

# ModEDI

An Extendable Software Architecture for Examining  
the Effects of Developmental Interactions on  
Evolutionary Trajectories

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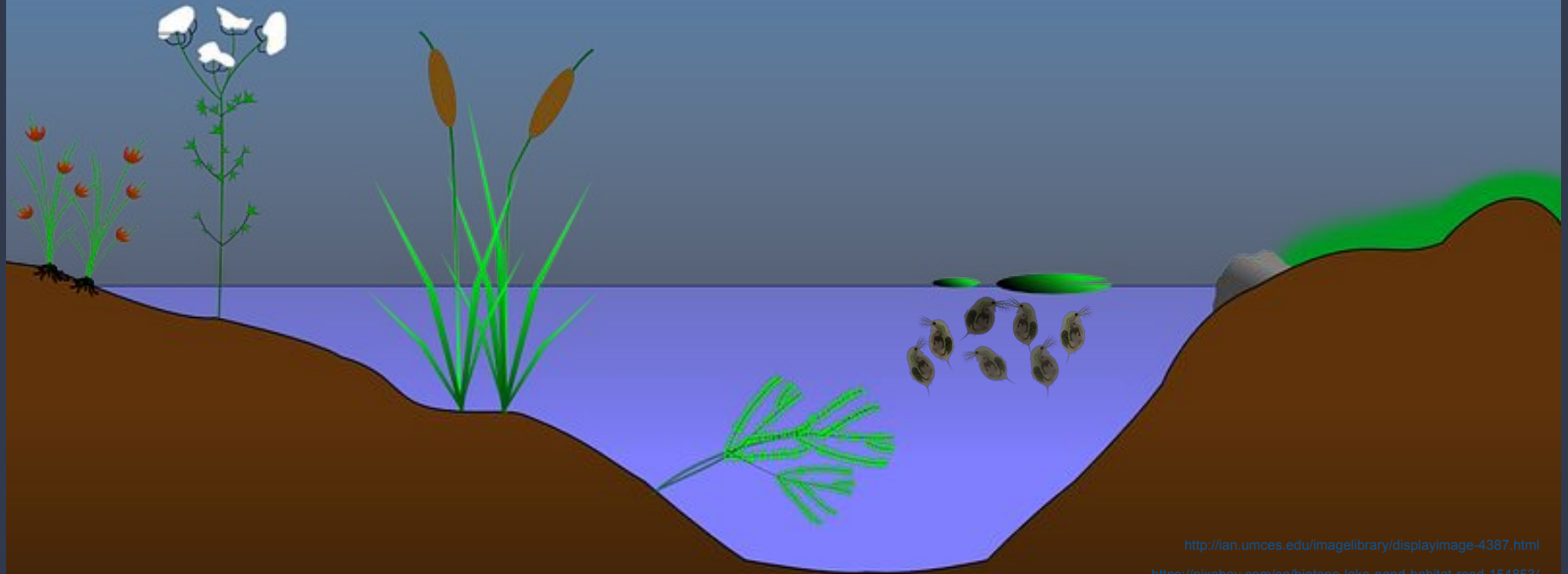
# Background – *Quantitative Genetics*



# Case Study – *Models for Daphnia*

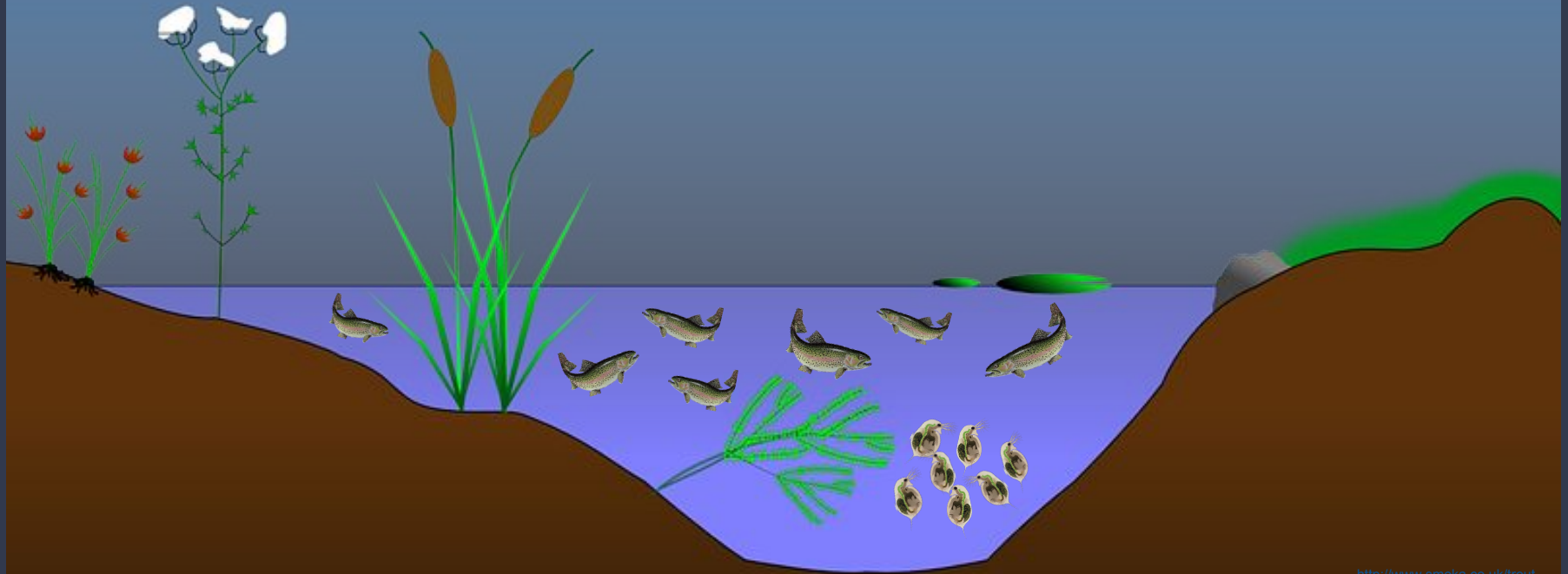


# Nonlinear Developmental Interactions (NDI)

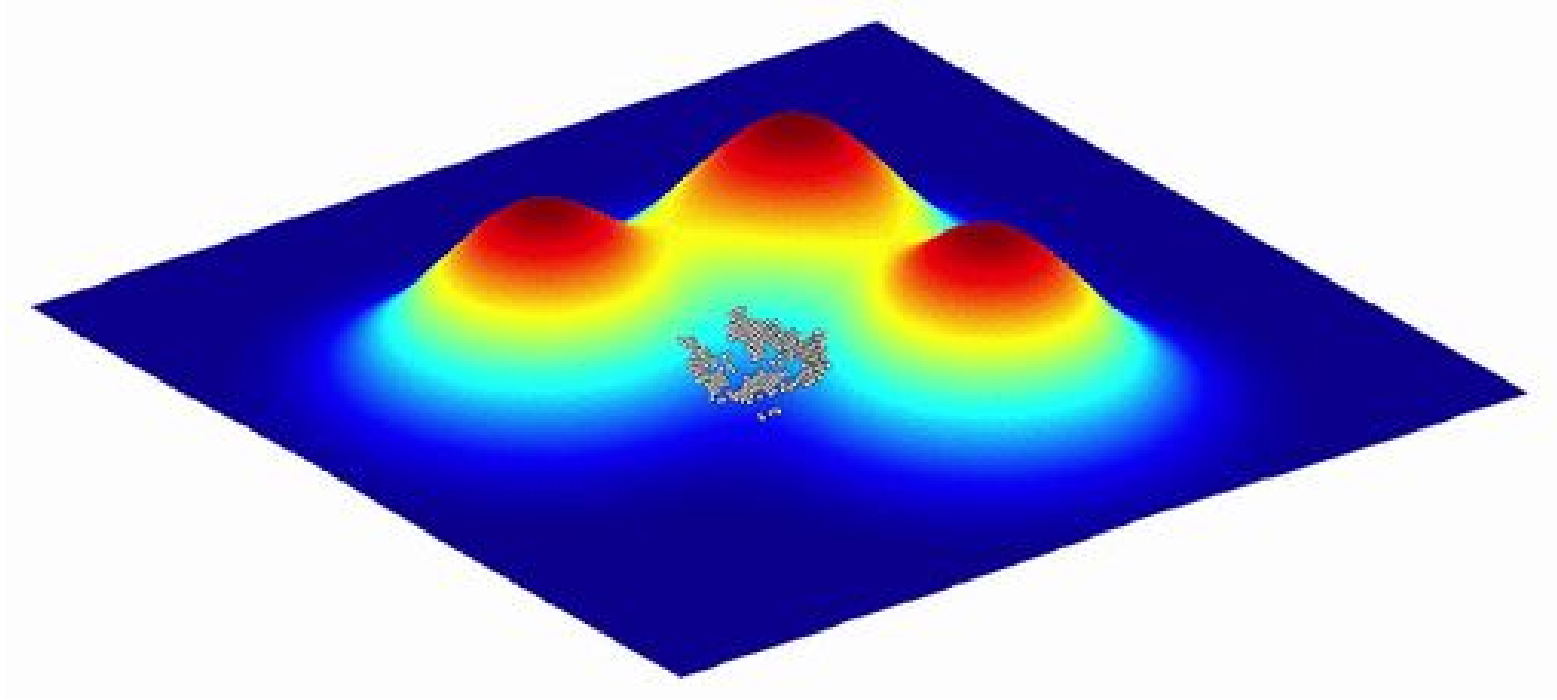




# Nonlinear Developmental Interactions (NDI)



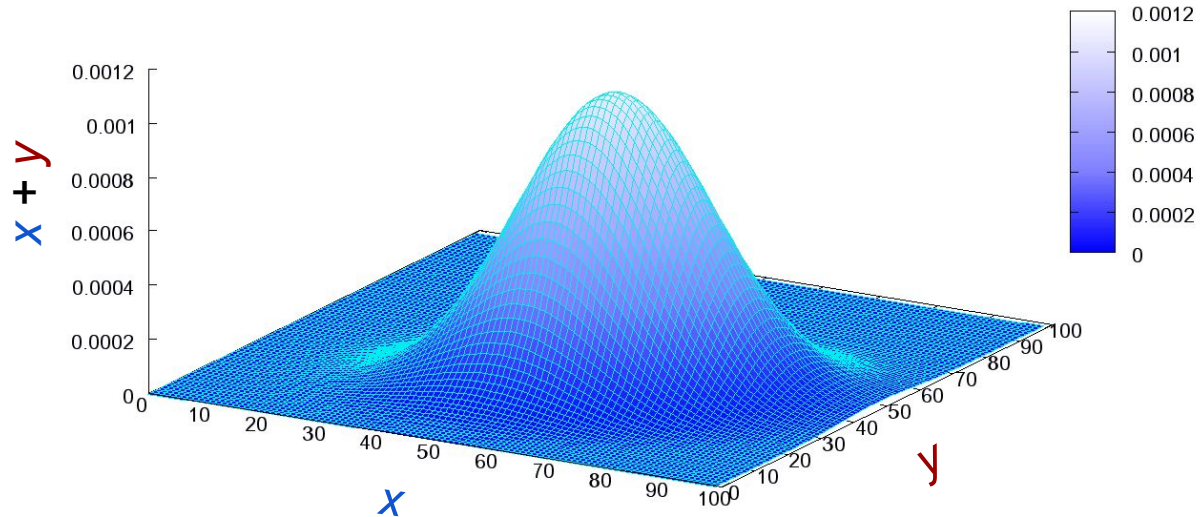
# Central Concept – *Fitness Surface*



# Surface Distribution – *Bivariate Normal*

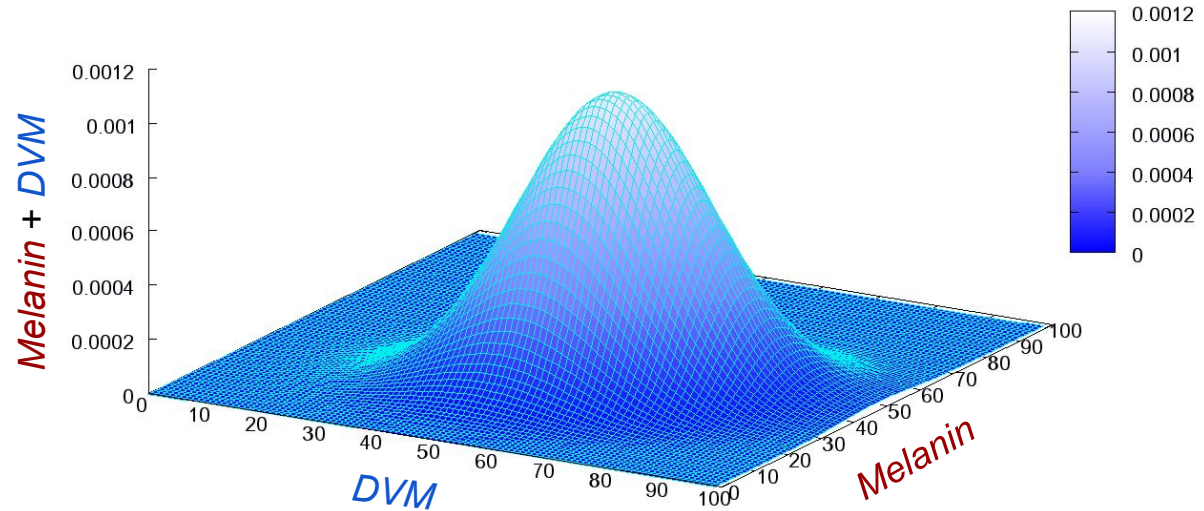
- $x$  and  $y$  are normally distributed values
- The sum of  $x$  and  $y$  form the bivariate normal distribution

$$\rightarrow N(\langle x \rangle, \sigma_x) + N(\langle y \rangle, \sigma_y)$$



# Surface Distribution – *Bivariate Normal*

- **Melanin** and **DVM** are normally distributed trait values
- The sum of **Melanin** and **DVM** form the bivariate normal distribution

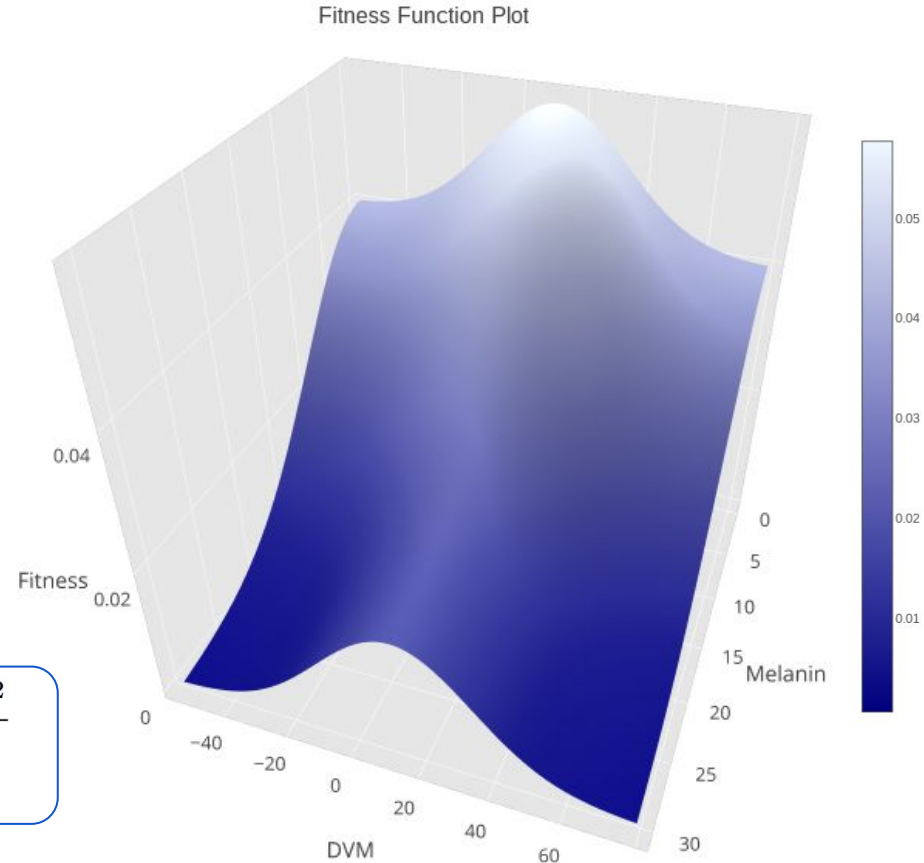




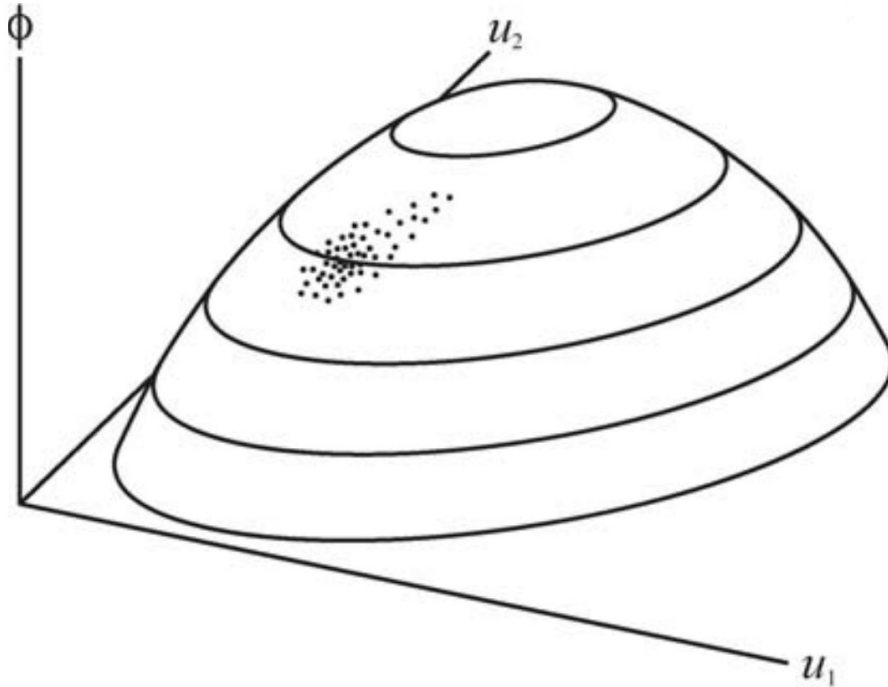
# Central Concept – *Fitness Surface*

- **Melanin** and **DVM** are normally distributed trait values
- The sum of **Melanin** and **DVM** form the bivariate normal distribution

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

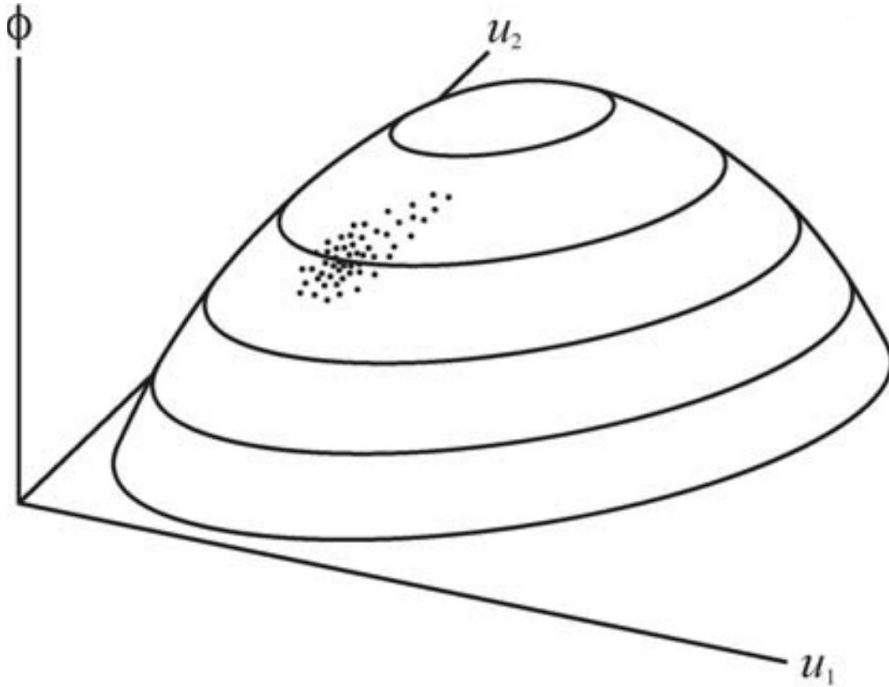


# Central Concept – *Phenotype Surface*

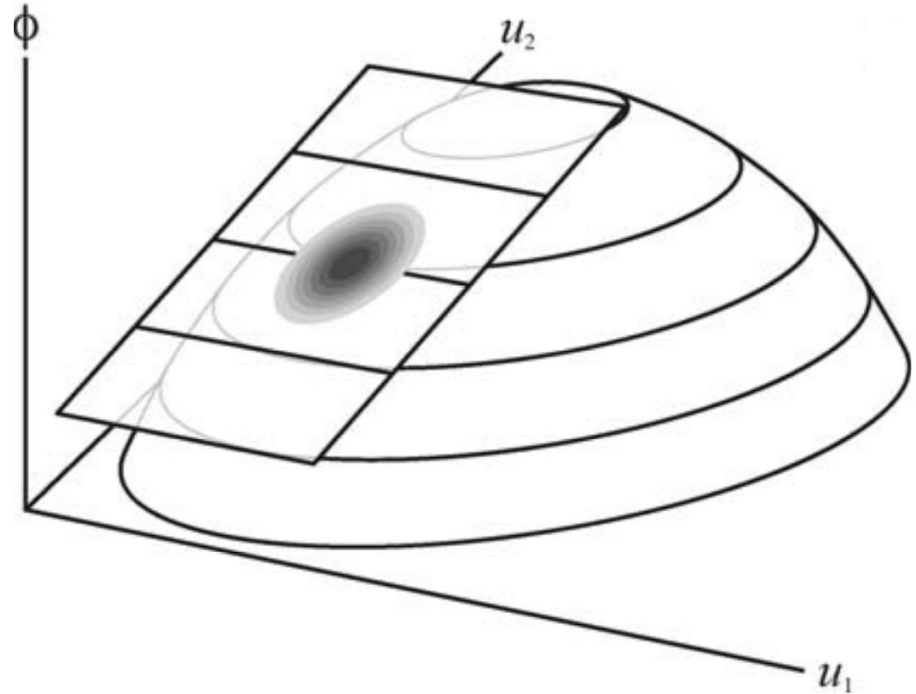


- $\phi$  represents a physical trait
- $u_1$  and  $u_2$  represent underlying genetic factors

# Phenotype Surface vs G-matrix



Phenotype Surface



G-matrix Approximation

# Classic Model – *G*-matrix

- $h^2$  is the diagonal values of the heritability matrix
- $\bar{w}$  is the mean population fitness
- $\sigma_d$  and  $\sigma_m$  are the DVM ( $\bar{d}$ ) and Melanin ( $\bar{m}$ ) phenotypic variances

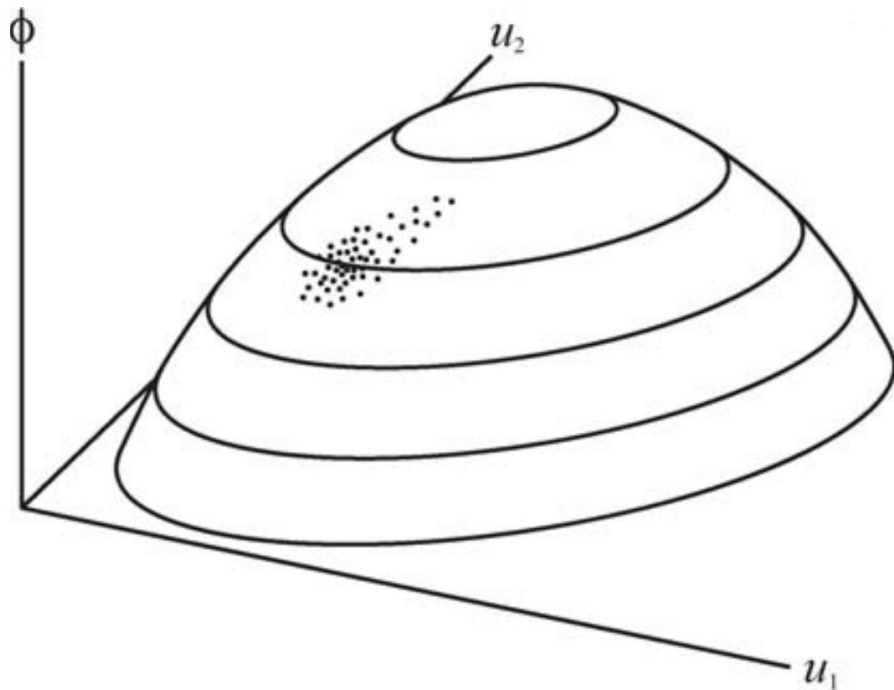
Melanin development:

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

DVM development:

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

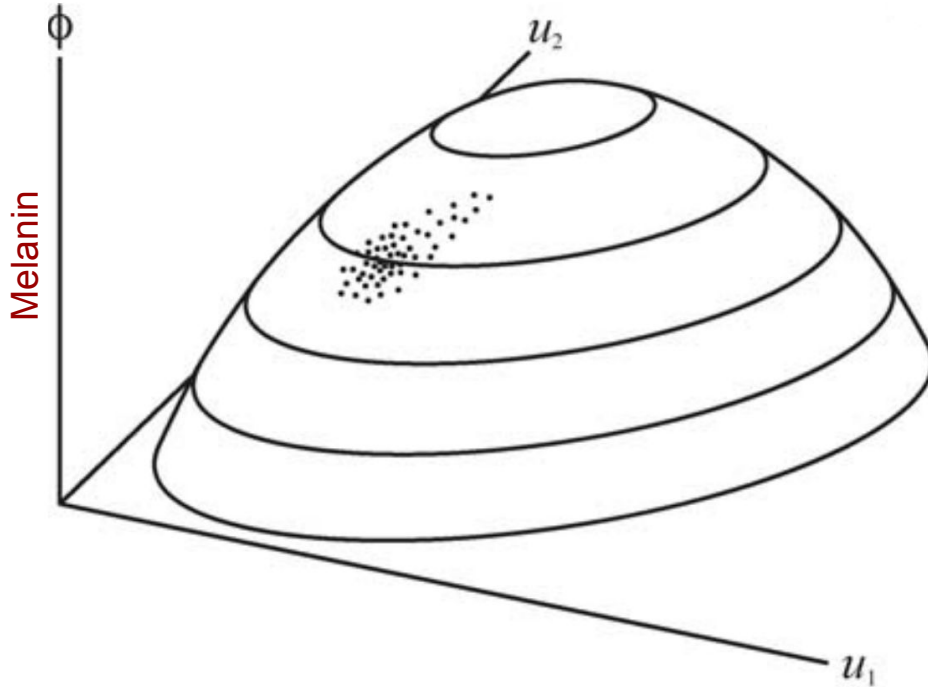
# Recall – *Phenotype Surface*



- $\phi$  represents a physical trait
- $u_1$  and  $u_2$  represent underlying genetic factors

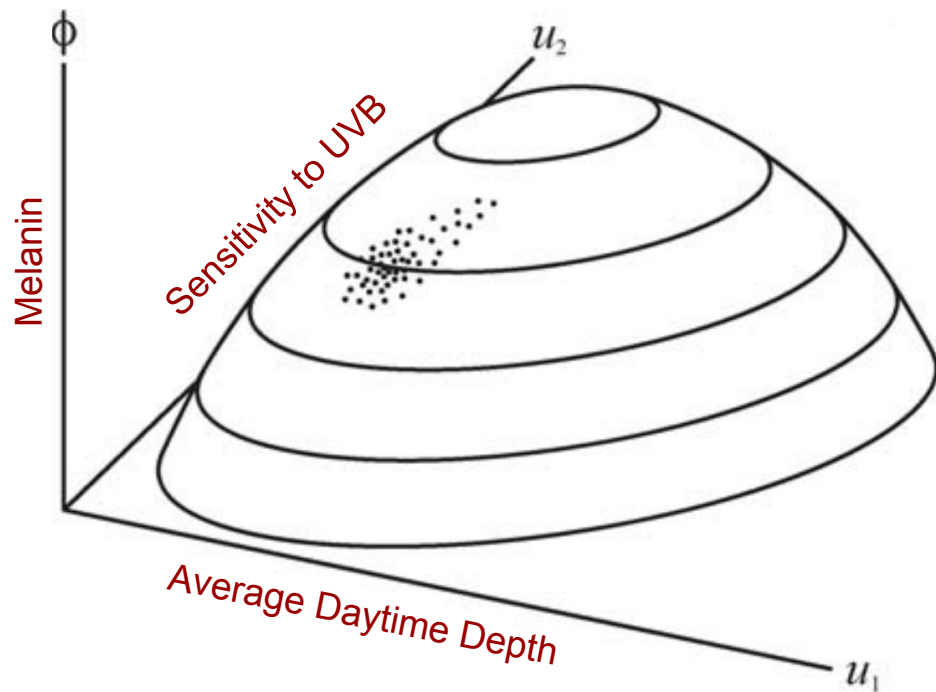


# Tanning Model – *Phenotype Surface*



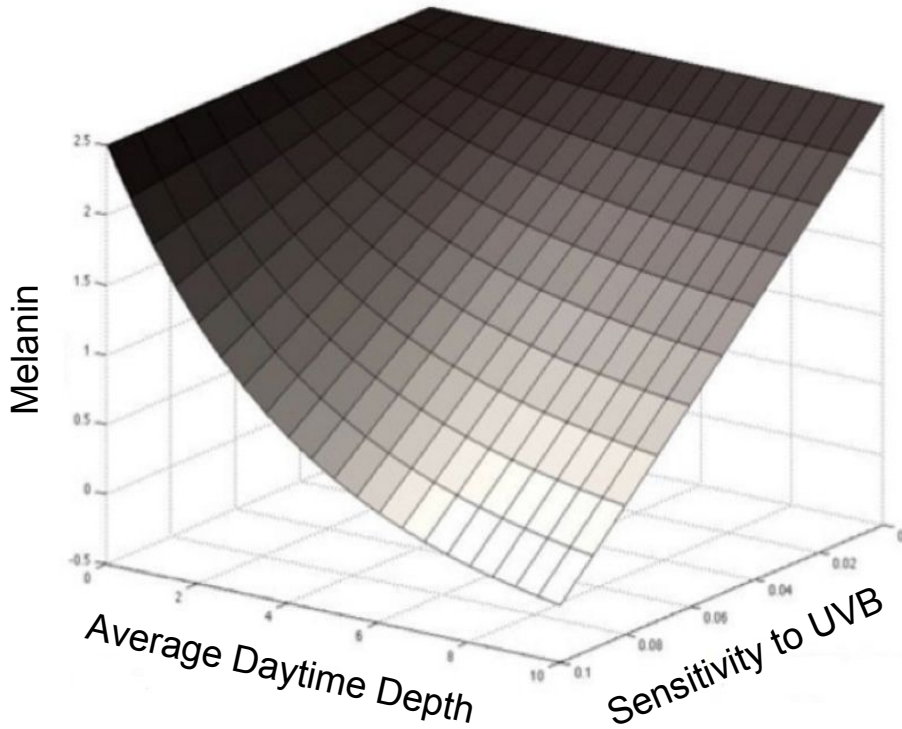
- $\phi$  represents a physical trait, **Melanin**
- $u_1$  and  $u_2$  represent underlying genetic factors

# Tanning Model – *Phenotype Surface*



- $\phi$  represents a physical trait, **Melanin**
- $u_1$  and  $u_2$  represent underlying genetic factors, **Average Daytime Depth** and **Sensitivity to UVB**

# Tanning Model – *Phenotype Surface*



$$m = z + pa$$

- $z$  is the concentration of melanin produced in response to UV light
- $p$  is the slope of the reaction norm indicating sensitivity to UVB
- $a$  is the change in UVB exposure

# Tanning Model - *NDI*

- $d$  is DVM, treated as a quantitative genetic trait
- $H$  is the heritability matrix
- $U$  represents the change in DVM, simplified
- $V$  represents the change in Melanin, simplified

Melanin production:

$$m = z + pa$$

Development of genetic factors:

$$\begin{pmatrix} \bar{z} \\ \bar{p} \\ \bar{d} \end{pmatrix}_{t+1} = \begin{pmatrix} \bar{z} \\ \bar{p} \\ \bar{d} \end{pmatrix}_t + H \frac{1}{\bar{w}} UV$$

# *Daphnia* Species Objects

- States represent phenotypic traits, **DVM** and **Melanin**
- Behaviours represent the phenotypic functions of our models for *Daphnia*, Classic and Tanning

*Daphnia* Blueprint

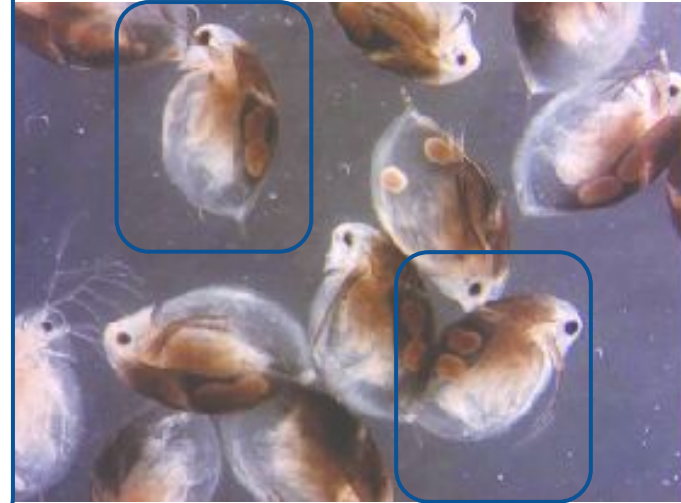


*Daphnia  
melanica*

- **DVM**: int  
- **Melanin**: int

+ setDVM  
+ setMelanin

*Daphnia* Objects

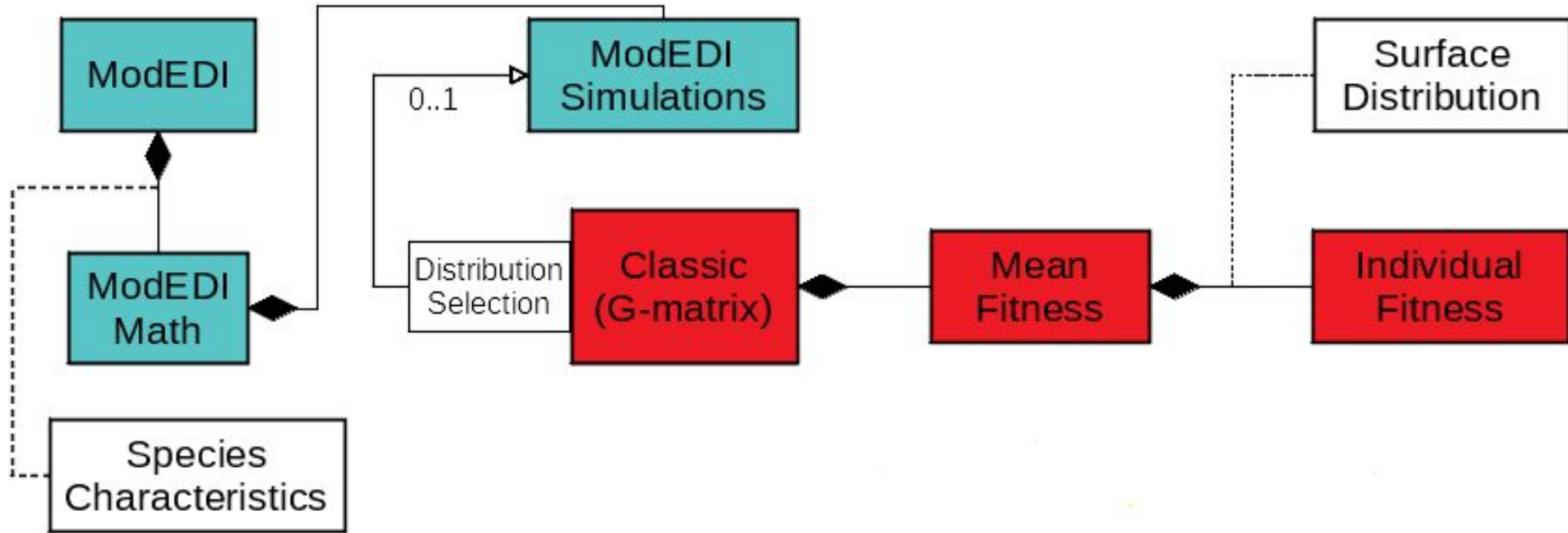


[https://t3.ftcdn.net/jpg/00/47/53/14/240\\_F\\_47531414\\_8Vj6iYmdowUNtgFrxmmtgPdT8gRTzCdy.jpg](https://t3.ftcdn.net/jpg/00/47/53/14/240_F_47531414_8Vj6iYmdowUNtgFrxmmtgPdT8gRTzCdy.jpg)

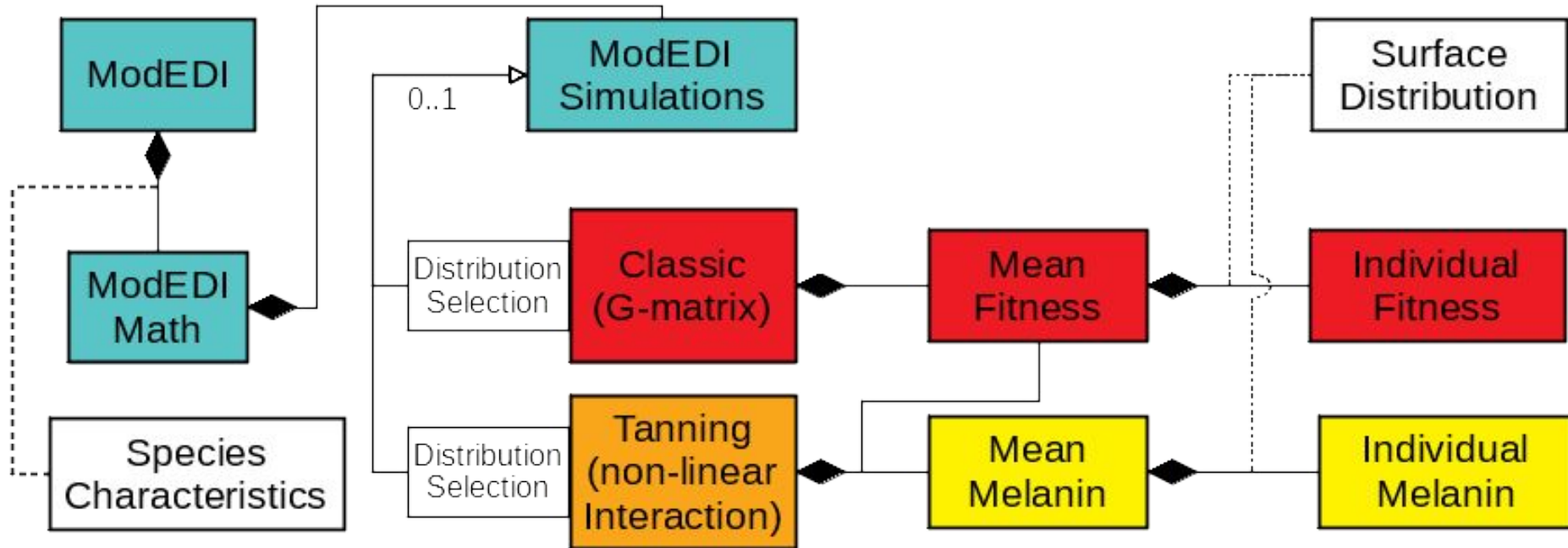
[https://www.researchgate.net/figure/51073279\\_fig5\\_Fig-5-Pigmented-zooplankton-Melanised-Daphnia-umbra-left-and-Eudiaptomus-graciloides](https://www.researchgate.net/figure/51073279_fig5_Fig-5-Pigmented-zooplankton-Melanised-Daphnia-umbra-left-and-Eudiaptomus-graciloides)



# Software Architecture – *Classic Model*



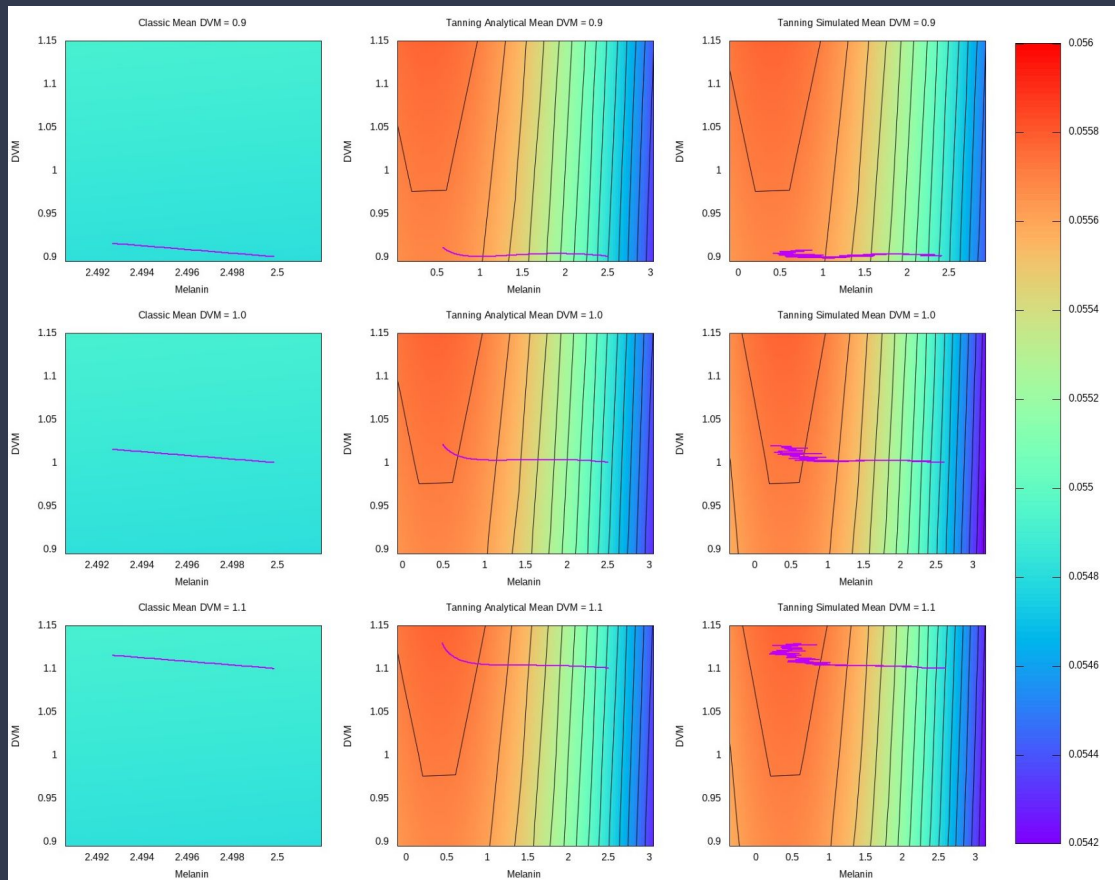
# Software Architecture – *Tanning Model*



# Initial DVM Parameter Sweep

Sweep conclusions:

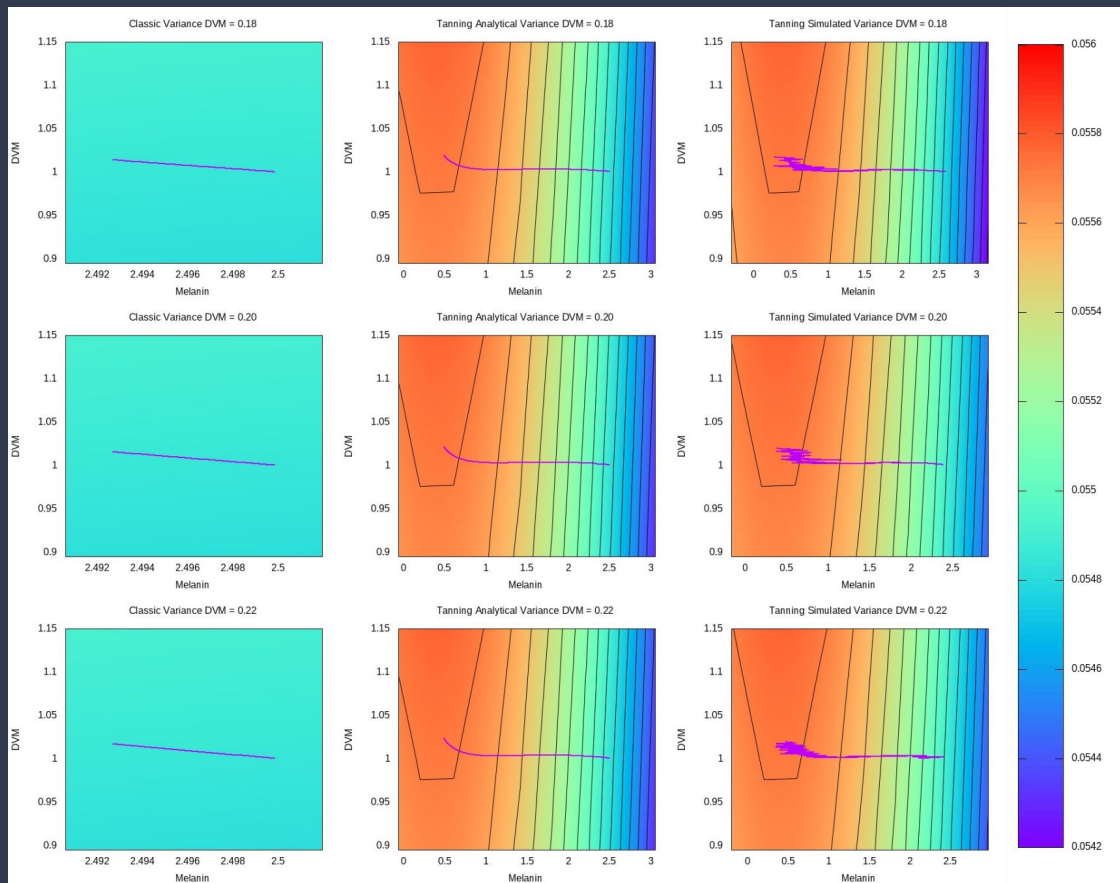
- Closer and Farther
- Little change in trajectory
- *Classic* model evolves more slowly than *Tanning*



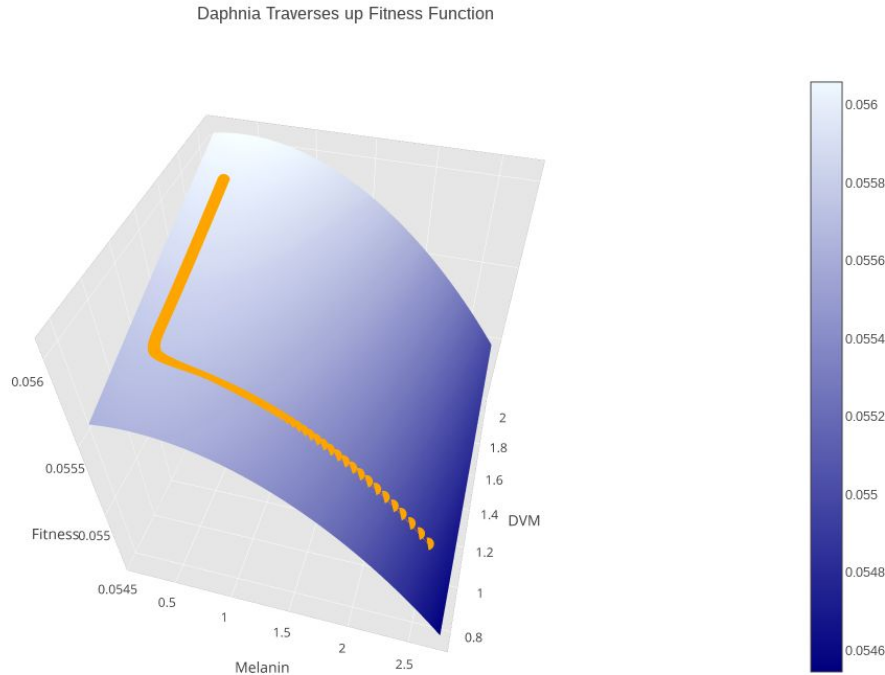
# Variance DVM Parameter Sweep

Sweep conclusion:

- Reasonable changes little effect
- *Classic* model evolves more slowly than *Tanning*
- *Tanning* model with simulation most reactive



# *Daphnia Case Study – Results*



- Melanin evolves relatively quickly
- Trajectories are generally the same for different parameters



# Conclusions

- *Classic* model evolves more slowly than *Tanning* model
- ModEDI predictions resistant to small parameter changes
- Modeled *Daphnia* populations evolve towards trait optima
- ModEDI as a powerful tool for analyzing the effects of multiple genes on physical traits

# Future Work

- Increase generalization
- Add support for other fitness distributions and organisms
- Make available an easy to use interface

# Acknowledgements

- CWU Science Honors Research Program, CWU
- College of the Sciences and Engineering, WWU