

# Host-Parasite Coevolution & Microbiome-Mediated Adaptation

*TransEvo Core Seminar, June 2024*

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🏡 [bobweek.github.io](https://bobweek.github.io)

🐦 @\_bobweek\_

# Adaptation is Fundamental for Both

**Host-Parasite Coevolution**

**Microbiome-Mediated Adaptation**

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- Coevolution is reciprocal adaptation

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## Host-Parasite Coevolution

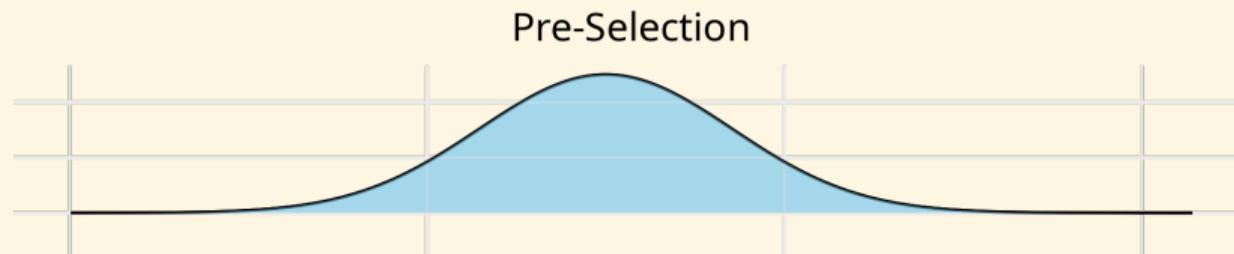
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## Microbiome-Mediated Adaptation

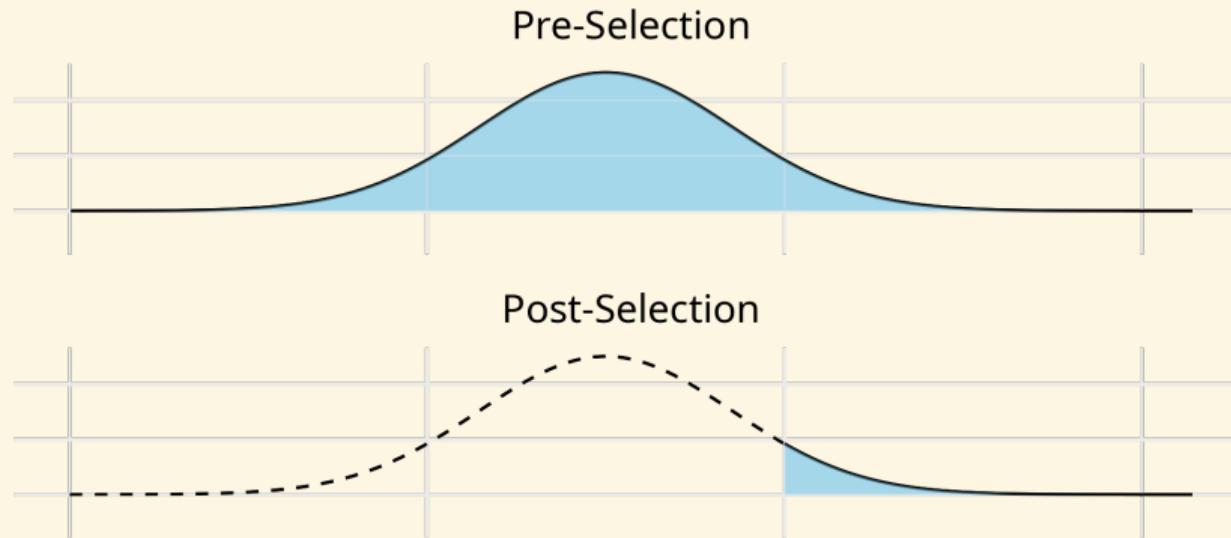
- Microbiomes can mediate host adaptation
- Applications:
  - Increase crop yield
  - Prevent/treat disease

Adaptation = Selection + Inheritance

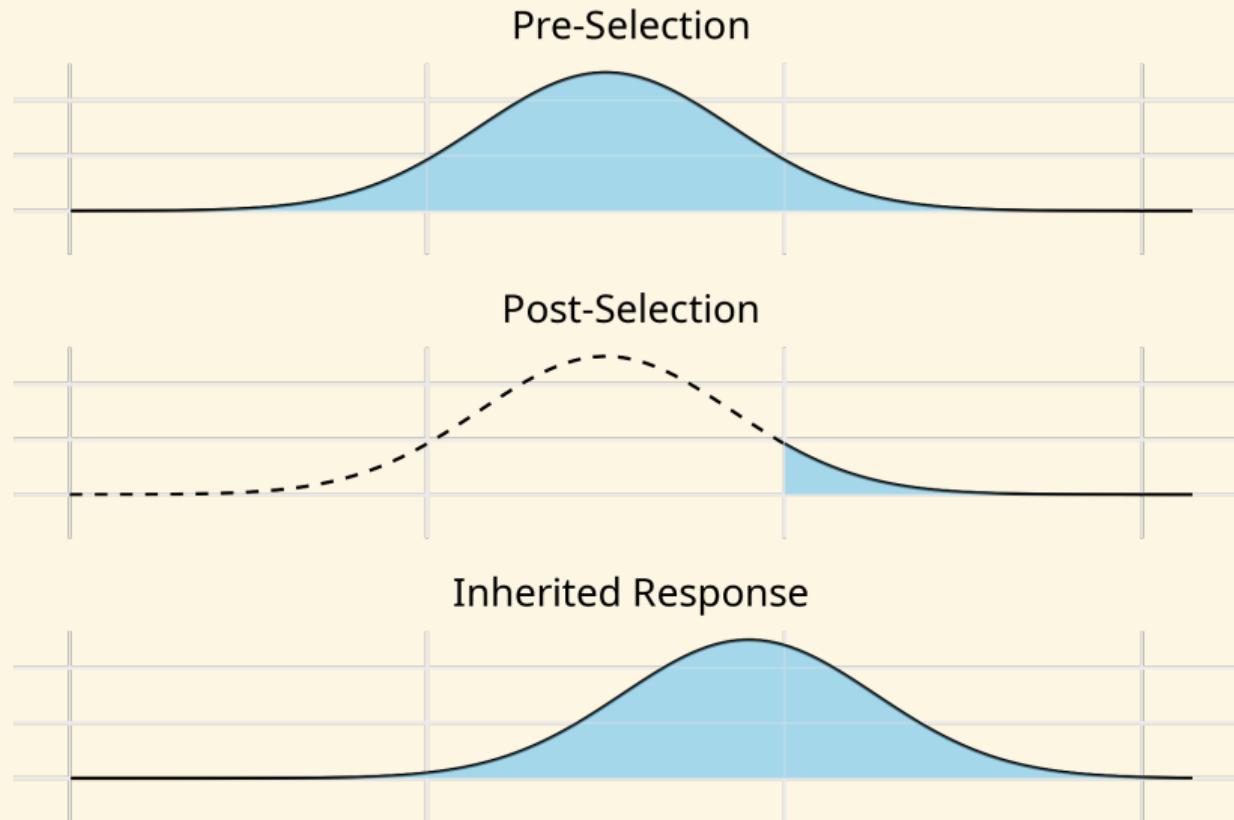
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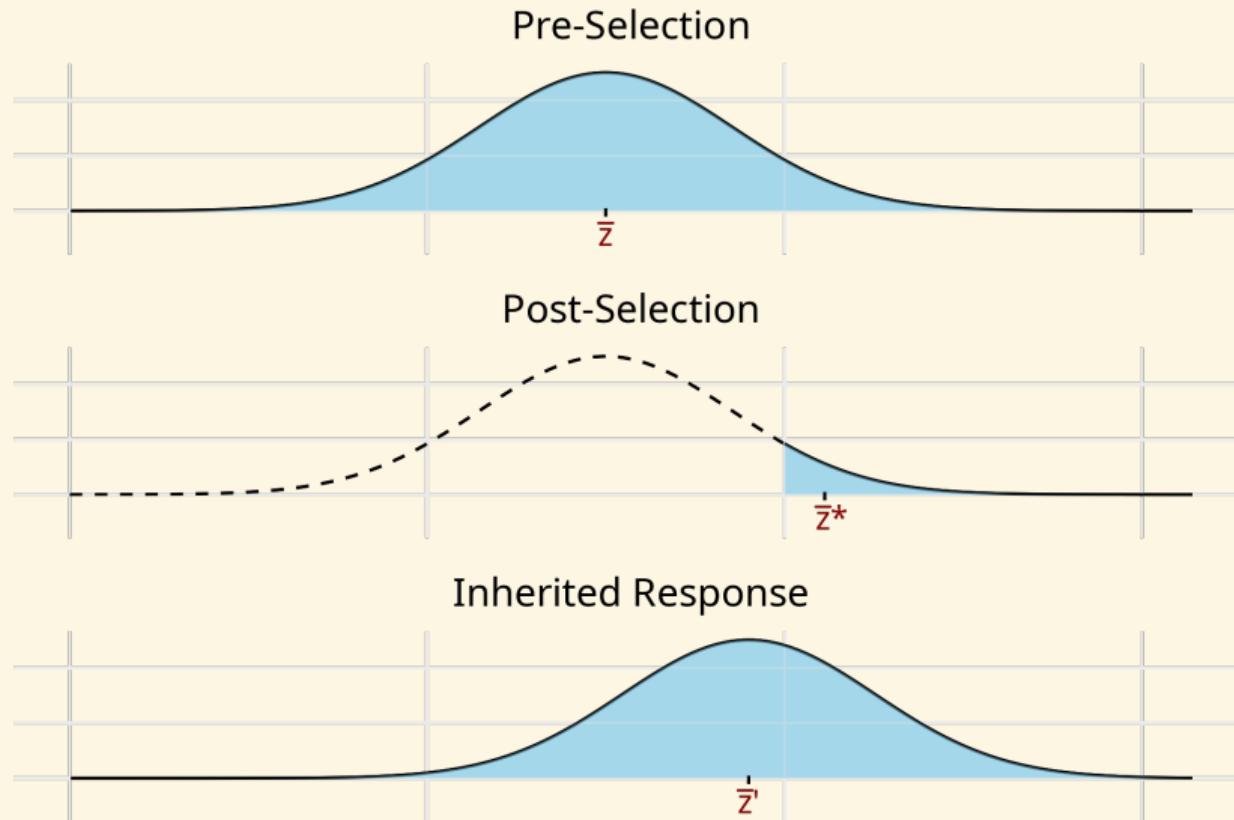
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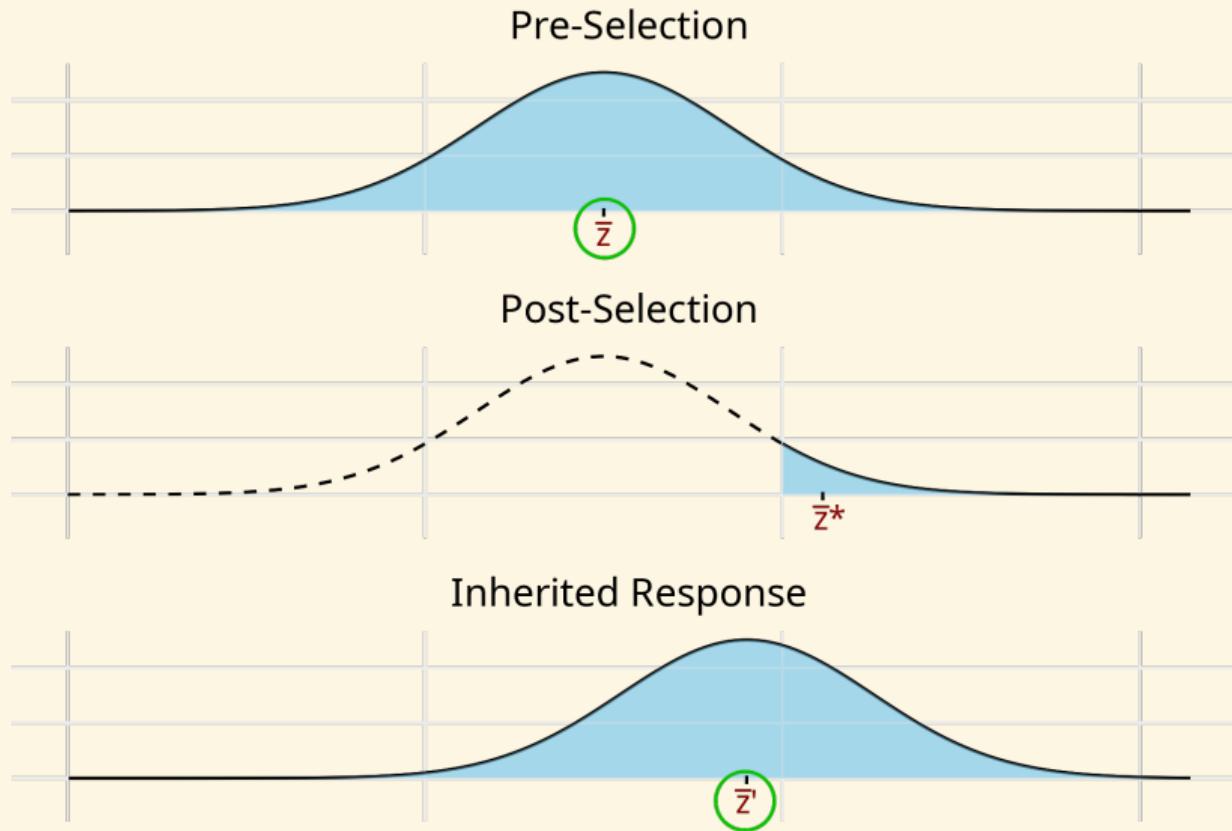
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# Focused on Mean Trait Dynamics: $\Delta\bar{z}$



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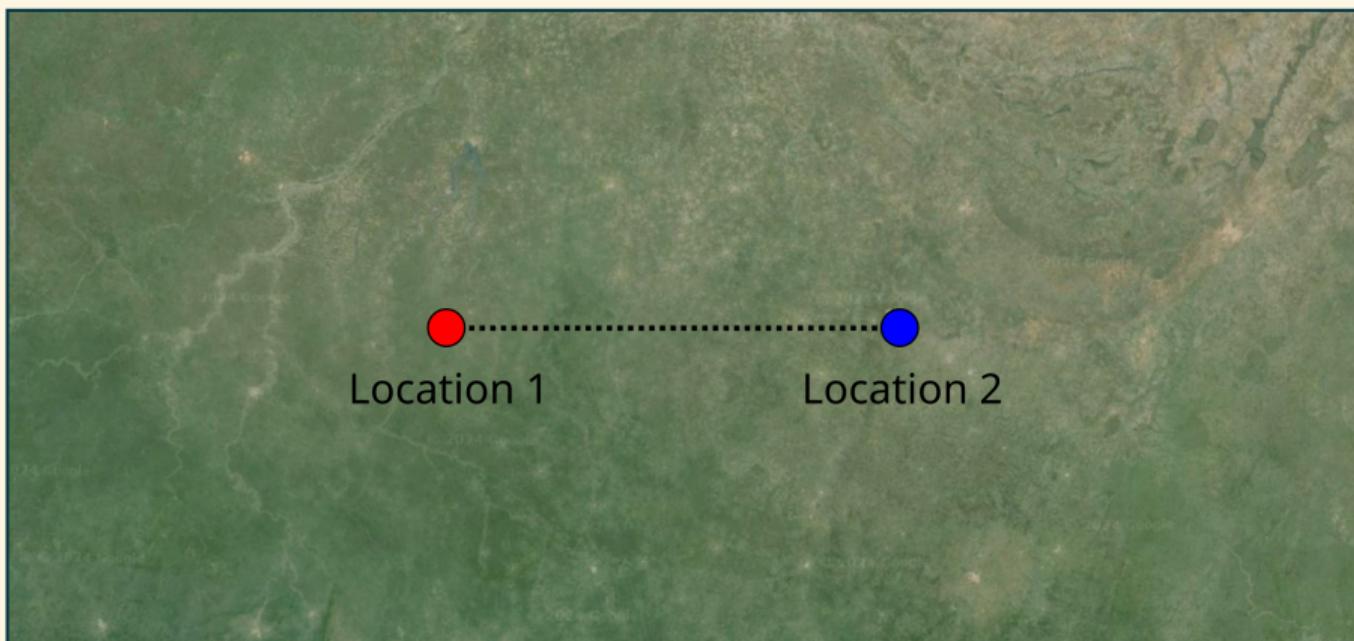


## **Part 1: Host-Parasite Coevolution in Continuous Space**

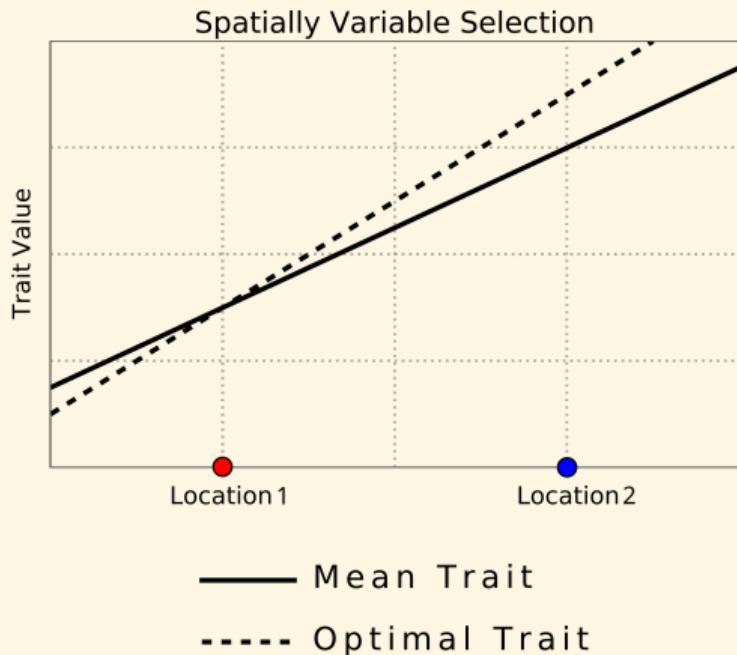
# Species are Distributed Continuously in Space



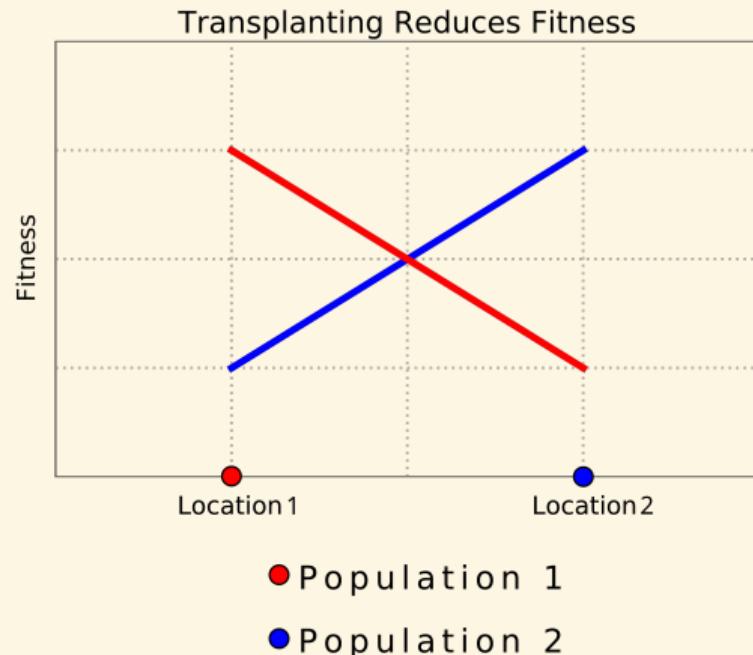
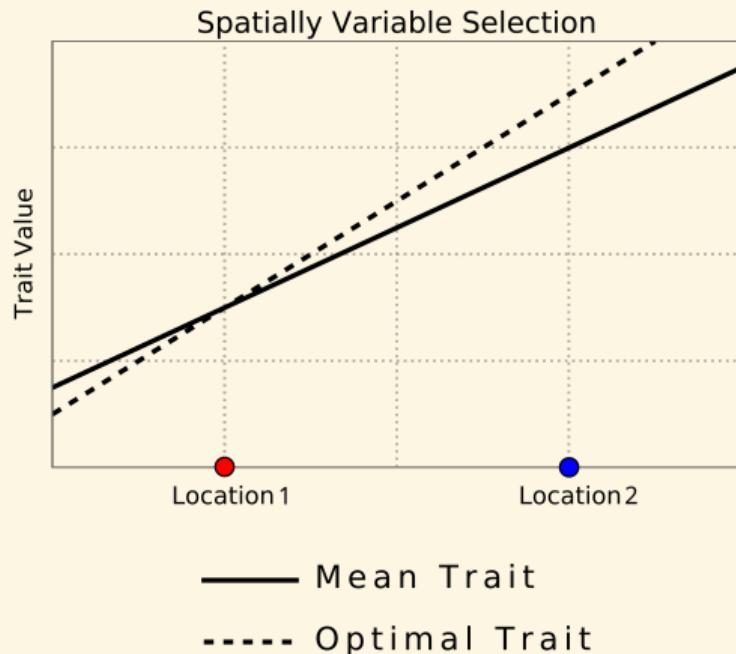
# Measure Along a Transect



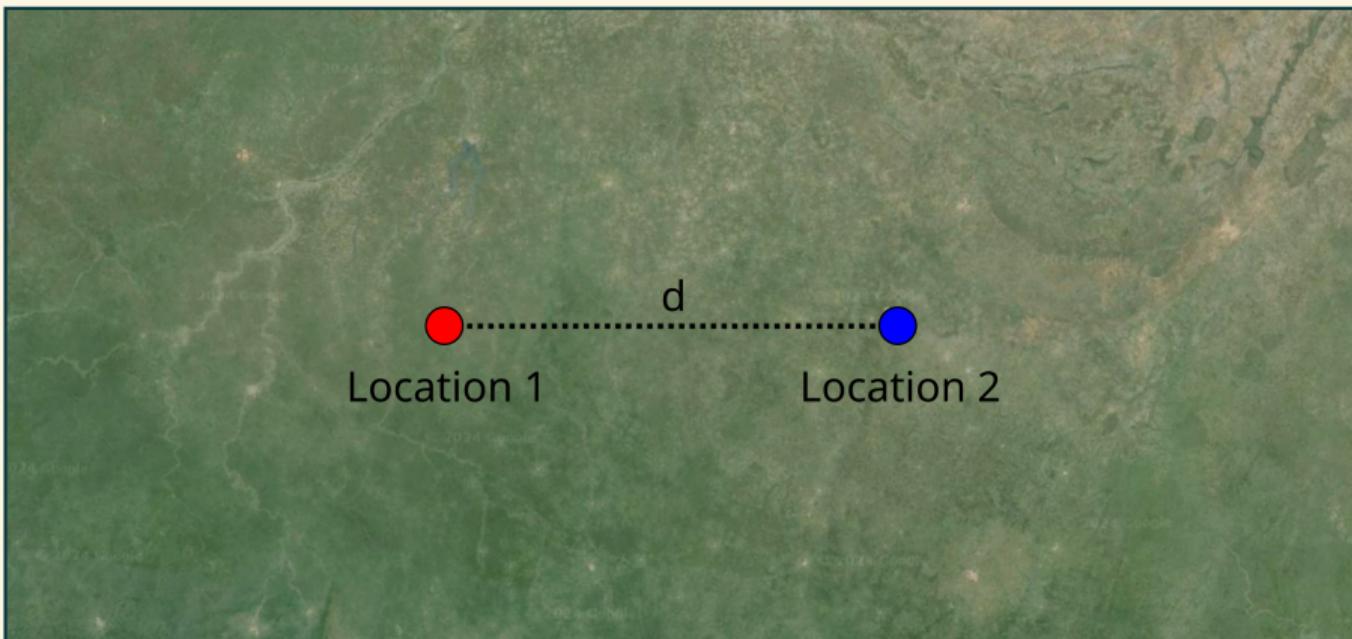
# Spatially Variable Selection Leads to Local Adaptation



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# Strength of Local Adaptation Depends on Distance



# Hoverfly Parasite is Locally Adapted to Ant Host

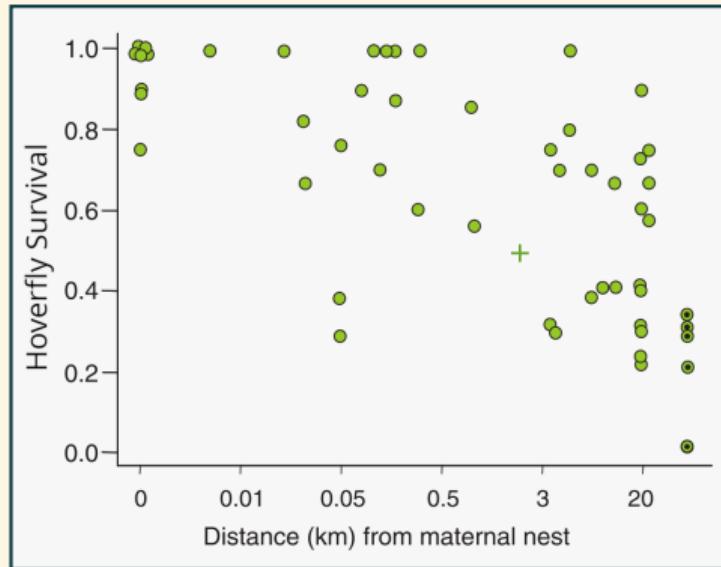


Courtesy [arthropodafotos.de](http://arthropodafotos.de)



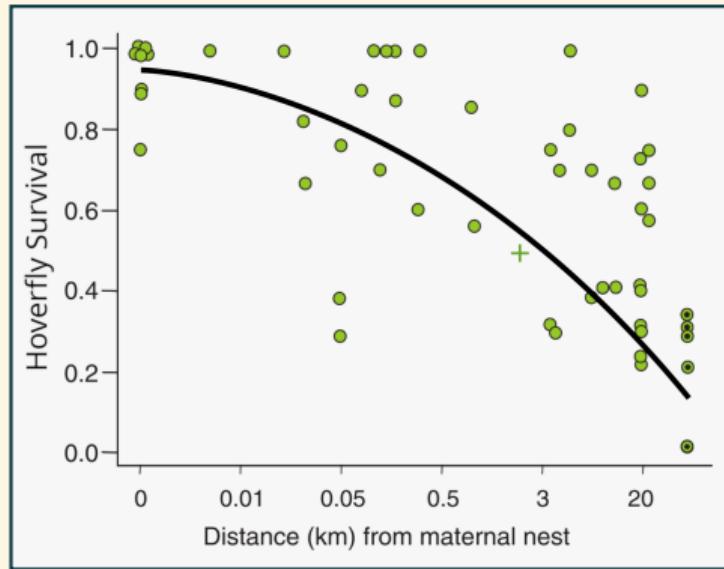
Courtesy [linsecterie.com](http://linsecterie.com)

# Parasite Local Adaptation Varies Across Spatial Scales



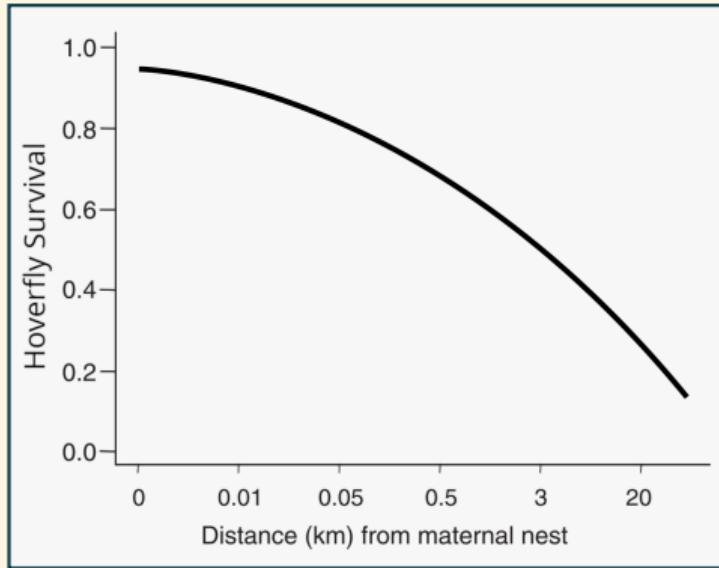
Courtesy Schönrogge et al. (2006)

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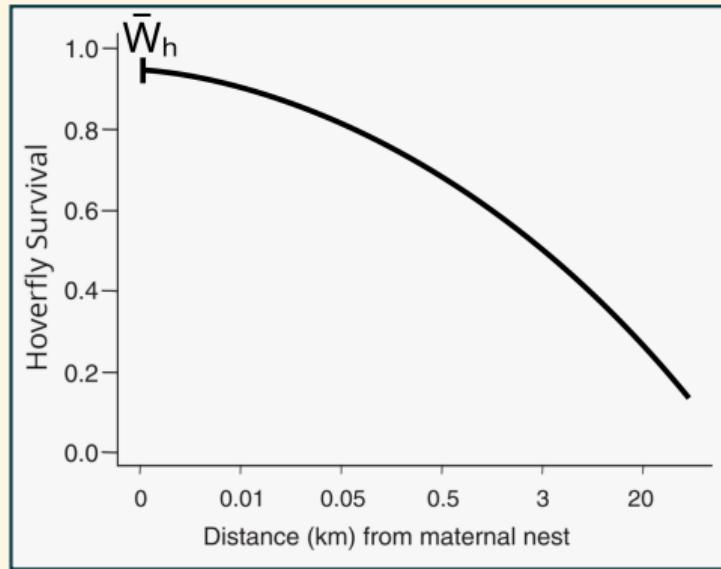
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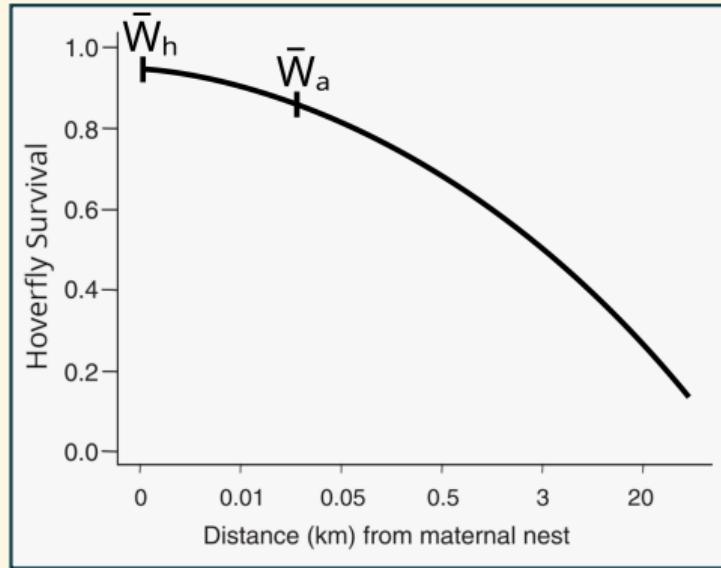
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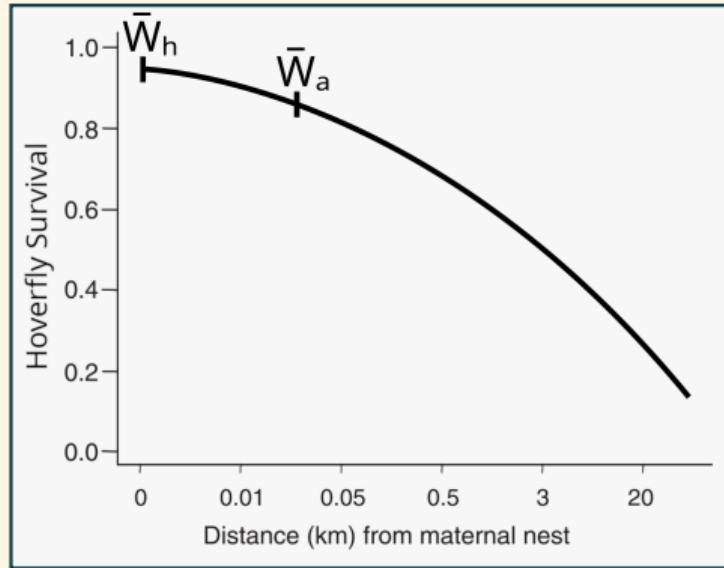
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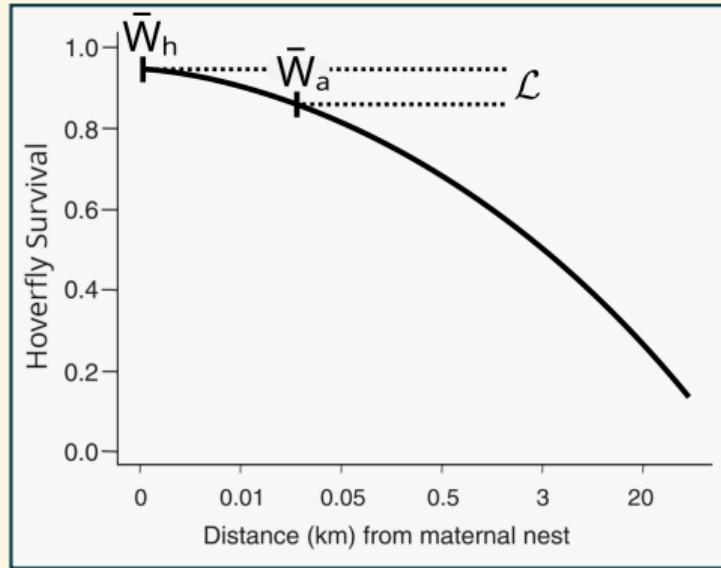
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- $\mathcal{L} = \bar{W}_h - \bar{W}_a$

Courtesy Schönrogge et al. (2006)

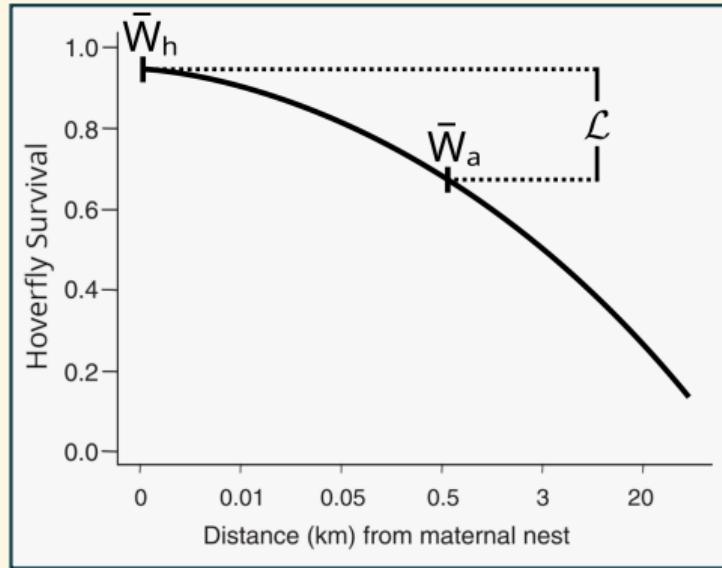
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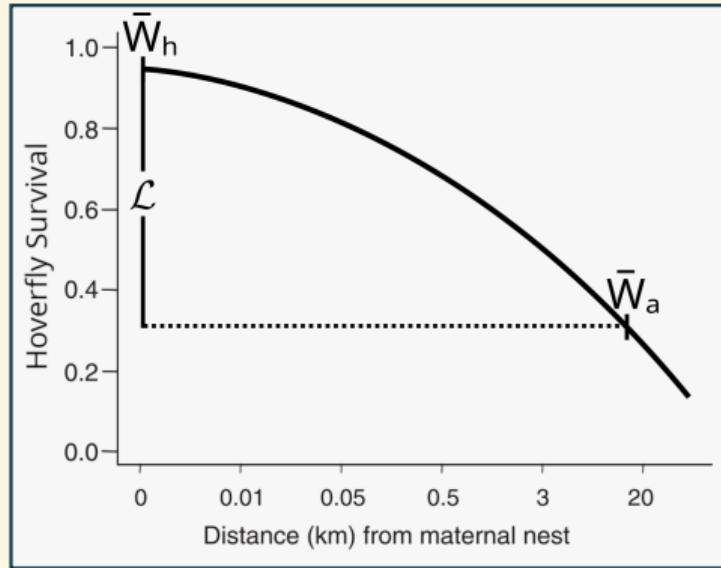
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- Moderate at intermediate distances

Courtesy Schönrogge et al. (2006)

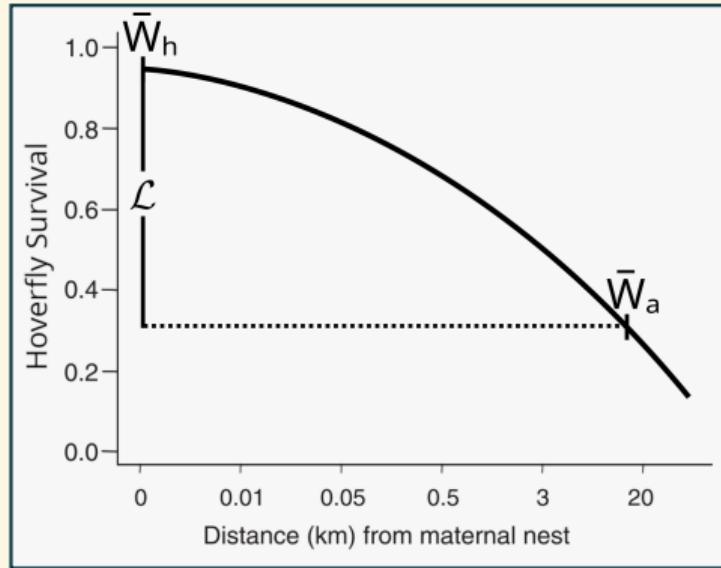
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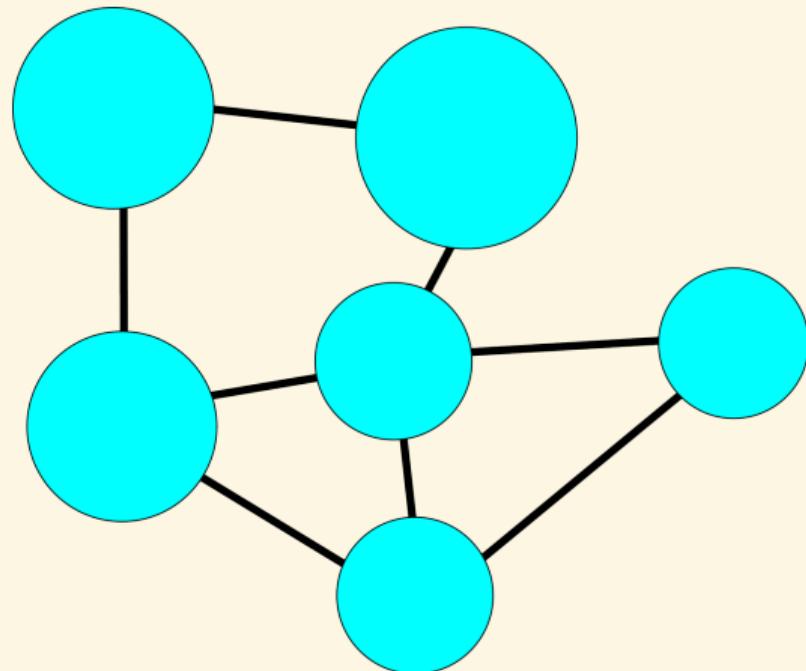


- $\mathcal{L} = \bar{W}_h - \bar{W}_a$
- Weak at shorter distances
- Moderate at intermediate distances
- Strong at further distances
  - Lacks theoretical explanation

Courtesy Schönrogge et al. (2006)

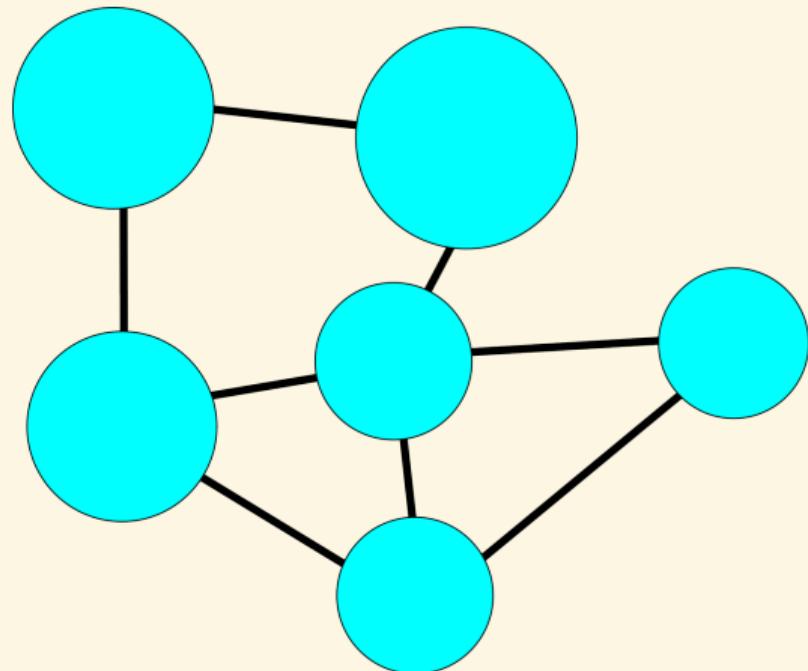
## Classical Indices of Local Adaptation Ignore Distance

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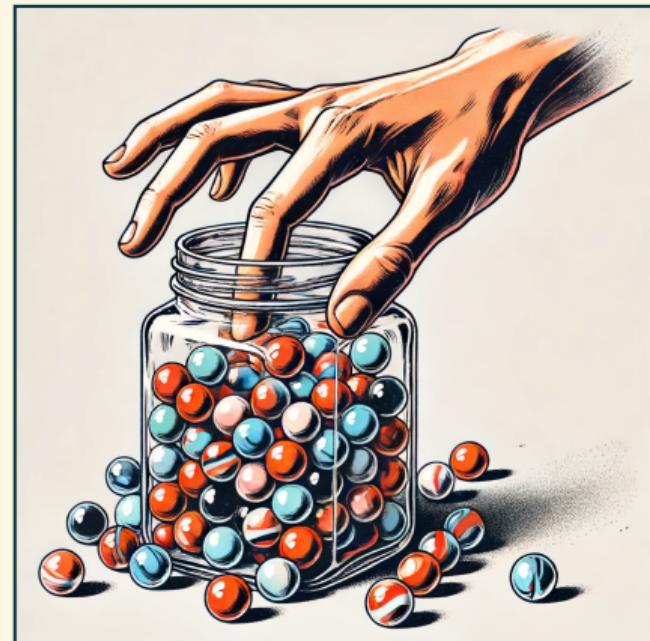


A Metapopulation

# Classical Indices of Local Adaptation Ignore Distance



A Metapopulation



Randomly Picking Marbles

# Explaining Cross-Scale Variation in Parasite Local Adaptation

**Need:**

# Explaining Cross-Scale Variation in Parasite Local Adaptation

## Need:

1. A continuous space index of local adaptation:  $\mathcal{L}(d)$

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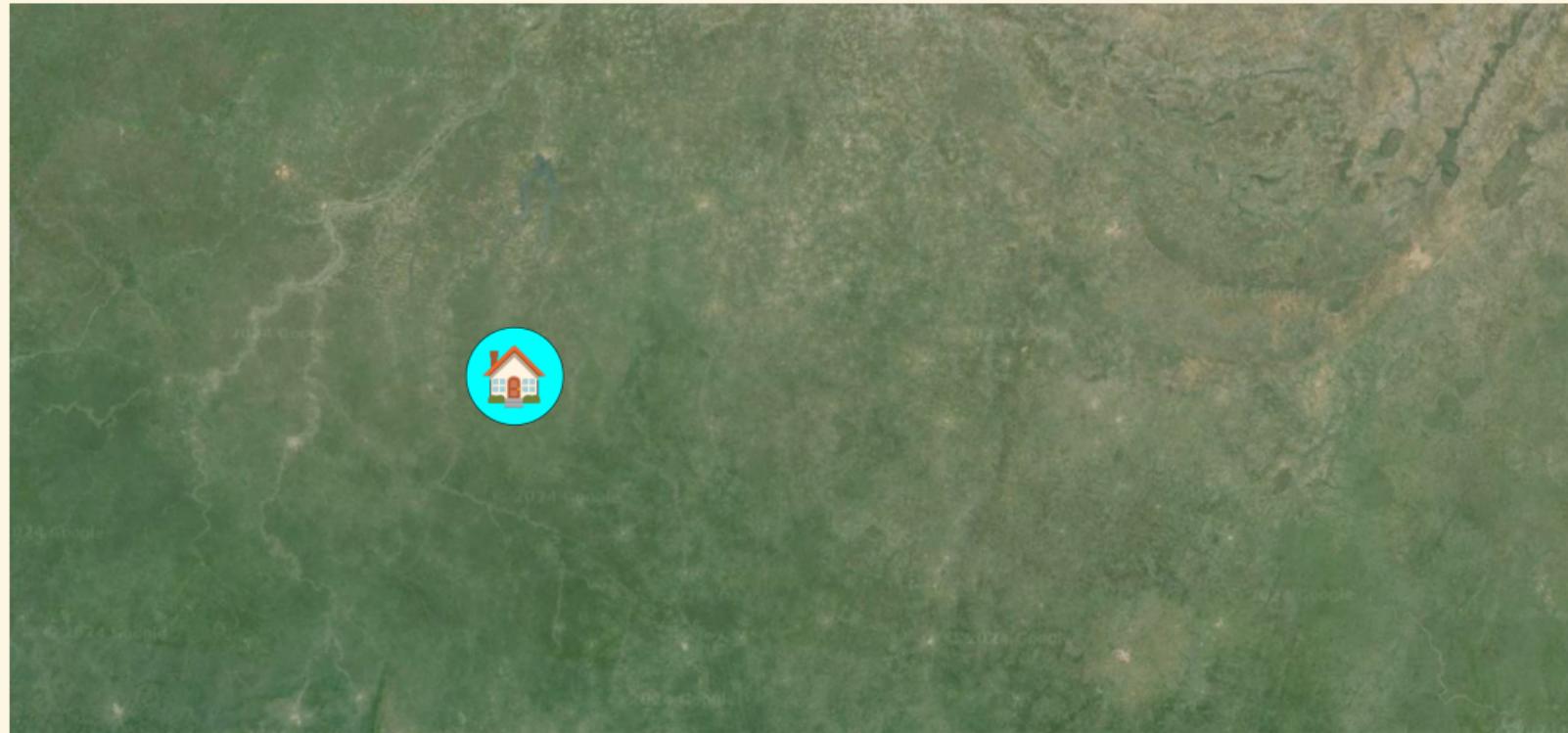
## Need:

1. A continuous space index of local adaptation:  $\mathcal{L}(d)$
2. A model of host-parasite coevolution: 

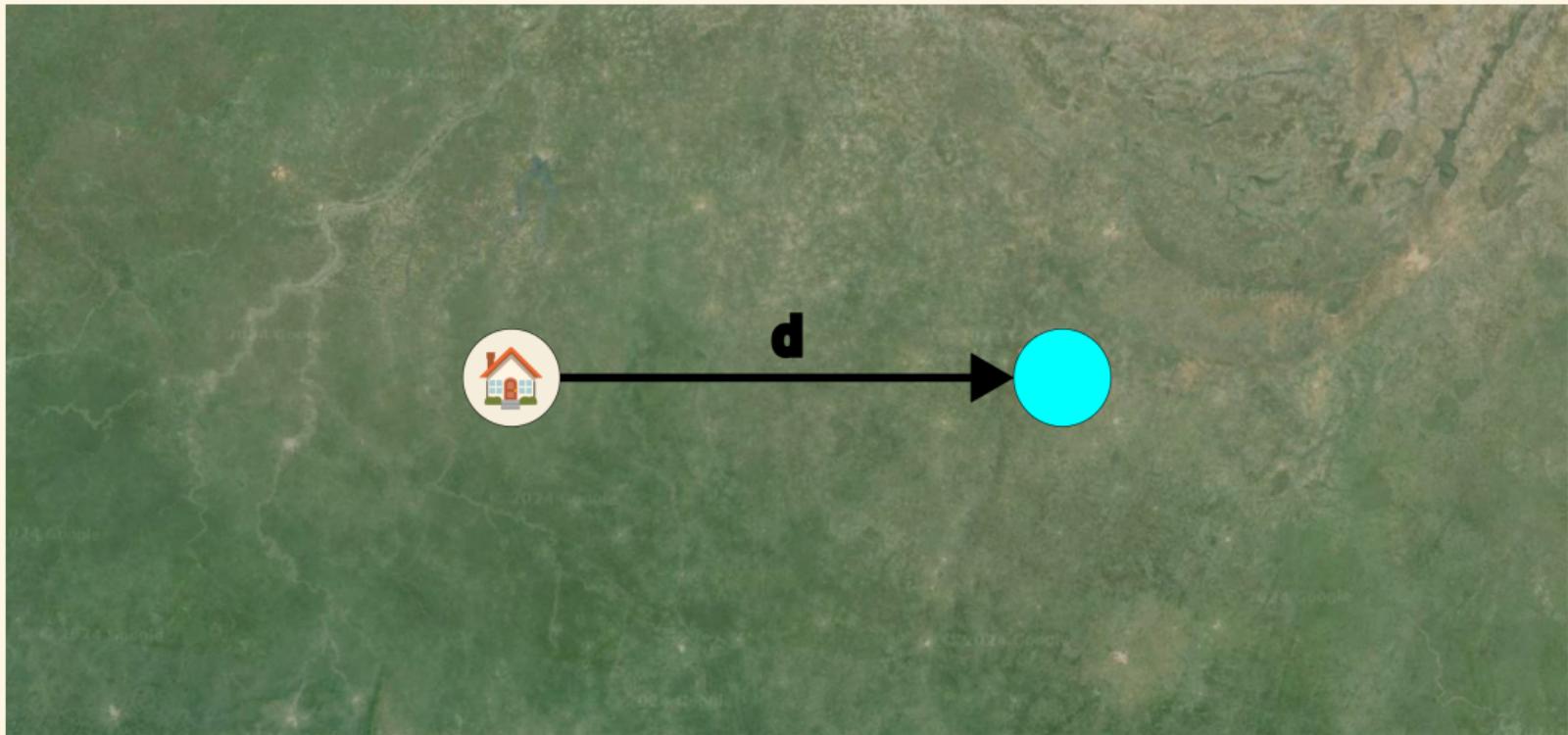
# To Measure Local Adaptation in Continuous Space



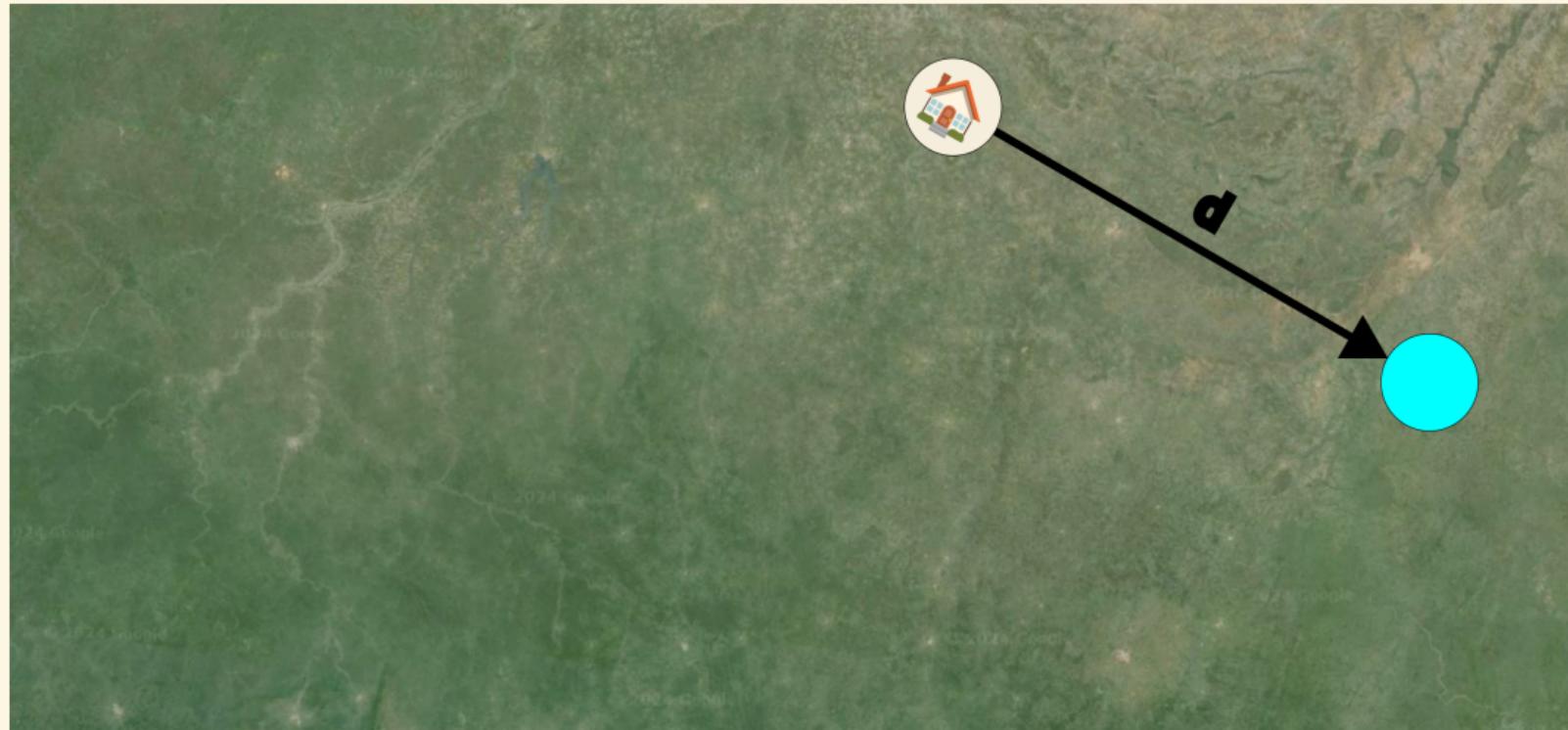
# Measure Fitness at Home



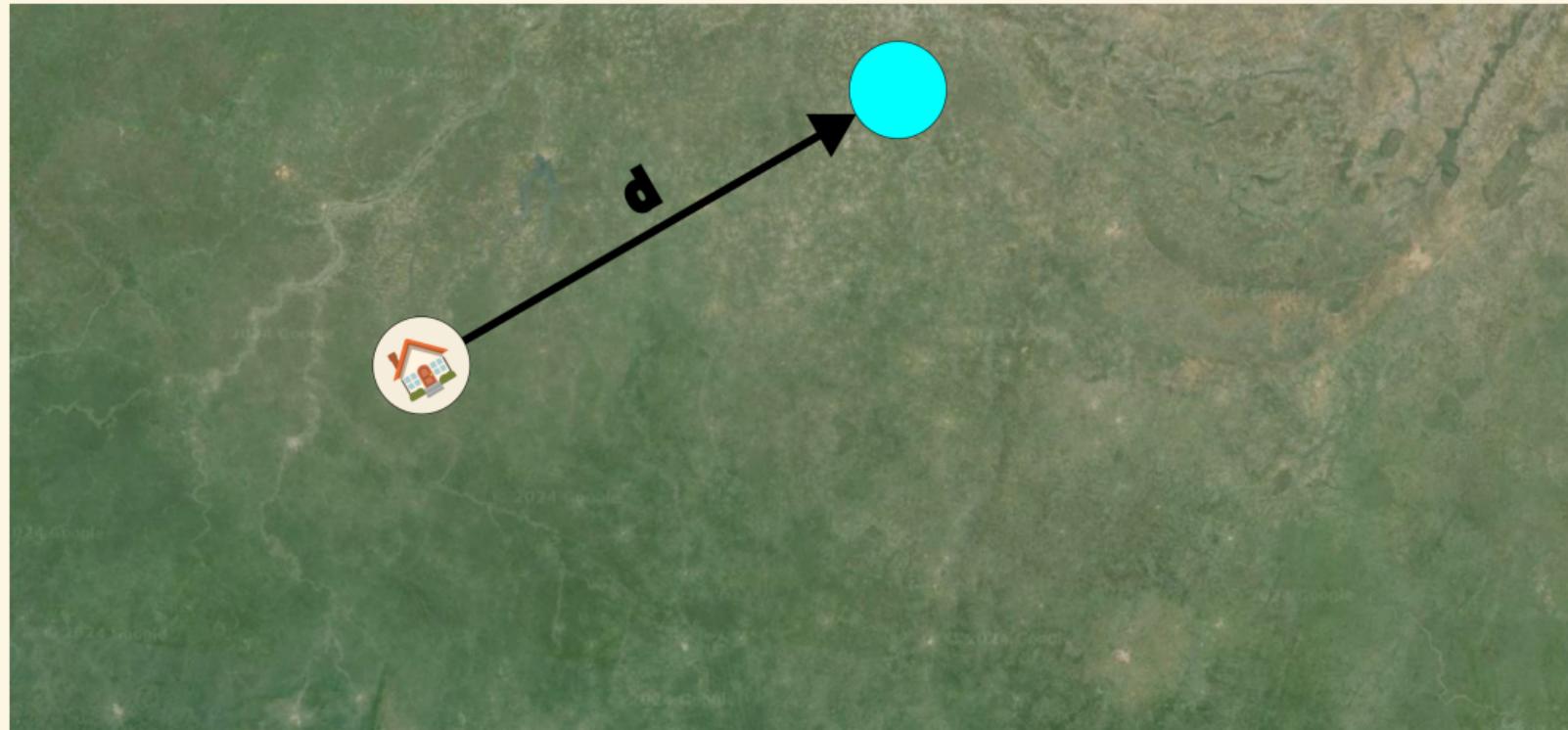
# Measure Fitness at Distance $d$



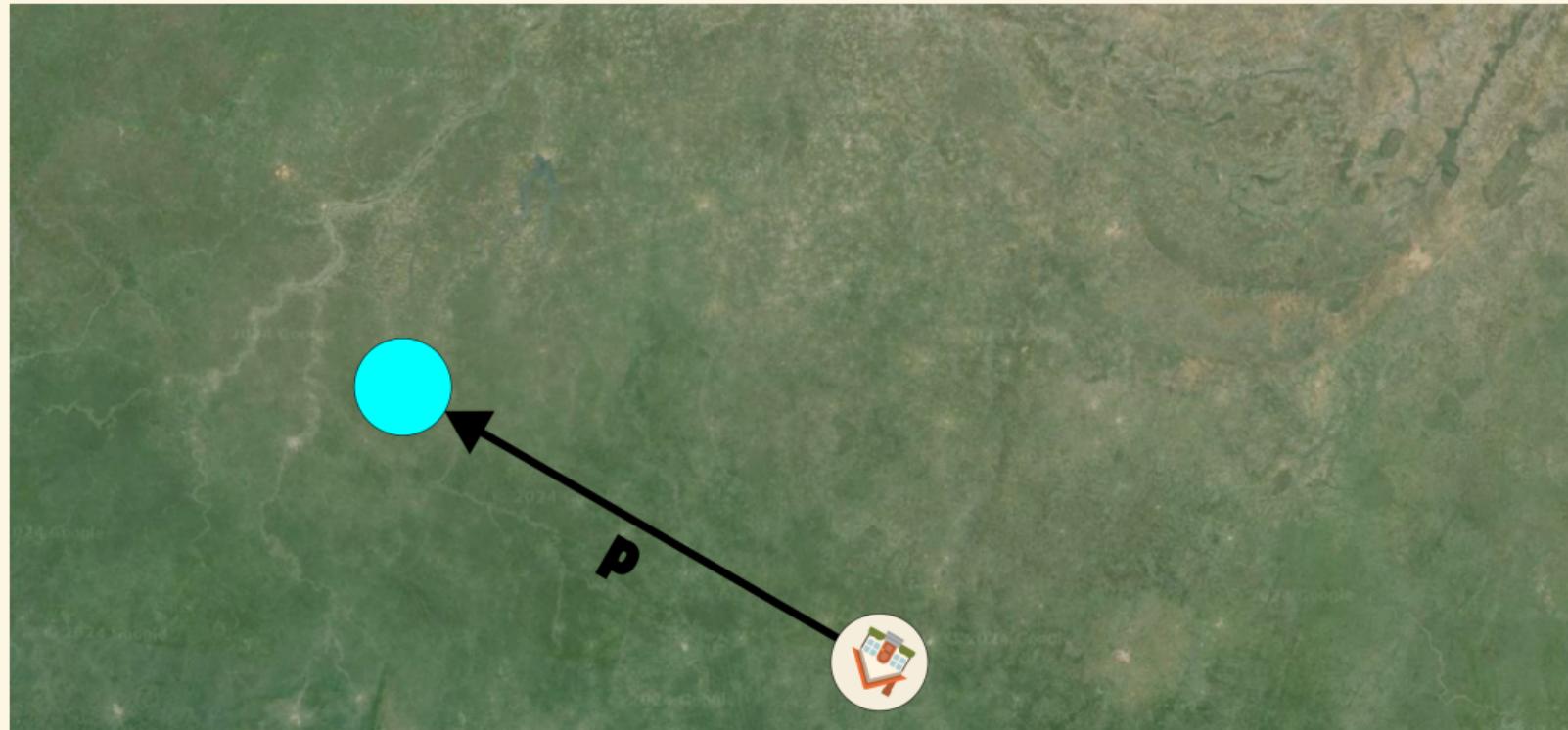
# Repeat While Keeping d Fixed



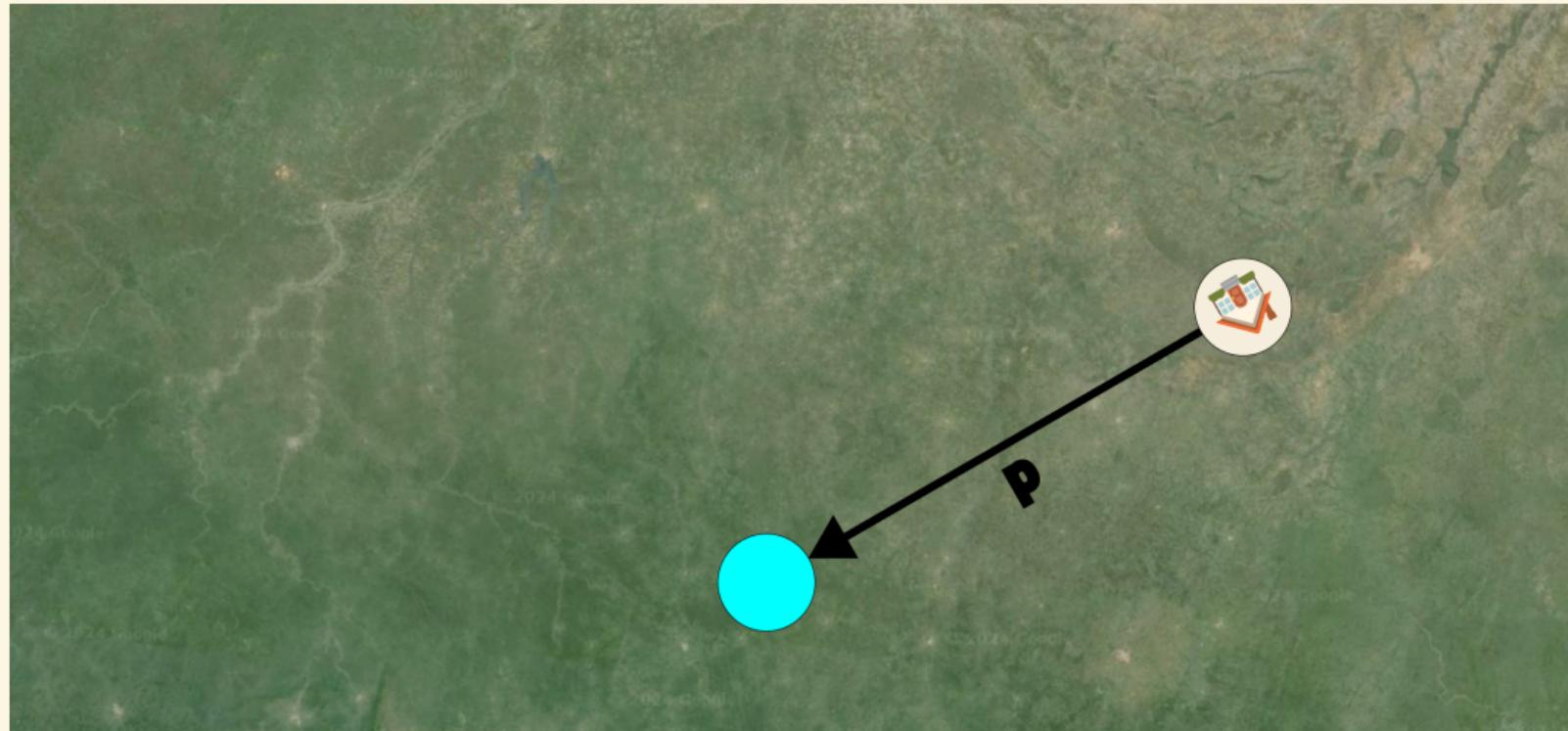
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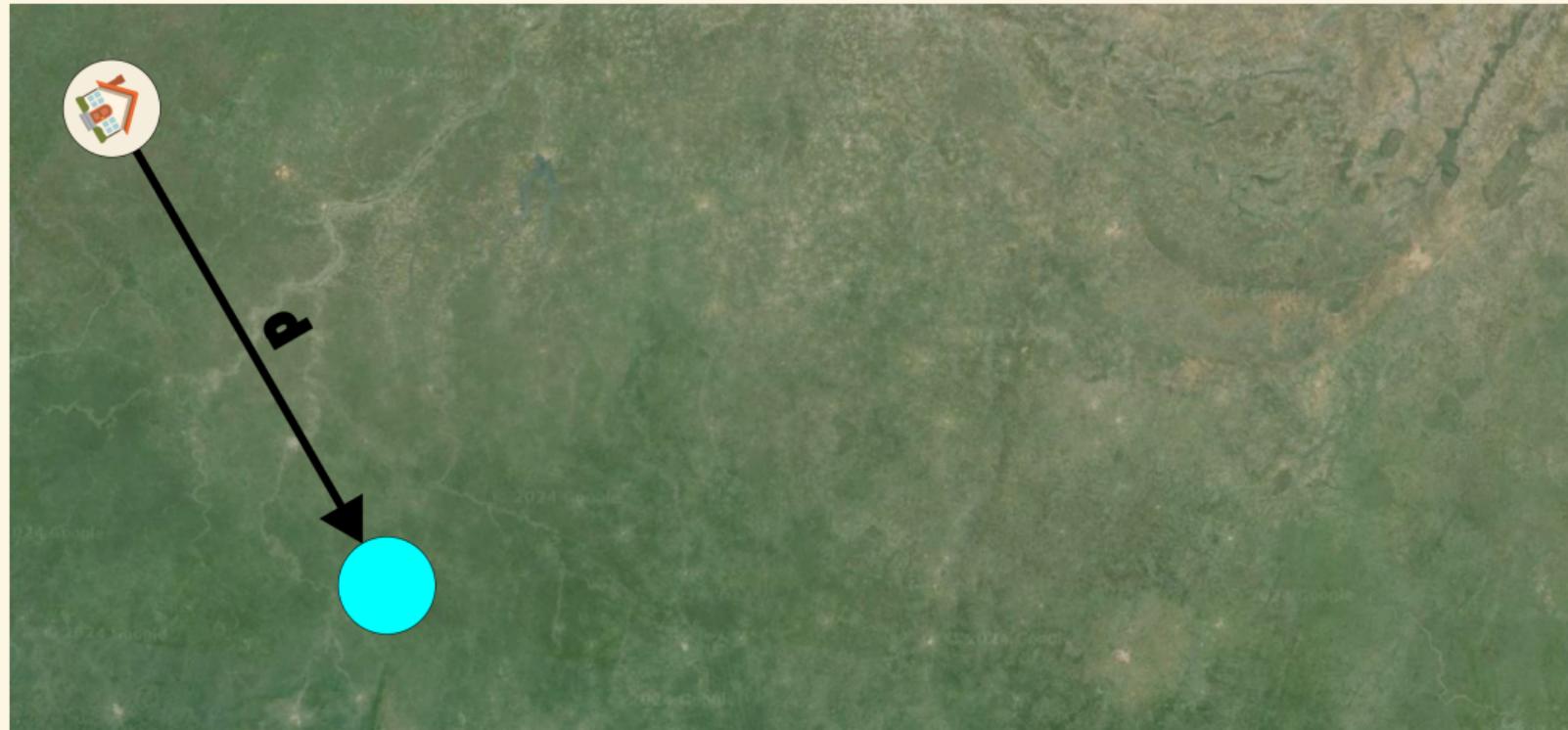
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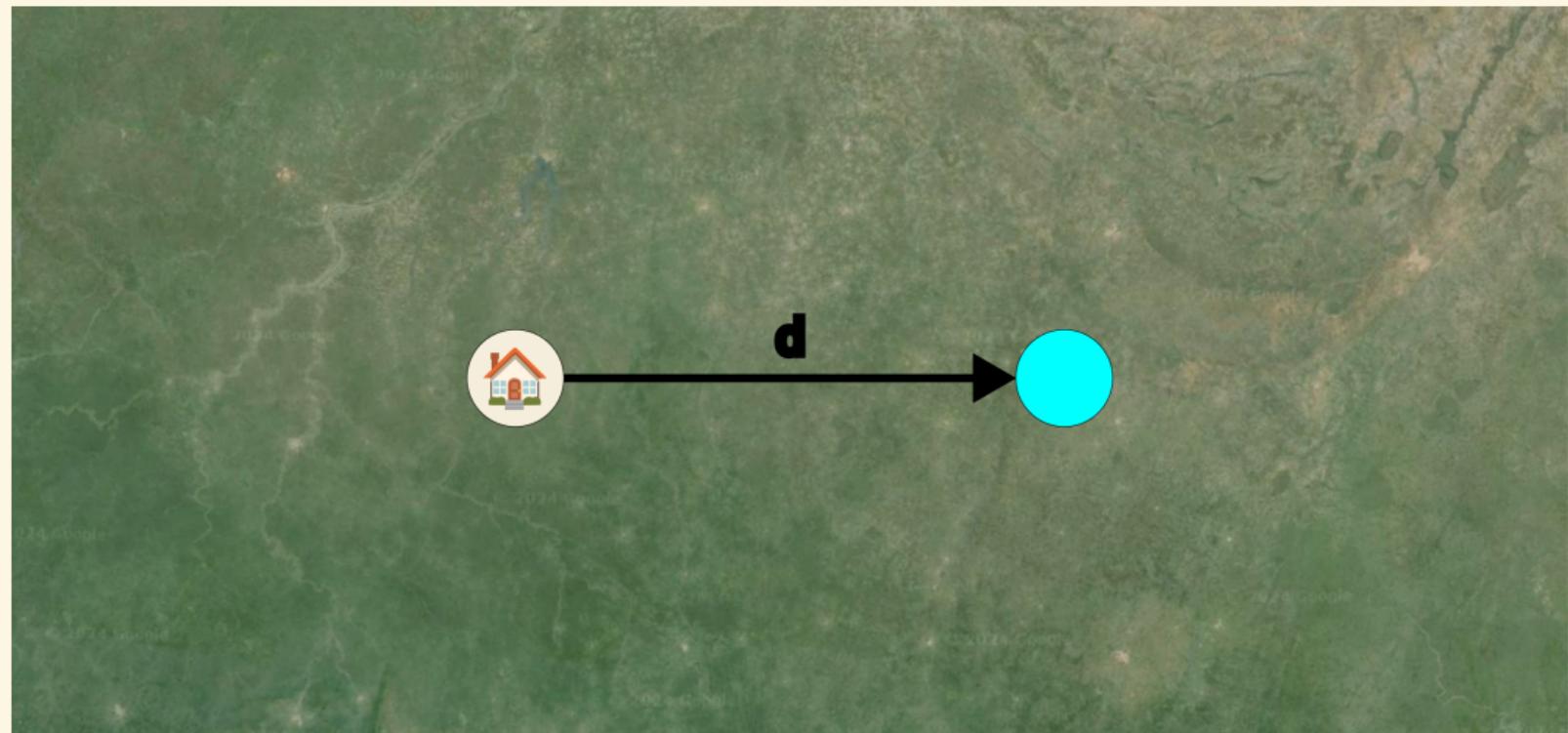
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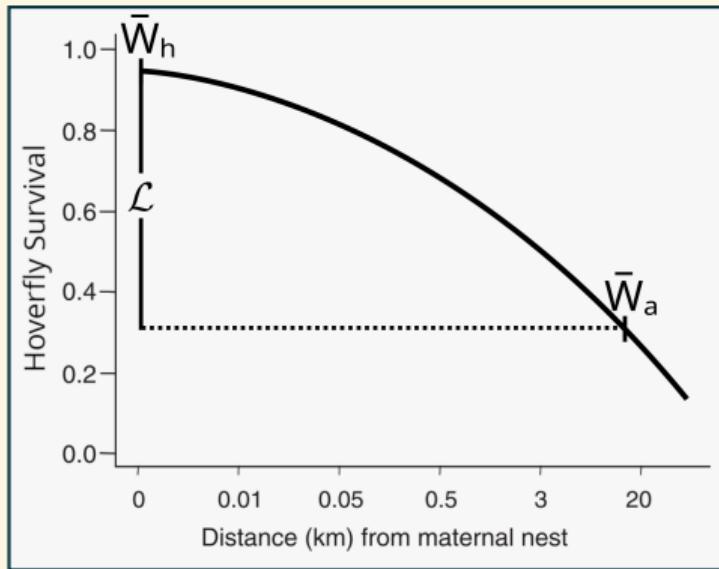
# Repeat While Keeping d Fixed



# Measures Local Adaptation as a Function of Distance: $\mathcal{L}(d)$

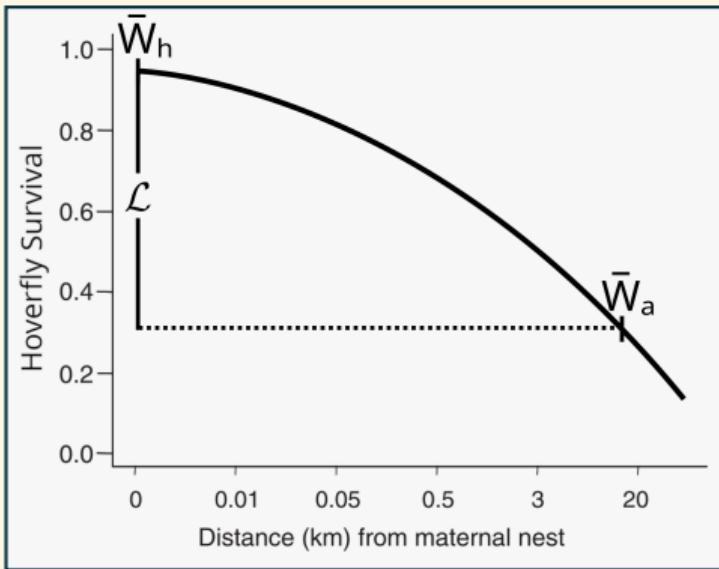


## $\mathcal{L}(d)$ Helps Measure Parasite Local Adaptation Variation

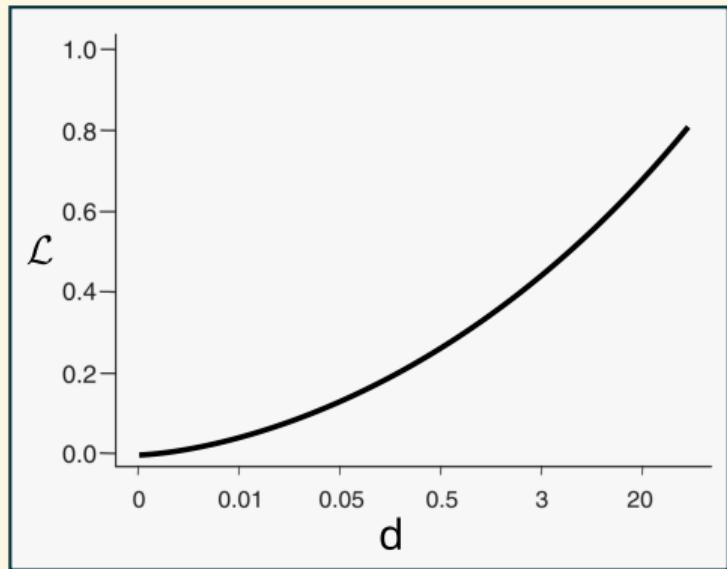


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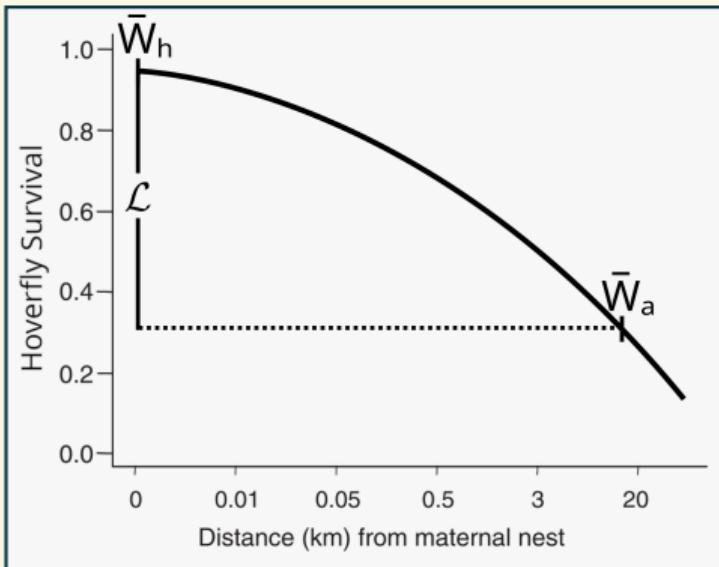


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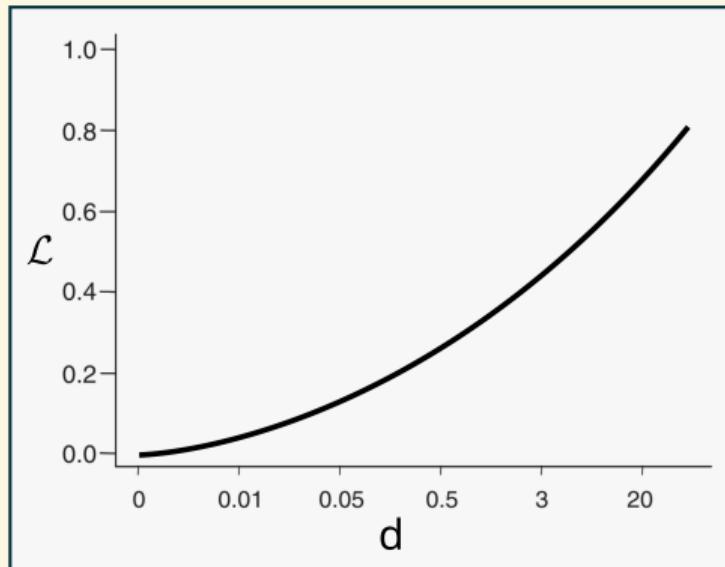


Continuous Space Index of Local Adaptation

# An Explanation Requires a Model



Courtesy Schönrogge et al. (2006)



Continuous Space Index of Local Adaptation

# A Model of Host-Parasite Coevolution in Continuous Space

**Three Main Components:**

# A Model of Host-Parasite Coevolution in Continuous Space

## Three Main Components:

- Random Genetic Drift 

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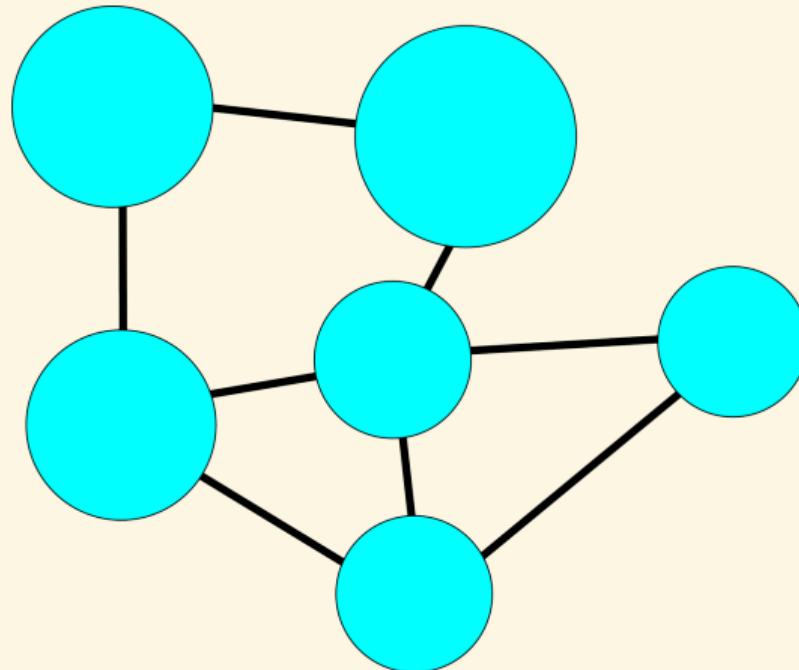
- Random Genetic Drift 
- Host-Parasite Interactions 
- Dispersal 

# Random Genetic Drift

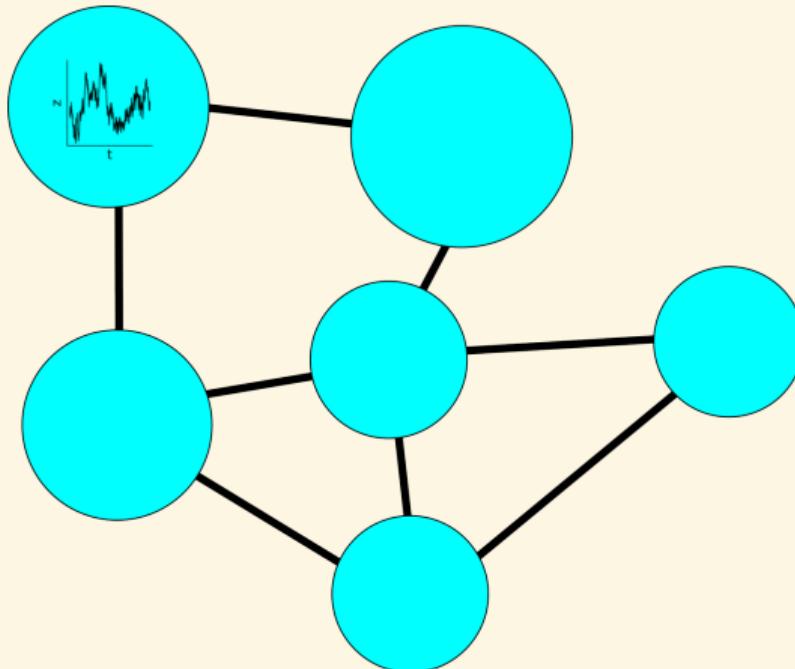


Stochastic evolution resulting from finite population size

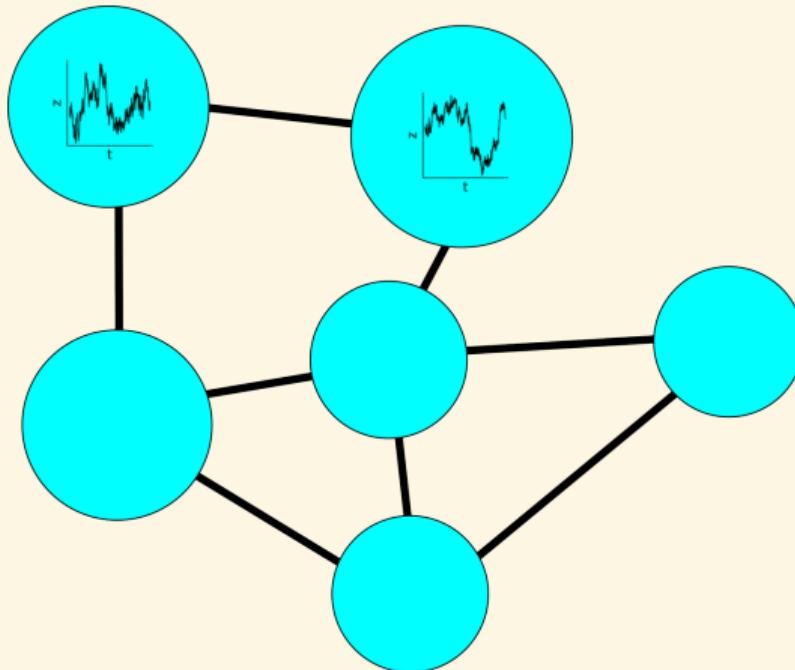
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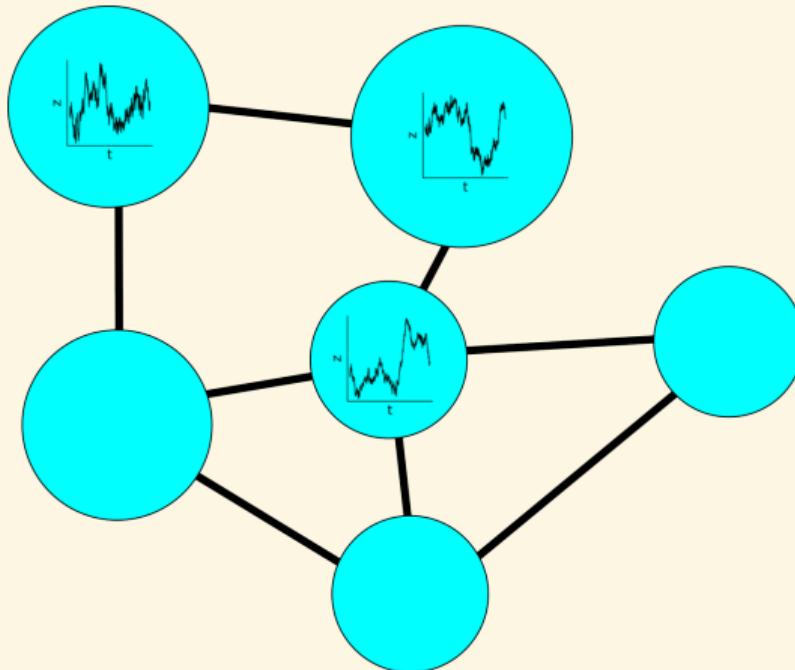
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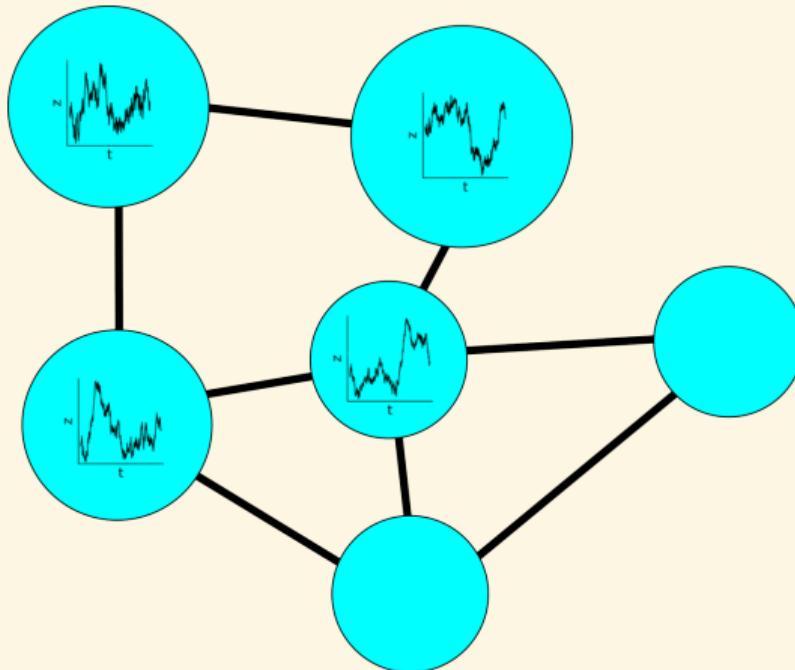
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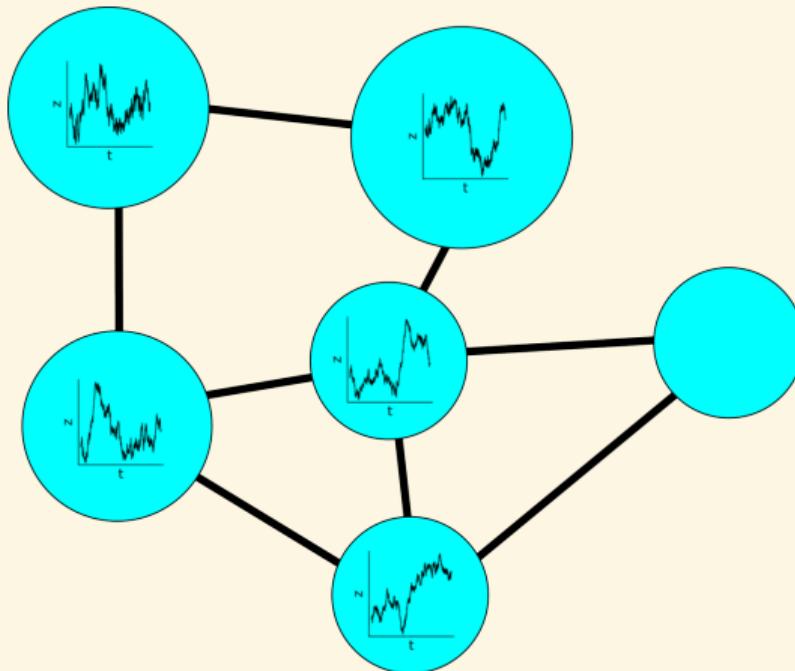
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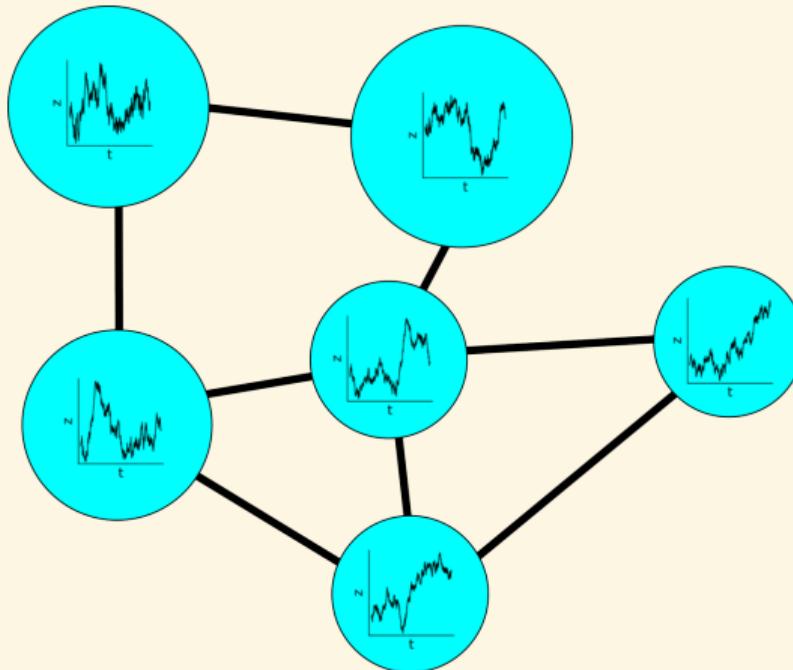
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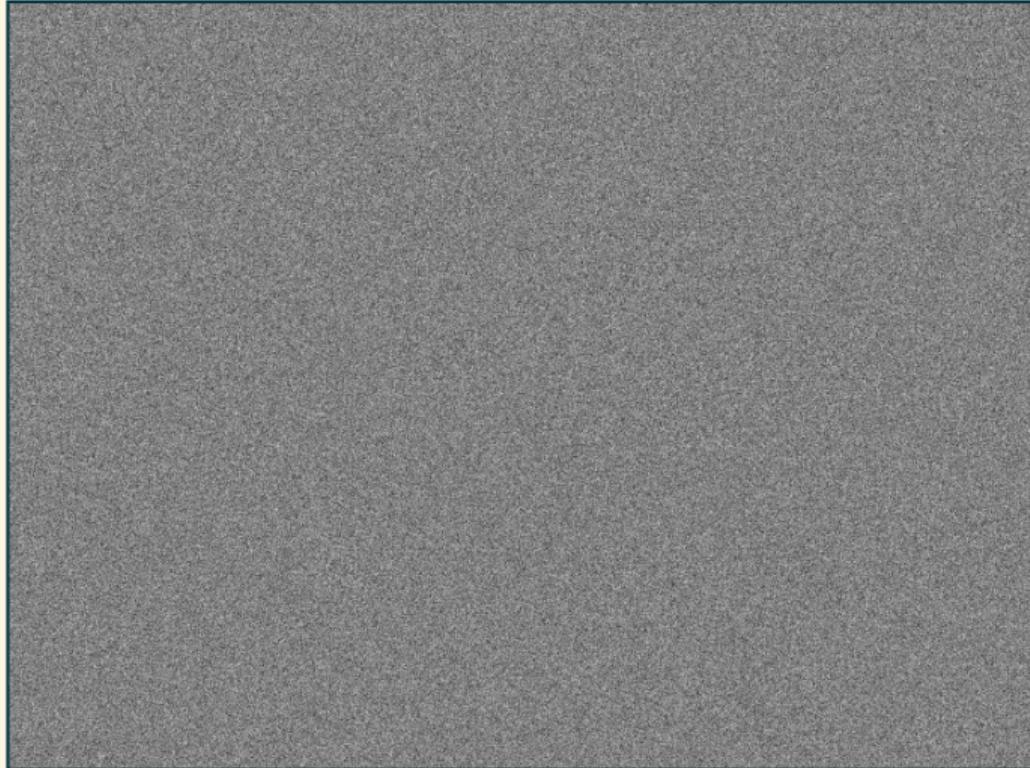
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# Random Genetic Drift in Continuous Space



# Random Genetic Drift in Continuous Space



White Noise

# Coevolution is a Consequence of Interactions

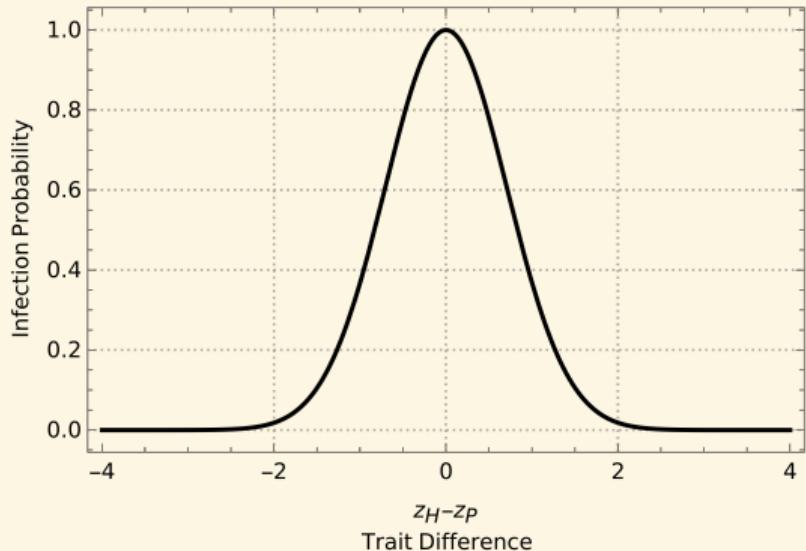


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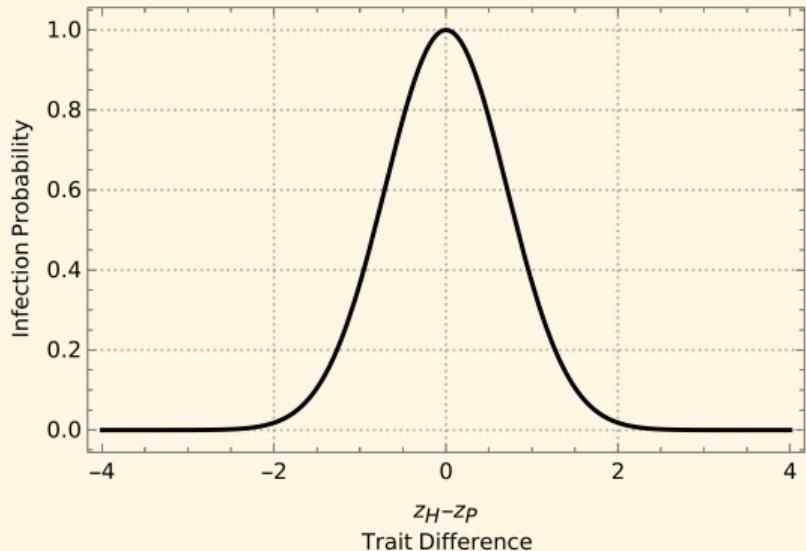


Interaction = Infection of host by parasite

## **Assumption:** Infection Increases with Trait Similarity

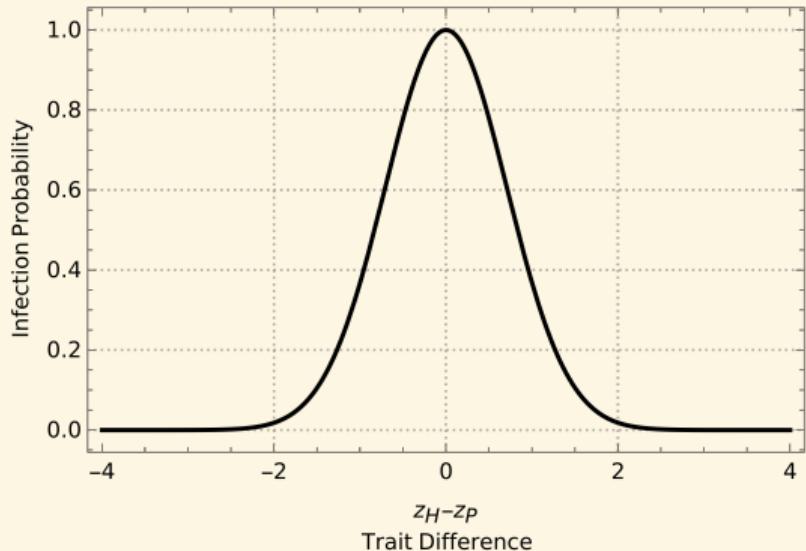


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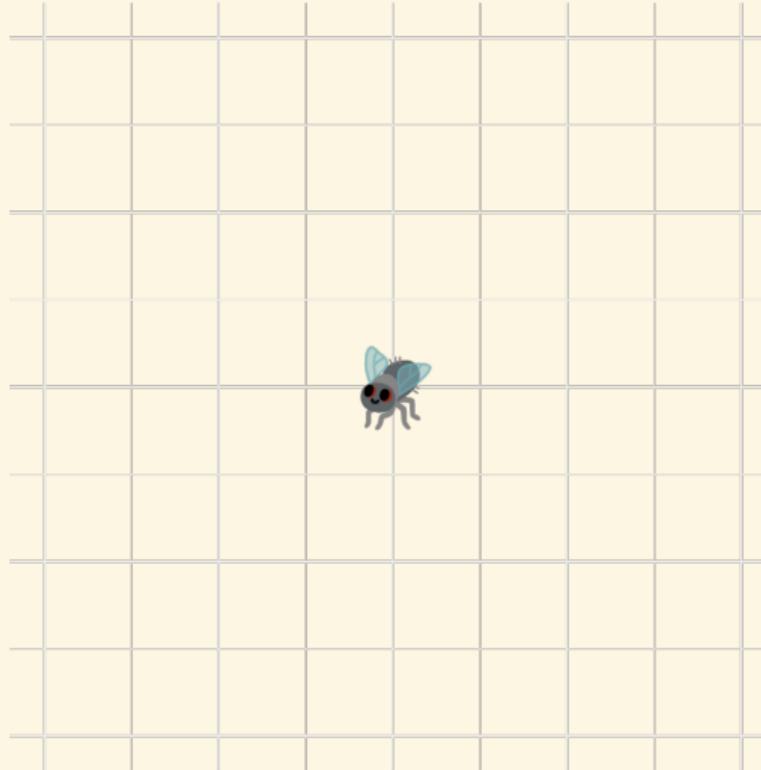
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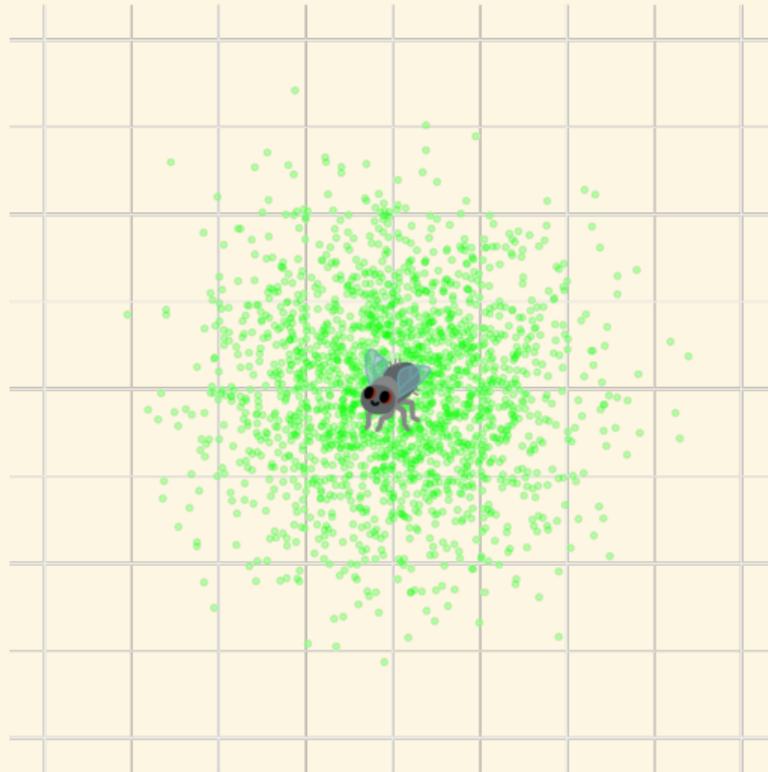


- $z_H$  = Individual host trait 
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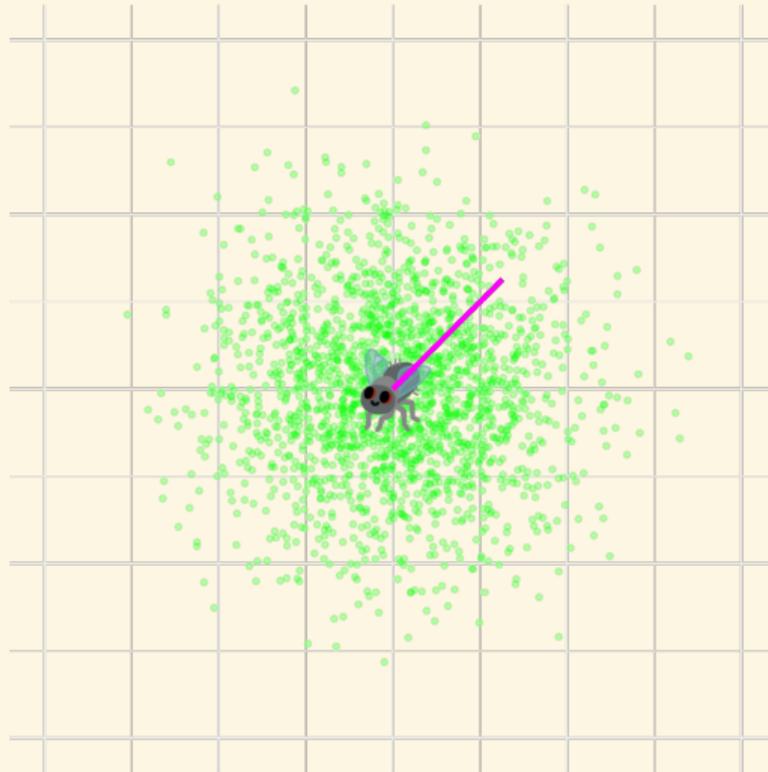
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$$\Delta \bar{z}_H = (\vec{v}_H \times \vec{B}_H) + \vec{\alpha}_H$$

# The Resulting Model

$$\Delta \bar{z}_H = (\text{wind} \times \text{wind})_H + \text{wind}_H + \text{wind}_H$$

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$$\Delta \bar{Z}_H = (\text{🐜} \times \text{🦋})_H + \text{✈️}_H + \text{🎲}_H$$

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# Host-Parasite Local Adaptation in Continuous Space

$$(\Delta\bar{z}_H, \Delta\bar{z}_P)$$

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$$(\Delta\bar{z}_H, \Delta\bar{z}_P) + \mathcal{L}(\mathbf{d})$$

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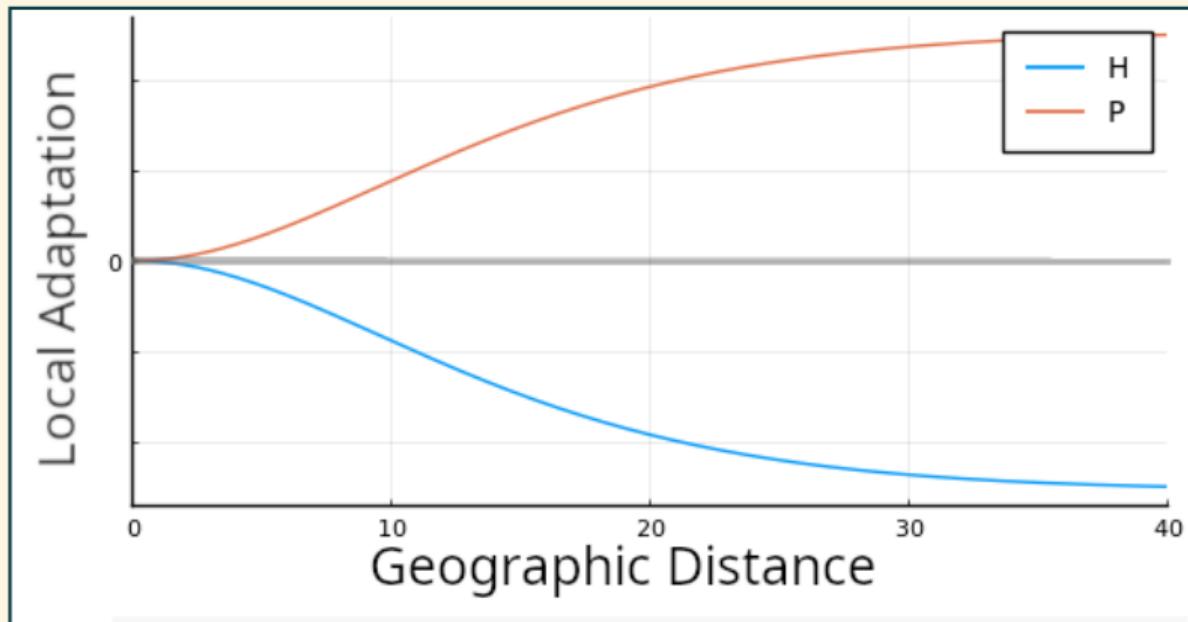
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## **Result:** Local Adaptation Depends on Spatial Distance



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# Cross-Covariance is Crucial for Local Adaptation

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But what causes Cross-Covariance?

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# Cross-Covariance is Crucial for Local Adaptation

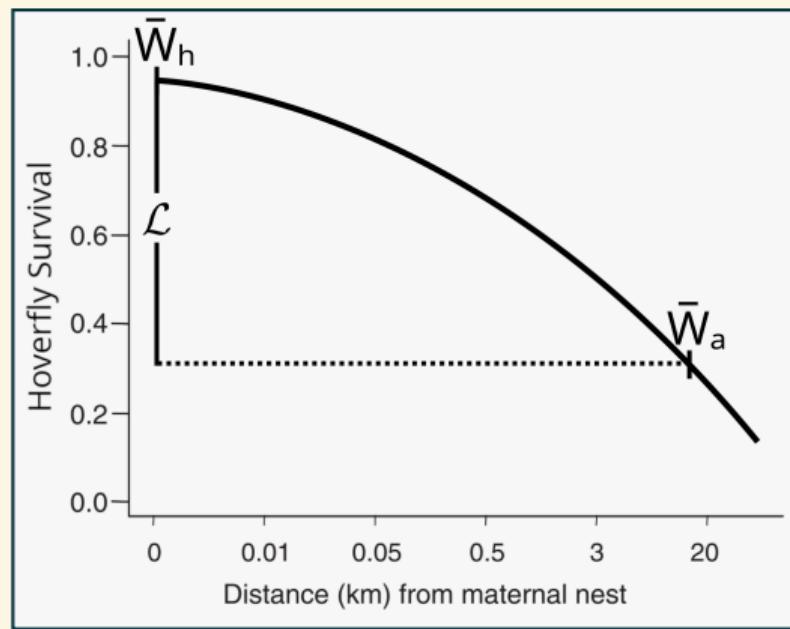
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- **Interaction strengths**
- **Disperal distances**

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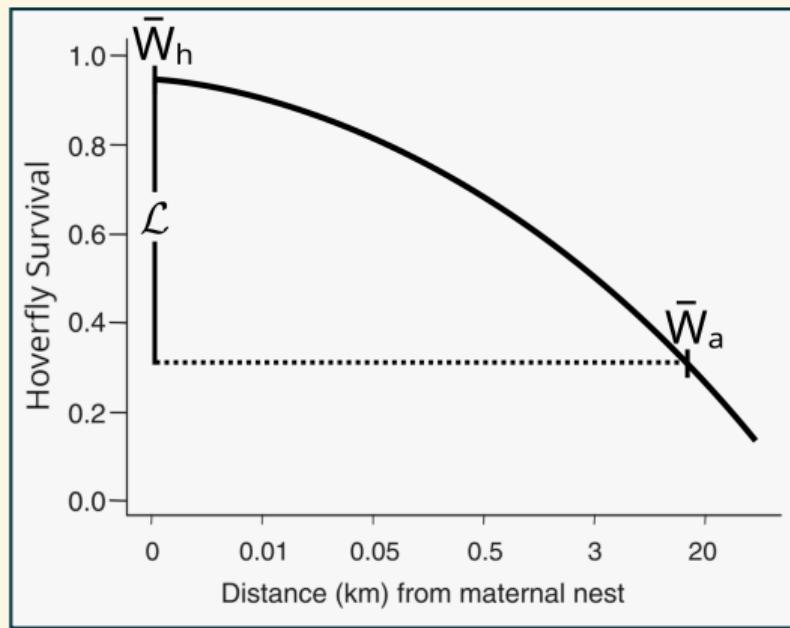
$$\mathcal{L}_P(d) = S_P(C_{HP}(0) - C_{HP}(d))$$

# Q: What Causes Spatial Variation of Parasite Local Adaptation?



Courtesy Schönrogge et al. (2006)

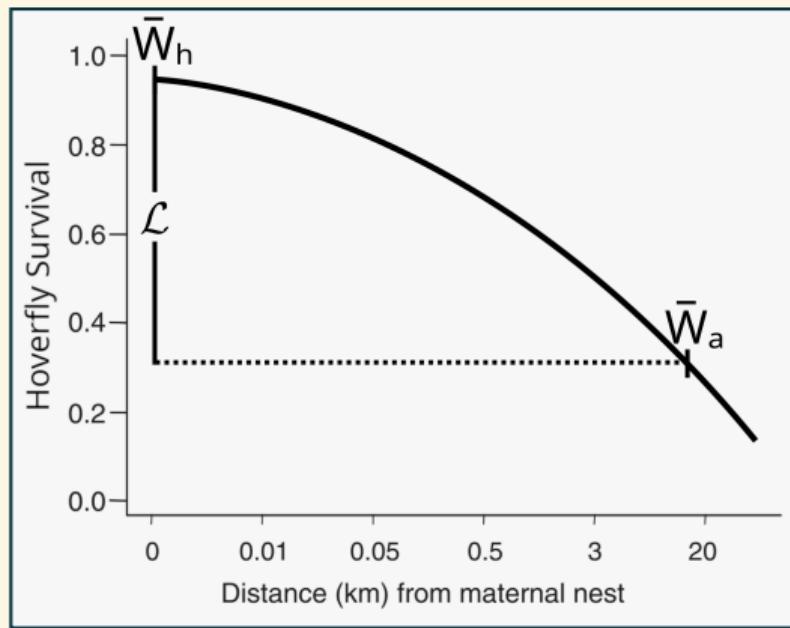
# Q: What Causes Spatial Variation of Parasite Local Adaptation?



**A: Cross-Covariance**

Courtesy Schönrogge et al. (2006)

# Q: What Causes Spatial Variation of Parasite Local Adaptation?



**A: Dispersal×Selection**

Courtesy Schönrogge et al. (2006)

# Recap

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- New continuous space index of local adaptation  $\mathcal{L}(\mathbf{d})$

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- New model of spatial host-parasite coevolution 

# Recap

- New continuous space index of local adaptation  $\mathcal{L}(\mathbf{d})$
- New model of spatial host-parasite coevolution 
- An explanation for spatial variation of parasite local adaptation

See Paper for Full Story

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## Host-Parasite Coevolution in Continuous Space Leads to Variation in Local Adaptation across Spatial Scales

Bob Week<sup>1,\*</sup> and Gideon Bradburd<sup>2</sup>

## **Part 2: Microbiome-Mediated Host Adaptation**

## Examples of Microbiome-Mediated Host Traits

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Human gut microbiome  
aids in nutrient absorption

# Examples of Microbiome-Mediated Host Traits



Human gut microbiome  
aids in nutrient absorption



Fish skin microbiome  
protects against pathogens

# Hosts Inherit Microbes Differently from Genes

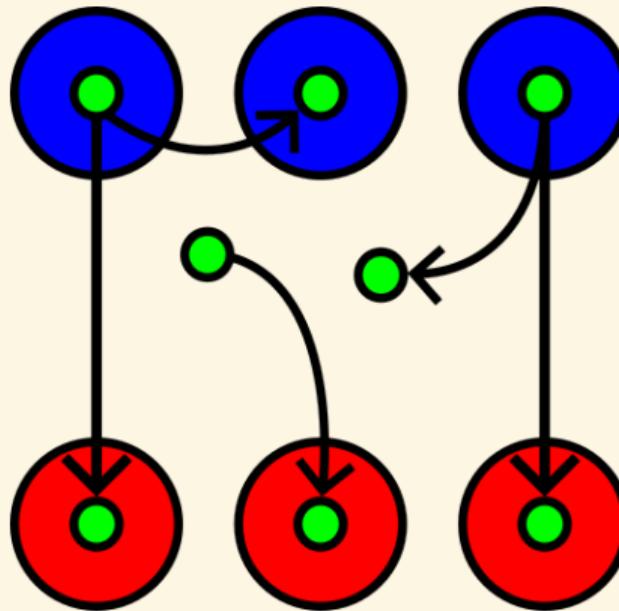


Inheritance of Genes

# Hosts Inherit Microbes Differently from Genes



Inheritance of Genes

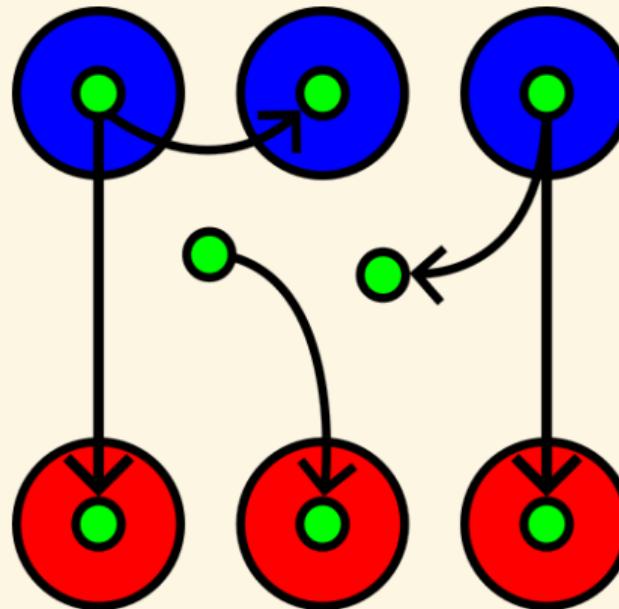


Inheritance of Microbes

# How do Microbiome-Mediated Host Traits Evolve?



Inheritance of Genes



Inheritance of Microbes

# A Model of Microbiome-Mediated Trait Evolution

**Three Main Components:**

# A Model of Microbiome-Mediated Trait Evolution

## Three Main Components:

- Host Life-Cycle 

# A Model of Microbiome-Mediated Trait Evolution

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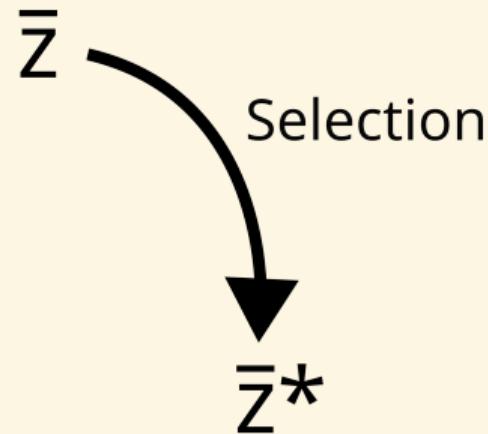
- Host Life-Cycle 
- Host Trait Architecture 

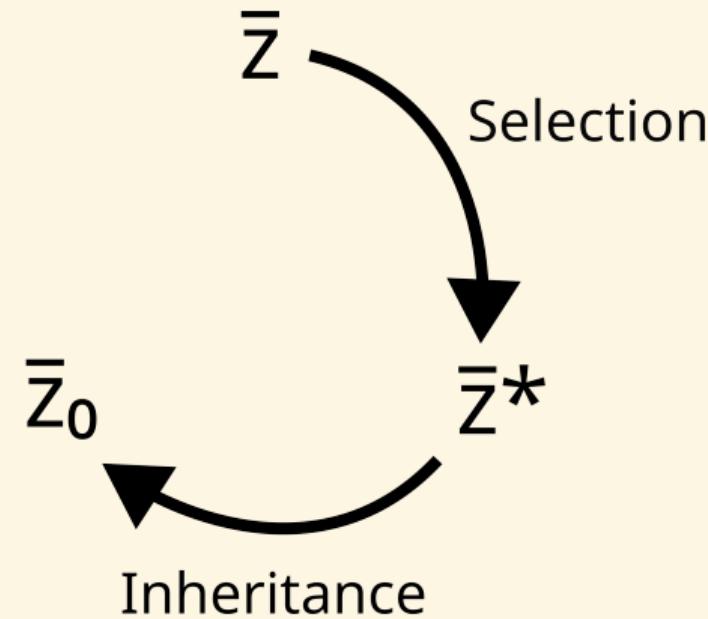
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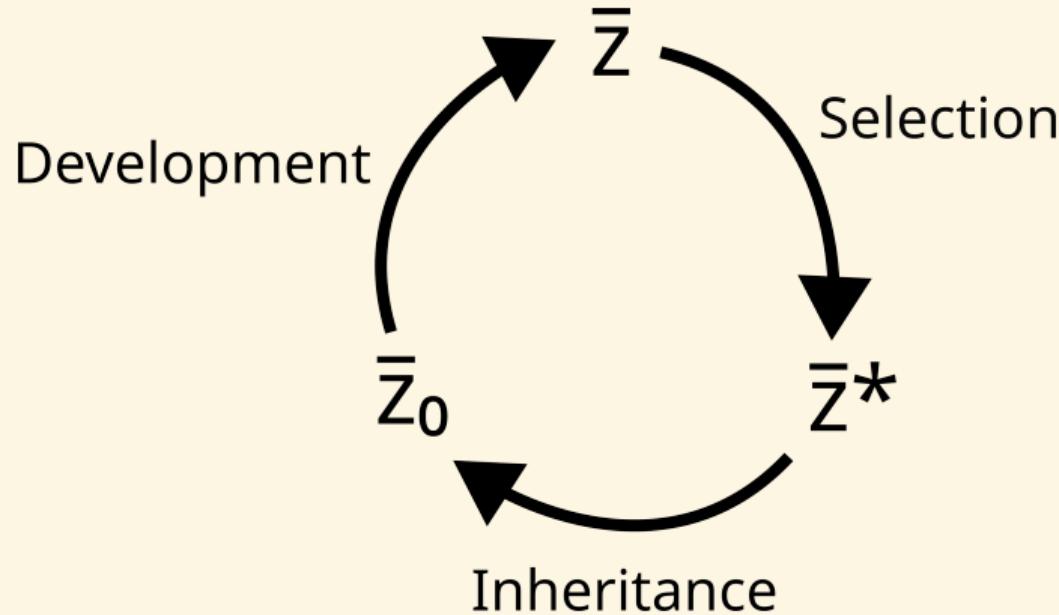
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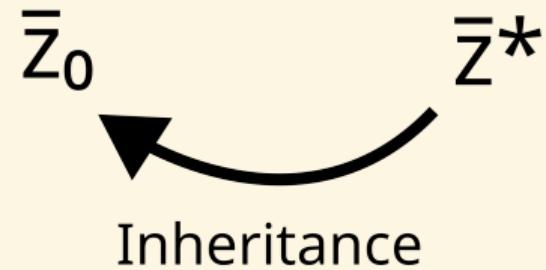
- Host Life-Cycle 
- Host Trait Architecture 
- Microbiome Inheritance 

$\bar{z}$









# Host Trait Architecture



**Z =**



$$z = \hat{g}$$

Genetic  
Effect

# Host Trait Architecture



$$z = \hat{g} + \hat{m}$$

Genetic      Microbiome  
Effect           Effect

# Host Trait Architecture



$$z = \hat{g} + \hat{m}$$

Ignore  
Genetic Effect      Microbiome Effect

# Focusing on Microbiome Effect

$Z = m$

# Microbiome Inheritance



**Three Main Components:**



## Three Main Components:

- Parent-Offspring Transmission



## Three Main Components:

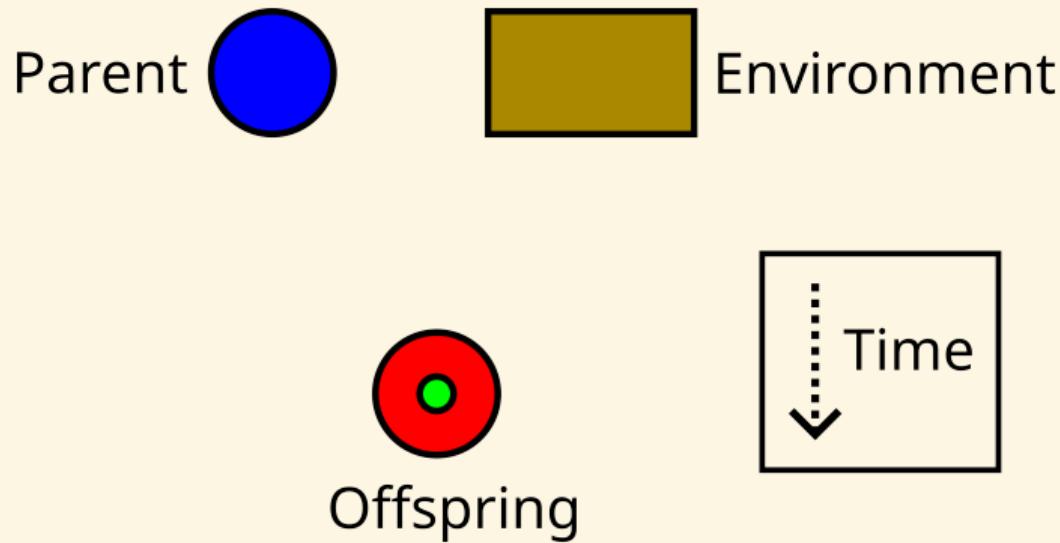
- Parent-Offspring Transmission
- Shedding into Environment



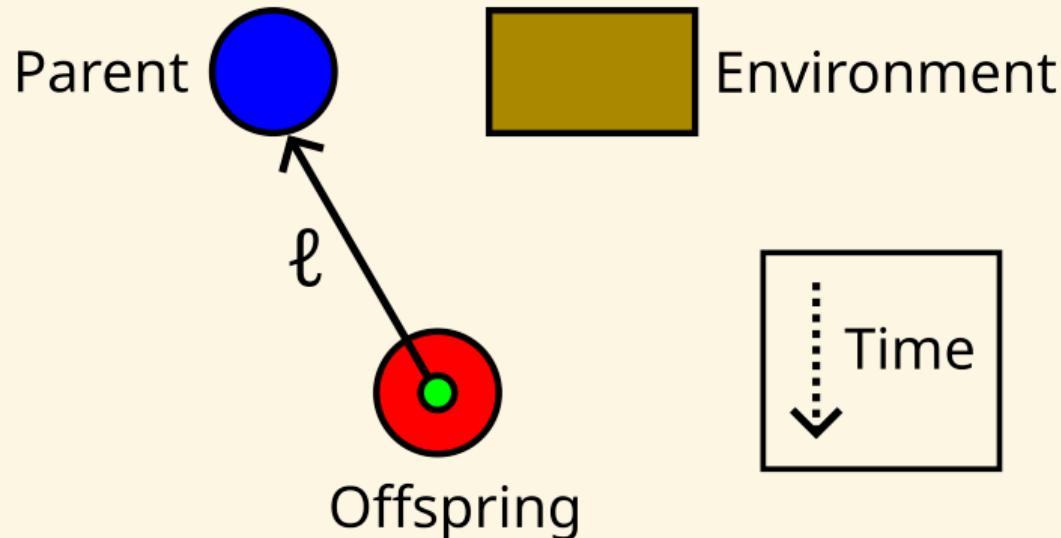
## Three Main Components:

- Parent-Offspring Transmission
- Shedding into Environment
- Acquisition from Environment

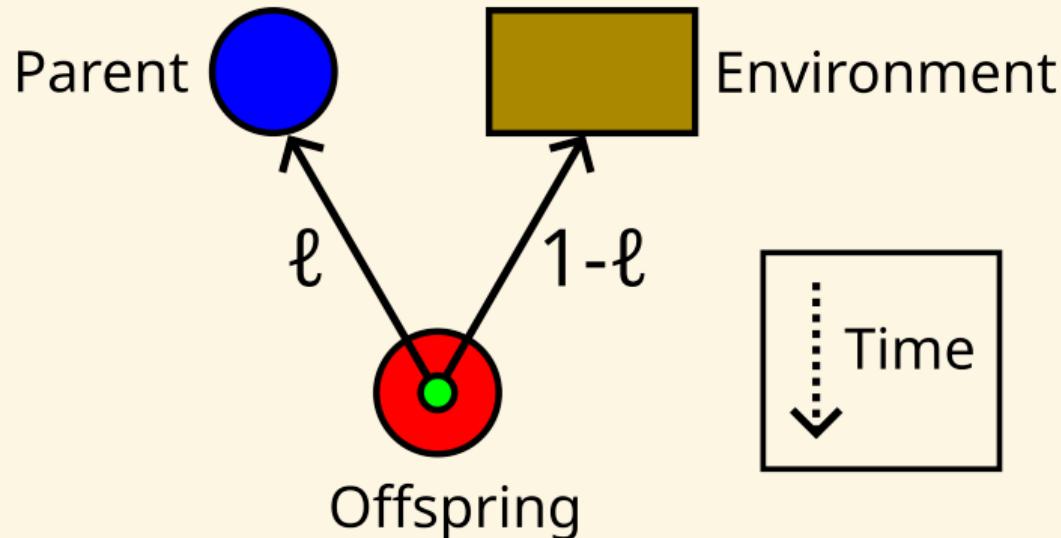
# Microbes Acquired from Parent or Environment



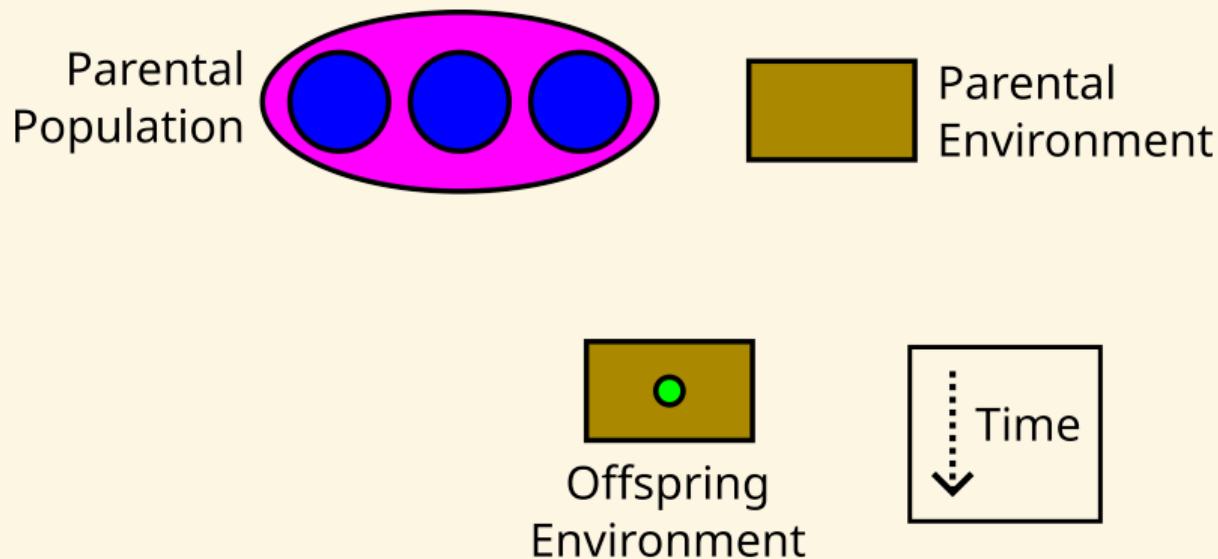
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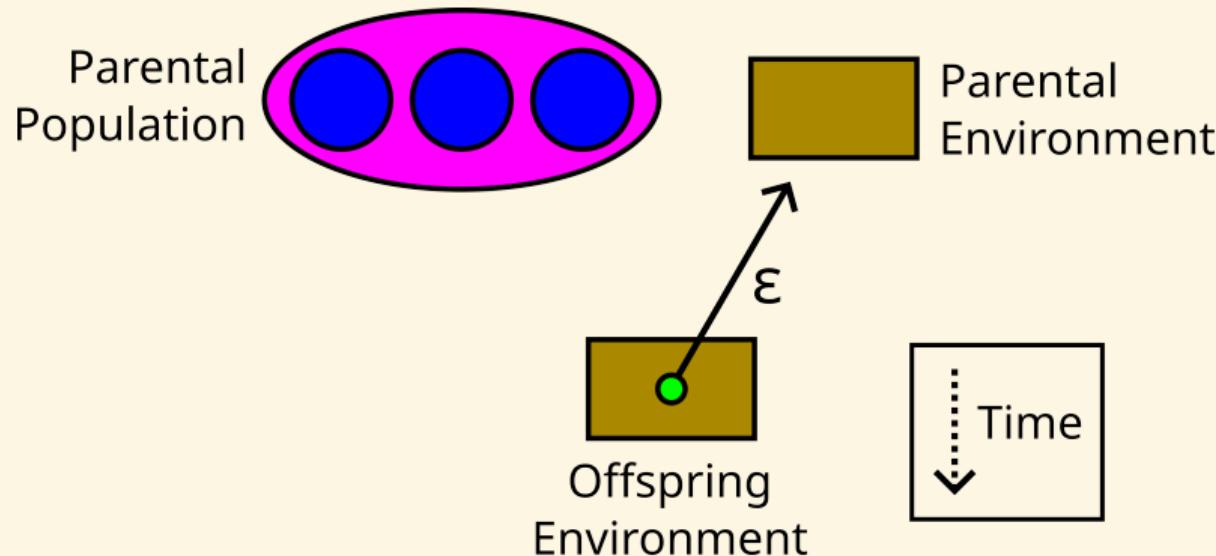
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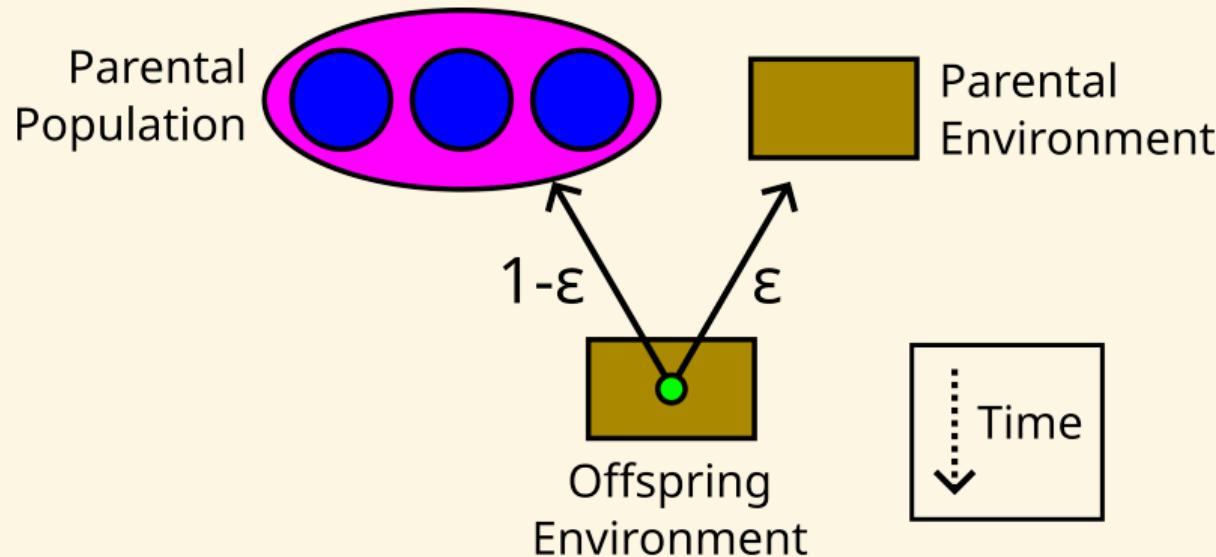
# Environmental Microbiome Shaped by Host Shedding



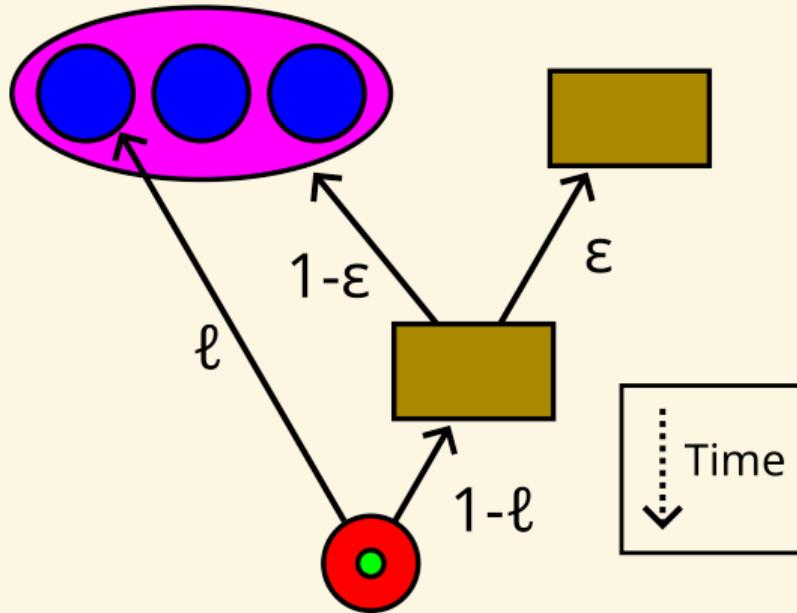
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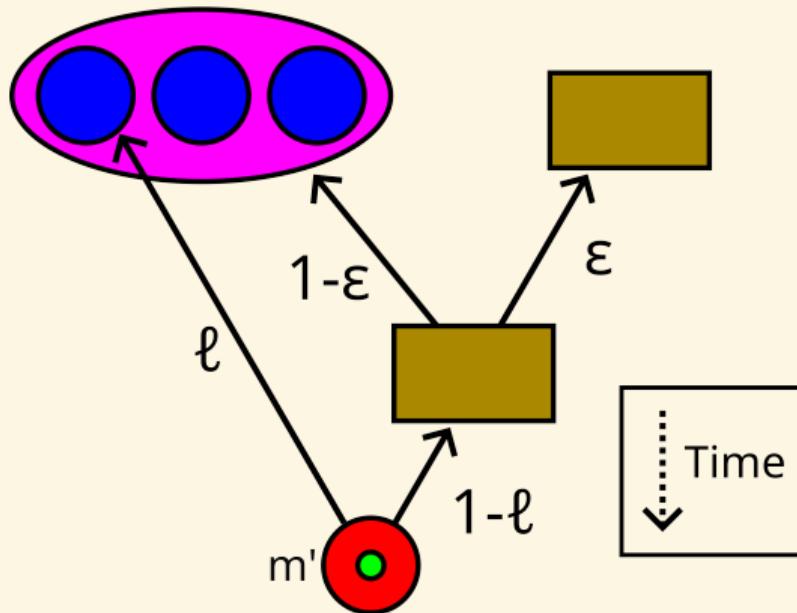
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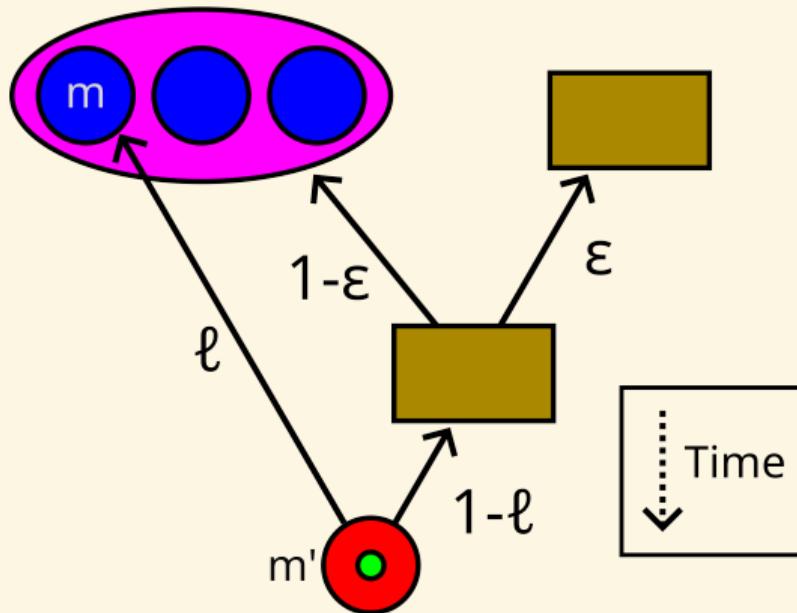
# A Model of Microbiome Inheritance



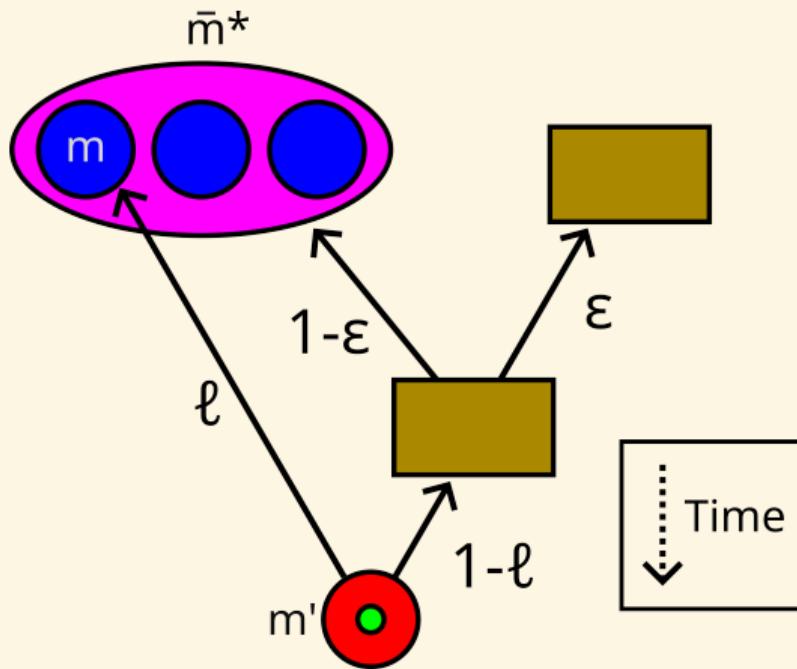
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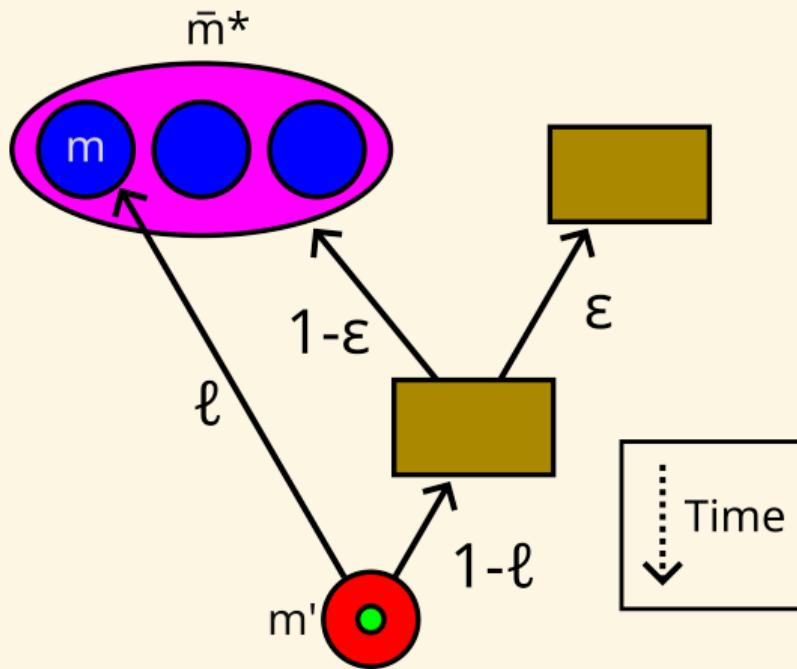
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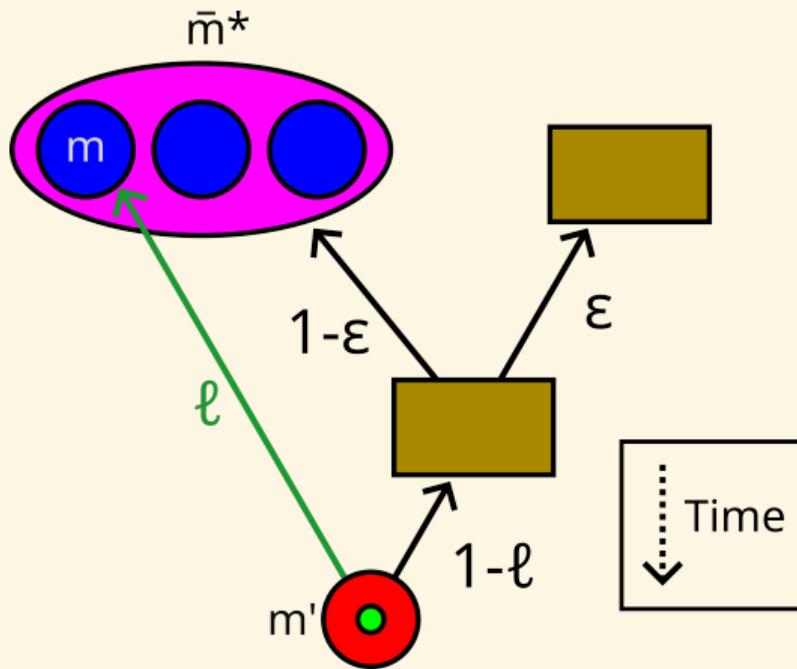


# A Model of Microbiome Inheritance



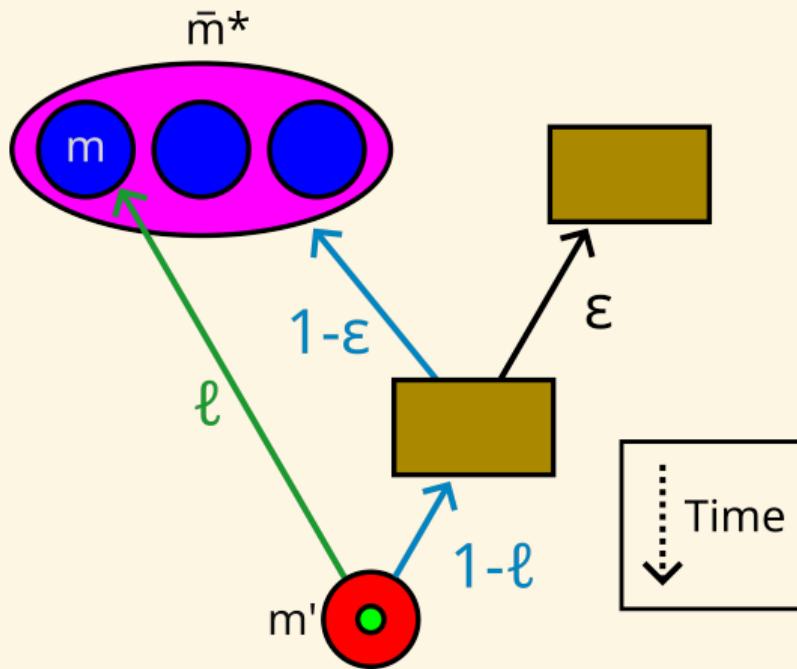
$$m' =$$

# A Model of Microbiome Inheritance



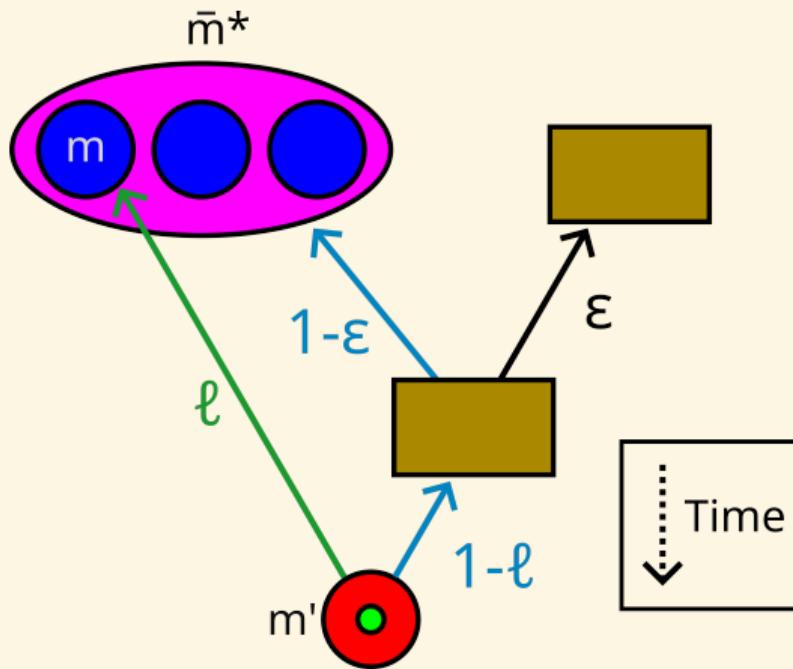
$$m' = \ell m$$

# A Model of Microbiome Inheritance



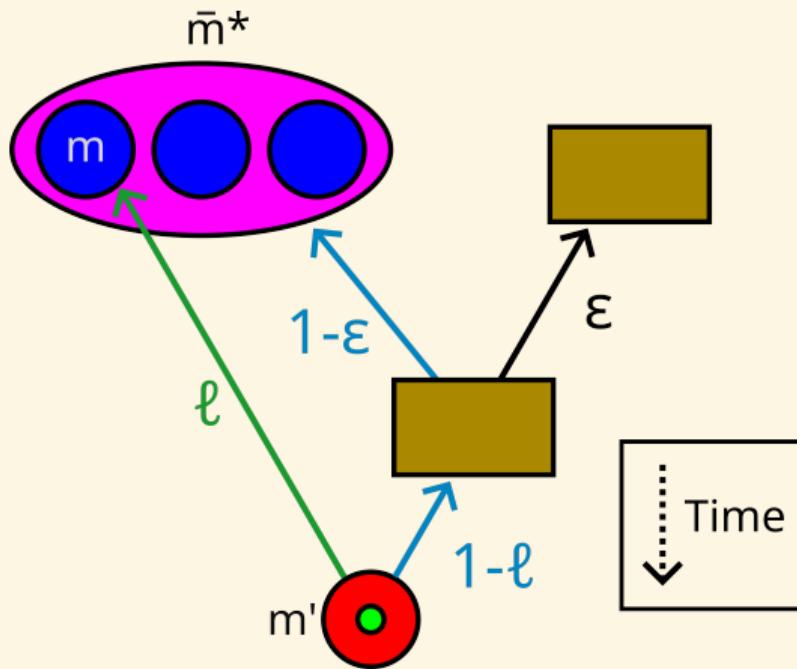
$$m' = \ell m + (1 - \ell)(1 - \varepsilon)\bar{m}^*$$

# A Model of Microbiome Inheritance



$$m' = \ell m + (1 - \ell)(1 - \varepsilon)m^* + E$$

# Microbiome-Mediated Trait Evolution



$$\bar{m}' = \ell \bar{m}^* + (1 - \ell)(1 - \varepsilon) \bar{m}^* + E$$

## **Result:** Adaptation Happens Without Parent-Offspring Transmission

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$$\ell = 0$$

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## **Result:** Adaptation Happens Without Parent-Offspring Transmission

$$\bar{m}' = (1 - \varepsilon)\bar{m}^* + E$$

$\rho = 0 \implies$  No parent-offspring resemblance

See Preprint for Full Story

## The Evolution of Microbiome-Mediated Traits

Bob Week, Andrew H. Morris, Brendan J. M. Bohannan

# Conclusion

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## Host-Parasite Local Adaptation

$$\mathcal{L}_H(d) = S_H(C_{HP}(d) - C_{HP}(0))$$

$$\mathcal{L}_P(d) = S_P(C_{HP}(0) - C_{HP}(d))$$

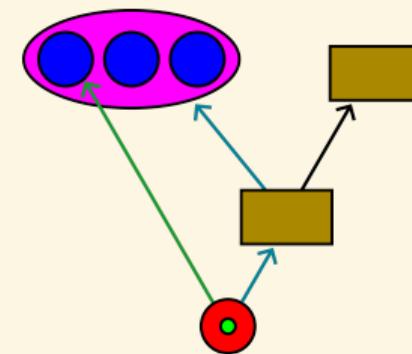
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## Microbiome-Mediated Evolution



# Thanks!



Brendan Bohannan



Karen L. Adair



Caitlin Smith



Bill Cresko

GORDON AND BETTY  
**MOORE**  
FOUNDATION



Peter Ralph