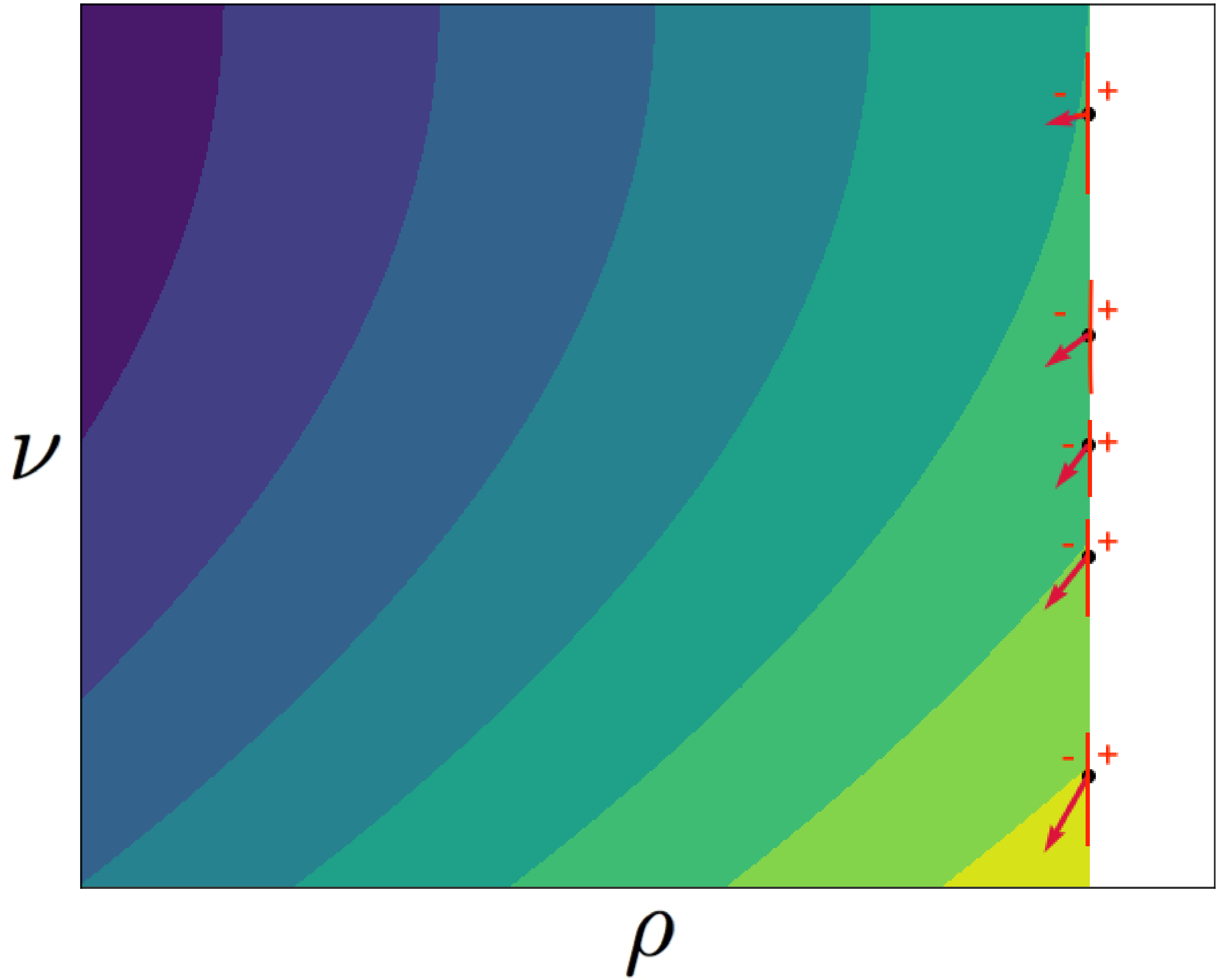
The steepest ascent of the invasion surface lies on the negative area





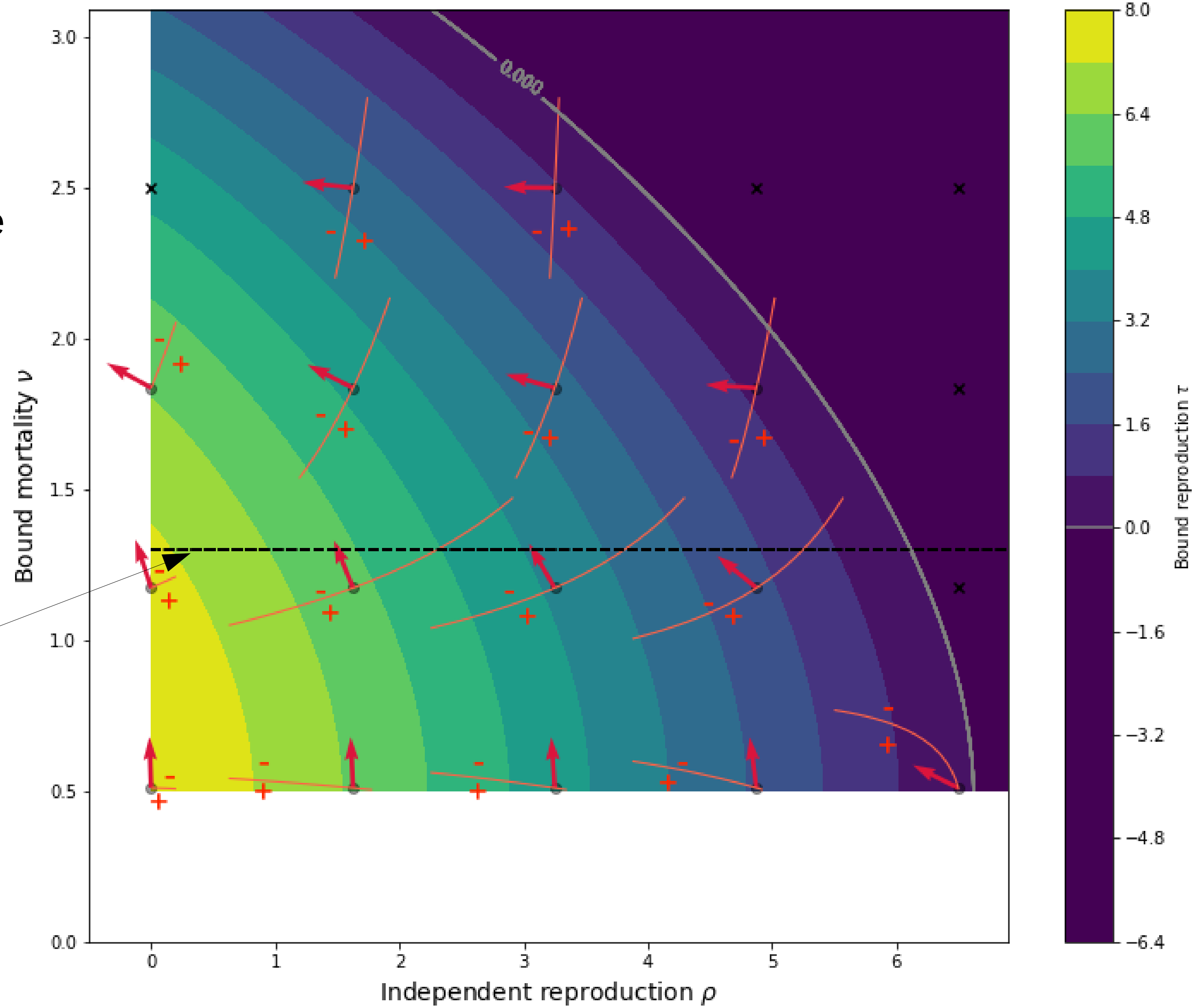
Multiple ESSs

Multiple residents with invasion boundaries parallel to one axis



Benefits from adaptation to symbiosis impose a small cost on independent reproduction

When adapting to the symbiotic lifestyle also provide host protection



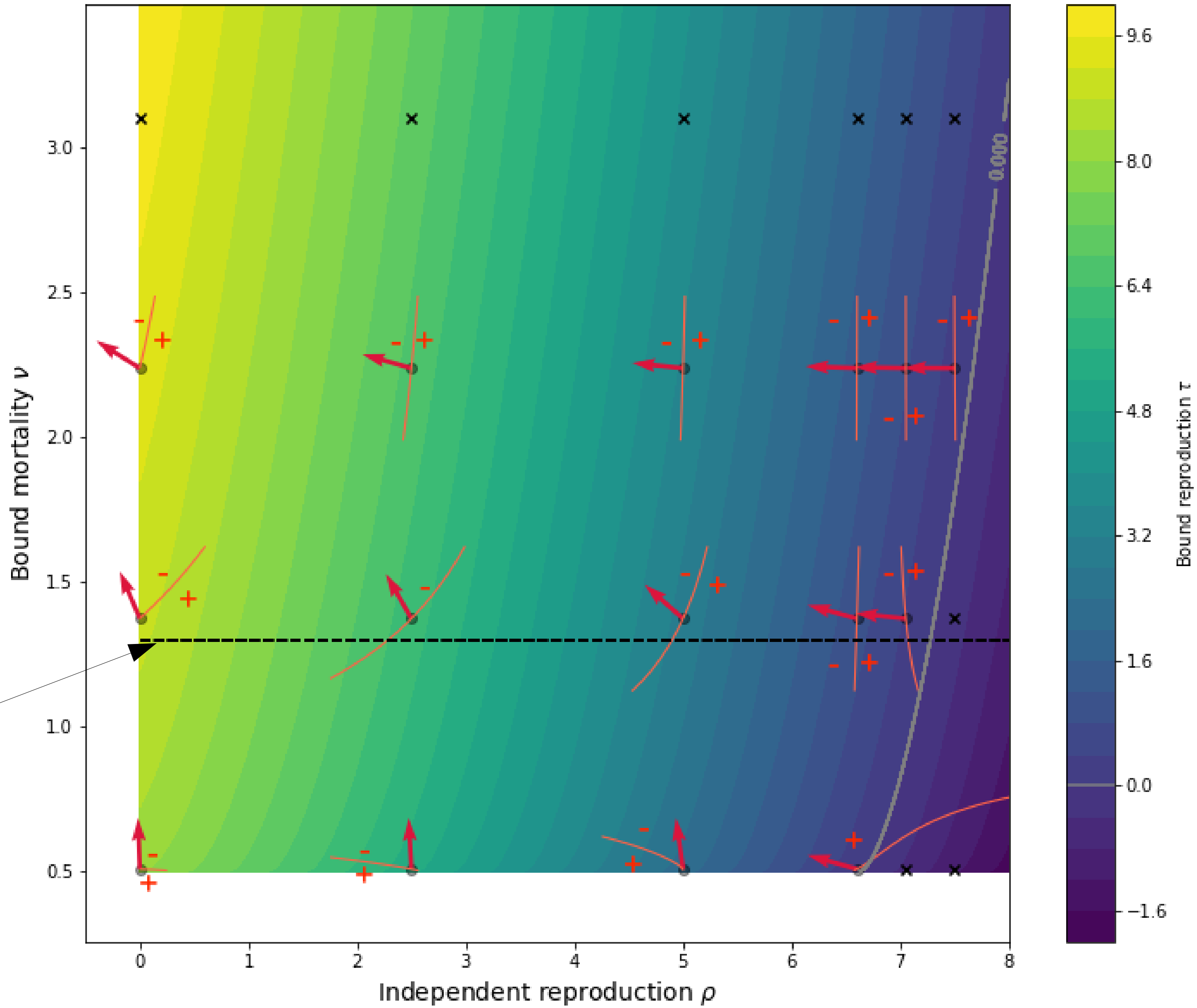
Mortality rate of free host

Benefits from adaptation to symbiosis impose a small cost on independent reproduction

When adapting to the symbiotic lifestyle is virulent

Parasites are incapable of inducing high virulence

Mortality rate of free host



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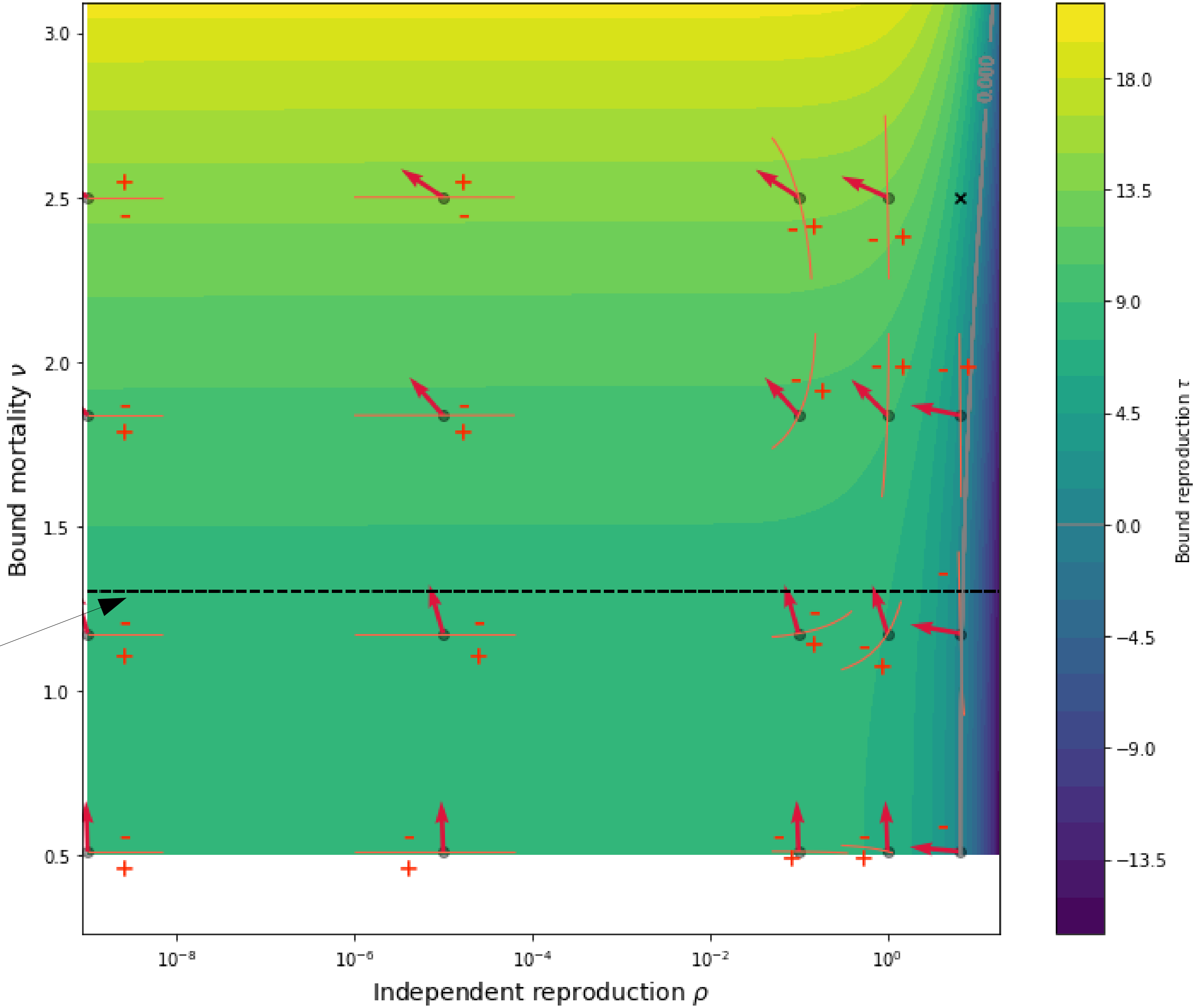

Conclusions

When benefits from the adaptation to the symbiosis impose a low cost on the independent reproduction:

- Obligate mutualism can evolve via small mutations
- Parasitism incapable of inducing high virulence never evolve dependency on the host
- Parasitism capable of inducing high virulence results in various scenarios


Questions?

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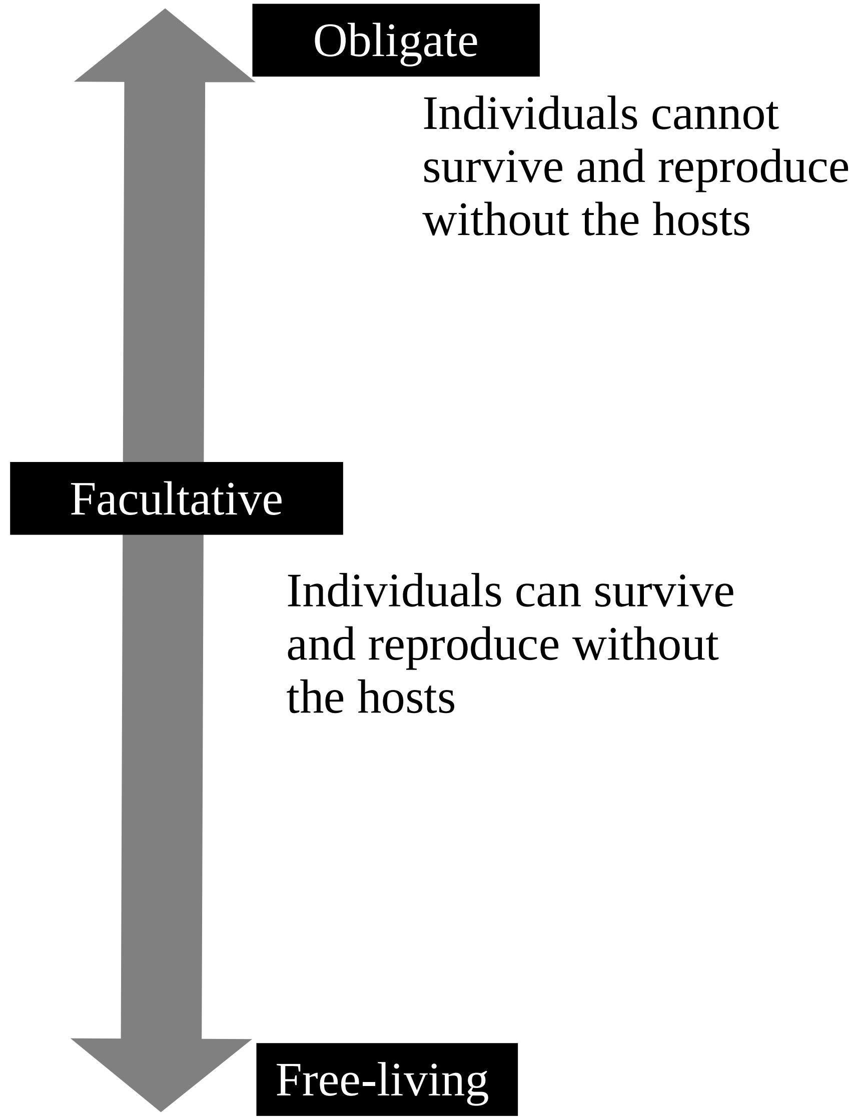
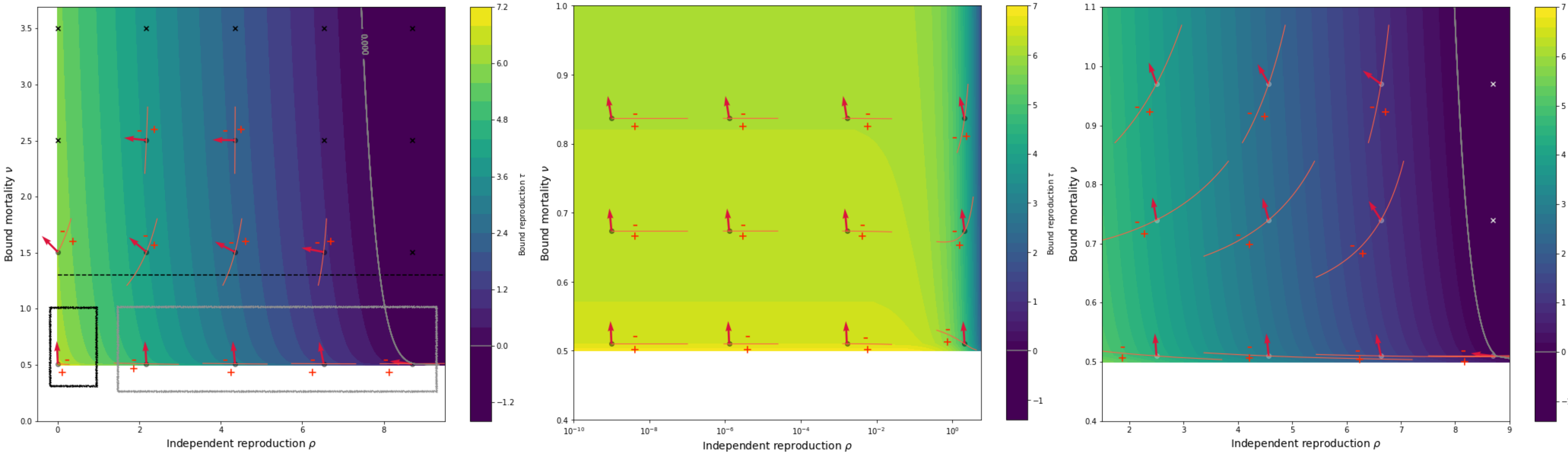


Benefits from adaptation imposes a high cost on the independent reproduction



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