# Modeling Perceptual Machinery and its Effects on Dispersal

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## Objectives

Understanding long-distance dispersal is a particularly important task as climates change. The aim of this project was to:

- Model the theoretical effect of perceptual machinery on dispersal patterns
- Determine the accuracy with which pair approximation estimates changing densities in an isotropic, heterogeneous lattice

## Introduction

**[JT]** employs an individual-based model (IBM) and a biased-correlated random walk (BCRW) to better understand the role various complex dispersal costs and natural selection play into the various stages of dispersal. They find that there exists a nonlinear relationship among the dispersal stages, and that the shape of various trade-offs can imply much about dispersal strategies that could evolve in response to environmental conditions **[JT]**. **[SI]** employs a lattice model with pair approximation to study organisms with equal probabilities of dispersing to any nearest habitats.

We develop a lattice model whose patches are either desirable or undesirable, understood ecologically as similarity to the natal patch, and examine changing equilibria with respect to the degree to which organisms have evolved to perceive differences in habitat suitability, given by $0 \leq w \leq 1$:

- $w = 1/2 \rightarrow$ No perceptual machinery
- $w > 1/2 \rightarrow$ Favors desirable habitats
- $w < 1/2 \rightarrow$ Favors undesirable habitats

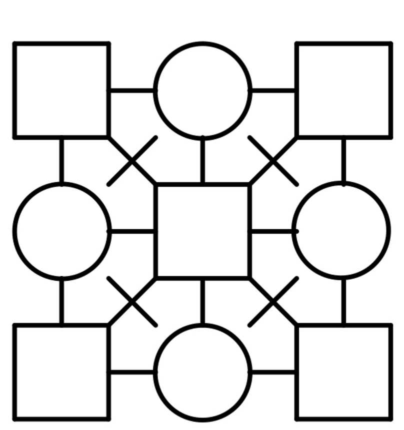
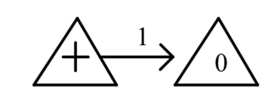


Figure 1: A Single "Neighborhood"

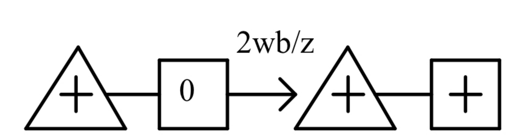
## Model Processes

The proposed model is defined by various processes, and their rates, that occur in the lattice over time:

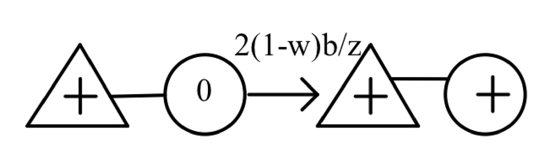
Death:




Desirable patch birth:




Undesirable patch birth:




## Pair Approximation

The purpose of pair approximation, also known as a "moment closure method," is to analyze lattice models in a simpler fashion without solely relying on direct computer simulation. As shown in **[SI]**, we can use this technique to close our dynamical system. We assume that the likelihood of a neighbor of a patch in state $\sigma$ to be in state $\sigma'$ is negligibly affected by another neighbor in state $\sigma''$.

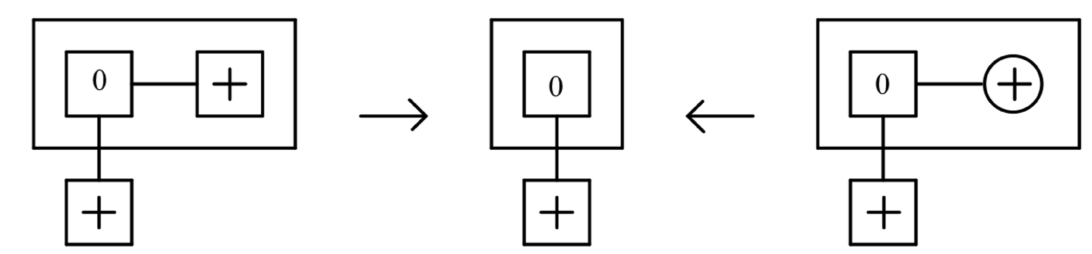


Figure 2: $\gamma_{+/0}$ as an approximation for $\gamma_{+/0+}$ and $\mu_{+/0+}$

## Implicit Competition Costs

As organisms develop greater perceptual machinery, reflected by extreme values of $w$, overall success of the species is reduced, revealing some type of implicit competition cost.

## Mathematical Model

**Original:** $H_+$ is the density of undesirable, propagated patches. Term 1 represents organism death, given at a constant rate of 1. Birth is represented by the second and third terms.

$$\frac{dH_+}{dt} = -H_+ + (1-w)b\left(\eta_{0/+}H_+ + i_{0/+}\Gamma_+\right)$$

**Improved:** The major difference in the equation below is how we represent death, which is given at a rate $d$ ($d \geq 1$). This is to account for a potential survival cost to settling in an undesirable patch.

$$\frac{dH_+}{dt} = -dH_+ + (1-w)b\left(\eta_{0/+}H_+ + i_{0/+}\Gamma_+\right)$$

## Results

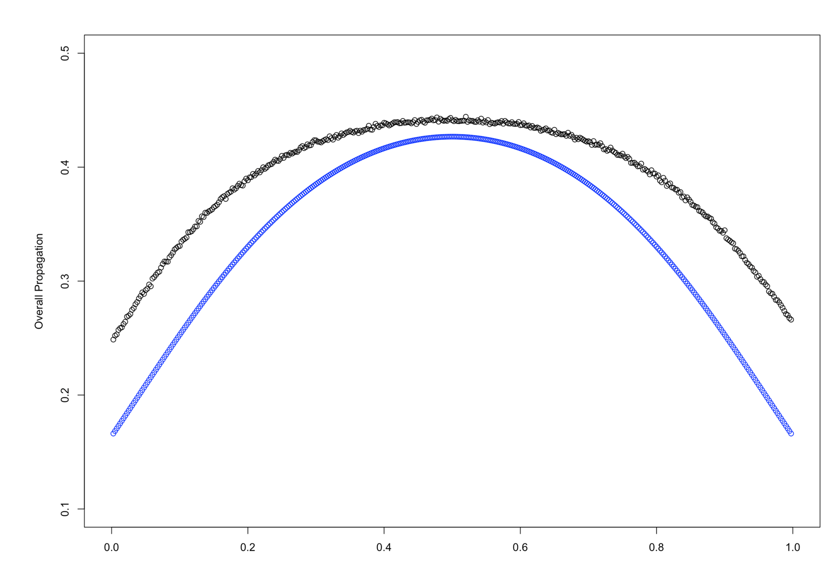


Figure 3: Numerical solutions v. simulation sampling

The Monte Carlo simulation and numerical solutions for the pair approximation model show qualitatively similar behavior, with the closest values occuring at central values of $w$. This suggests that pair approximation is at least somewhat effective in accounting for the theoretical behavior of the model.

## Conclusion

Though we have developed a mathematical model that allows for organisms to selectively place themselves in habitats that they find more or less suitable, it also appears that certain implicit costs are associated with this choice. It remains to be shown through empirical study whether or not this behavior actually occurs in the environment. Regardless, our model, which takes into account the ability of organisms to perceive the friendliness of their environment, hopefully lays groundwork for future examinations of the role perceptual ability plays in the likelihood of species to disperse far away from unsuitable, changing environments, as modeled by a lattice.

## References

[SI] Sato, K., Iwasa, Y. "Pair approximations for lattice-based ecological models," The Geometry of Ecological Interactions, pp. 341-358, edited by Dieckmann, U., Law, R., Metz, J.A.J., Cambridge University Press, Cambridge, NY, 2000.

JT Travis, J.M.J. et al., "Modelling dispersal: an eco-evolutionary framework incorporating emigration, movement, settlement behaviour and the multiple costs involved," Methods in Ecology and Evolution, Vol. 3, pp. 628-641, 2012.

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