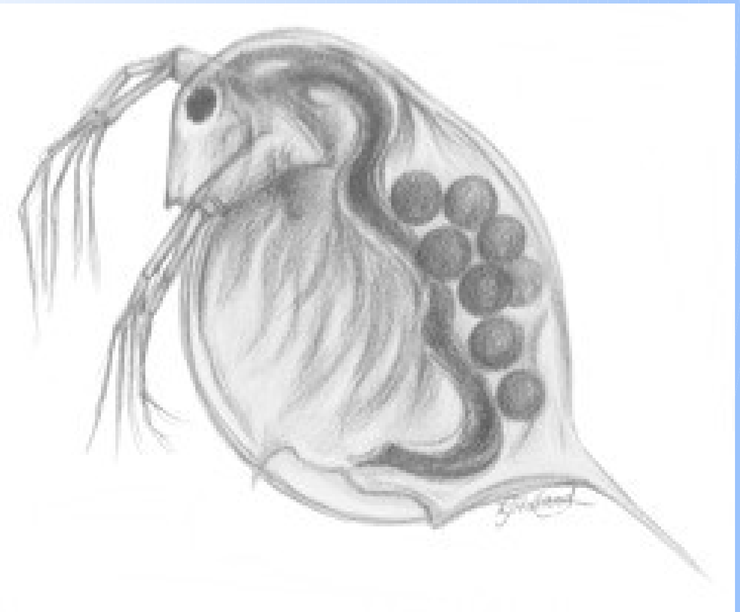
An Extensible Software Infrastructure for Testing the Evolutionary Consequences of Developmental Interactions



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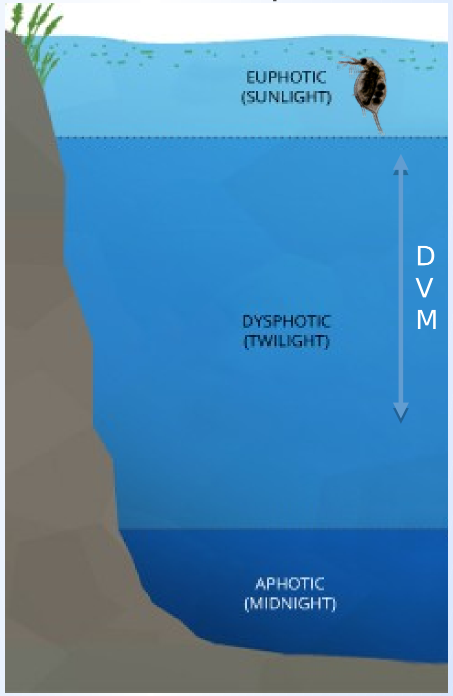
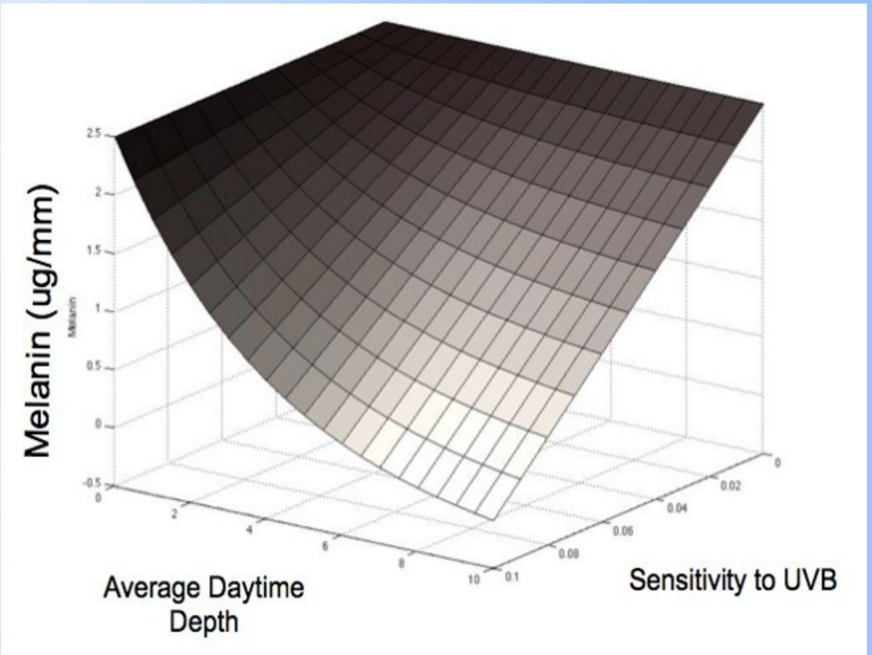
Research Motivation

- Genes controlling one trait may overlap with genes influencing other traits.
  - The G-matrix describes the extent to which traits have genetic variation and whether or not different traits are genetically related.
  - Non-additive developmental interactions can alter genetic variances.

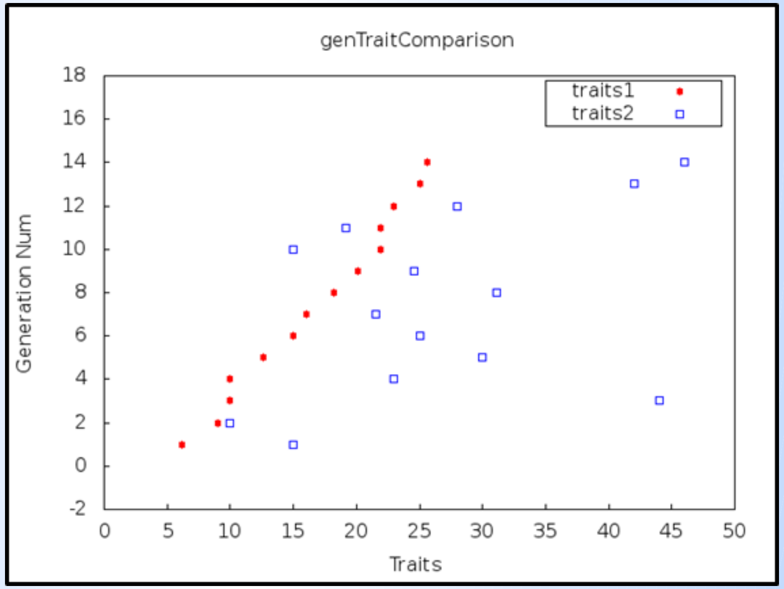


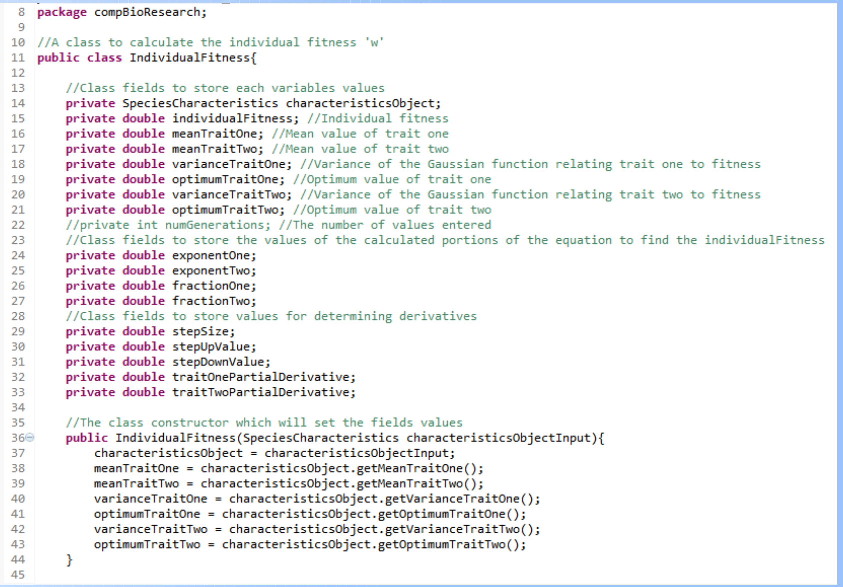


- Traits often result from nonlinear interactions between developmental factors.
  - May produce large and rapid changes to trait (co)variances.
  - The G-matrix may become unstable, and may therefore not accurately predict evolutionary dynamics.

Research Objectives

- The development of a program that will determine the extent to which the interactions of traits, melanin and diel vertical migration (DVM), affects the evolutionary response of *Dapnia melanica*.





```java
package compBioResearch;

//A class to calculate the individual fitness 'w'
public class IndividualFitness{

    //Class fields to store each variables values
    private SpeciesCharacteristics characteristicsObject;
    private double individualFitness; //Individual fitness
    private double meanTraitOne; //Mean value of trait one
    private double meanTraitTwo; //Mean value of trait two
    private double varianceTraitOne; //Variance of the Gaussian function relating trait one to fitness
    private double optimumTraitOne; //Optimum value of trait one
    private double varianceTraitTwo; //Variance of the Gaussian function relating trait two to fitness
    private double optimumTraitTwo; //Optimum value of trait two
    //private int numGenerations; //The number of values entered
    //Class fields to store the values of the calculated portions of the equation to find the individualFitness
    private double exponentOne;
    private double exponentTwo;
    private double fractionOne;
    private double fractionTwo;
    //Class fields to store values for determining derivatives
    private double stepSize;
    private double stepUpValue;
    private double stepDownValue;
    private double traitOnePartialDerivative;
    private double traitTwoPartialDerivative;

    //The class constructor which will set the fields values
    public IndividualFitness(SpeciesCharacteristics characteristicsObjectInput){
        characteristicsObject = characteristicsObjectInput;
        meanTraitOne = characteristicsObject.getMeanTraitOne();
        meanTraitTwo = characteristicsObject.getMeanTraitTwo();
        varianceTraitOne = characteristicsObject.getVarianceTraitOne();
        optimumTraitOne = characteristicsObject.getOptimumTraitOne();
        varianceTraitTwo = characteristicsObject.getVarianceTraitTwo();
        optimumTraitTwo = characteristicsObject.getOptimumTraitTwo();
    }

```

- Deliverables:
  1. Graphical representation of numeric program results.
  2. Extensible codebase to produce custom models for specific species of organisms.
  3. Web-based tool that accepts user supplied functions of developmental interactions.

Mathematical Framework

Model One

$$\overline{m}_{t+1} = \overline{m}_t + h^2 \frac{1}{\overline{w}} \frac{\partial w}{\partial m} \sigma_m$$

$$\overline{d}_{t+1} = \overline{d}_t + h^2 \frac{1}{\overline{w}} \frac{\partial w}{\partial d} \sigma_d$$

1. Predicts the evolution of mean melanin and mean diel vertical migration (DVM) of Daphnia over time, based on the genetic (co)variances of these traits.

Model Two

$$\begin{pmatrix} \overline{z} \\ \overline{p} \\ \overline{d} \end{pmatrix}_{t+1} = \begin{pmatrix} \overline{z} \\ \overline{p} \\ \overline{d} \end{pmatrix}_t + H \left(\frac{1}{\overline{w}} \frac{\partial w}{\partial d} \left[\begin{pmatrix} 0 \\ 0 \\ \sigma_d \end{pmatrix} \right] + \frac{1}{\overline{w}} \frac{\partial w}{\partial m} \left[\begin{pmatrix} \sigma_z \\ (u_0 e^{-dK} - u_0)\sigma_p \\ K p u_0 e^{-dK} \sigma_d \end{pmatrix} \right] \right)$$

$$\overline{m} = \overline{z} + (-1 + e^{\frac{1}{2}K(-2\overline{d} + K\sigma_d)})\overline{p}u_0$$

2. Predicts the evolution of mean melanin and mean diel vertical migration (DVM) over time, while allowing for nonlinear interactions between these traits.

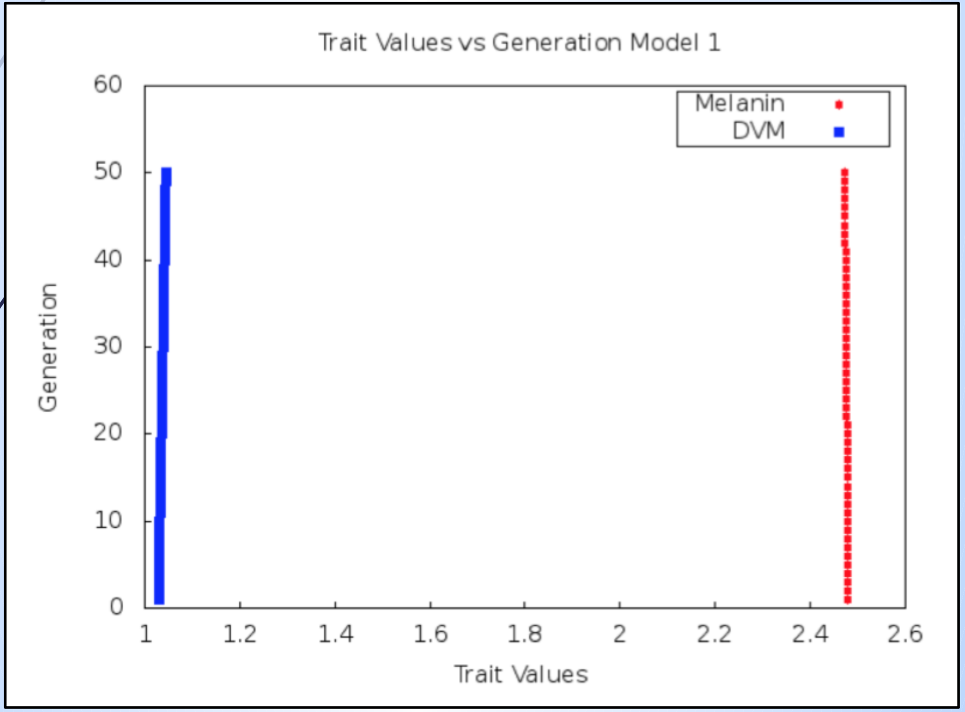
Shared Fitness Function

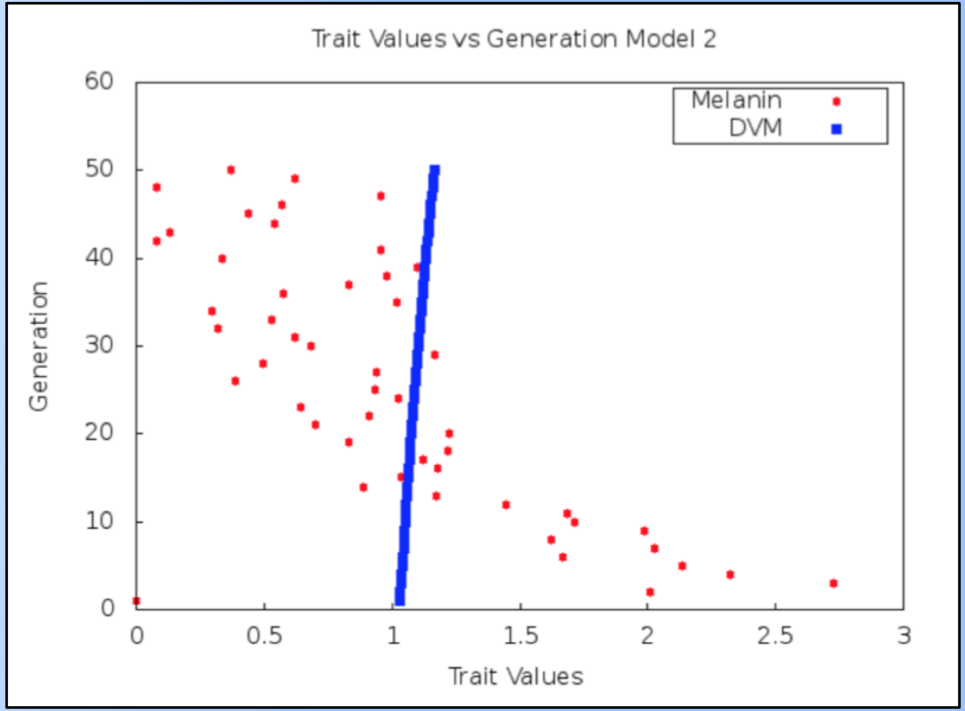
$$w = \frac{1}{\sqrt{v_m 2\pi}} e^{-\frac{(m-\omega_m)^2}{2v_m}} + \frac{1}{\sqrt{v_d 2\pi}} e^{-\frac{(m-\omega_d)^2}{2v_d}}$$

The individual fitness surface (*w*) is defined by the sum of fitness values associated with the trait values (*m*,*d*) of an individual.

Preliminary Results

The G-matrix based model (left) predicts a small variation in the evolutionary trajectory of traits for the modeled *Daphnia* population. The second, more advanced model (right) incorporates underlying developmental factors of traits, resulting in an increased calculated evolutionary response.





Initial parameters for model testing have been estimated using empirical data from multiple populations of *Daphnia melanica* in high altitude alpine lakes of Sierra Nevada.

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