Phenotypic Noise and the Cost of Complexity
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**Background**

Theory predicts that phenotypic noise is positively selected under directional selection because it increases the mean fitness value, and counter-selected under stabilizing selection (1).

It has been suggested that under directional selection, the fitness gain provided by phenotypic noise also promotes adaptive evolution (2), while the link is unclear.

Evolution on multiple phenotypic characters suffers from the cost of complexity (3). The impact of phenotypic noise in multidimensional phenotypes is less understood.

**Methods**

We used a quantitative model to study the adaptive evolution of organisms with multiple phenotypic traits under selection and evolvable phenotypic noise (4) in a generalized fitness landscape.

**Results**

Phenotypic noise promotes adaptive evolution under directional and/or stabilizing selection if the logarithmic fitness plateau.

For multiple phenotypic characters under selection, the phenotypic noise evolves to a one-dimensional noise aligned with the direction of the fitness optimum.

**Conclusion**

Phenotypic noise can decrease the cost of complexity and promotes adaptive evolution in flat regions of the fitness landscape.

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1. *Phenotypic Noise Effect on Fitness Depends on the Shape of the Fitness Landscape (Single Character)*

Generalized fitness function: \( w(z) = (1-\beta)\exp[-\alpha z^2] + \beta (5) \)

- **Stabilizing selection** (close to the fitness optimum)
  - \( Q > 2 \)
  -\( \beta = 0 \)
  -\( \beta > 0 \)

- **Directional selection** (far from the fitness optimum)
  -\( \beta > 0 \)
  -\( \beta < 0 \)

2. *A Model for Phenotypic Noise Evolution*

Multi-dimensional phenotypic noise is built from the mutable genotype \((\mu, \sigma, \Theta)\):

- Mean phenotype \( \mu \) (mutable),
- Variances \( \sigma^2 \) (mutable),
- Rotation angles \( \Theta \) (mutable),
- Covariance \( \Sigma \) built from \( \sigma^2 \) and \( \Theta \),
- Phenotype \( z = N_{n}((\mu, \Sigma)) \)

3. *Phenotypic Noise Dimensionality Reduction*

For multiple phenotypic characters under directional selection, we demonstrate that the best phenotypic noise configuration is aligned and fully correlated with the direction of the fitness optimum.

Example:

- Simulation for two phenotypic characters:
  - Initial distance: 4 units,
  - Population size: 1,000,
  - Mutation rate: \( 1\% \),
  - Phenotype size: 0.01.

4. *Phenotypic Noise Promotes Adaptive Evolution and Decreases the Cost of Complexity*

Gaussian-shaped fitness function

\( w(z) = \exp(-z^2) \)

Under directional selection, phenotypic noise dimensionality reduction and alignment with fitness optimum promotes the fixation of beneficial mutations and strongly decreases the cost of complexity.

Experimental results on Yeast (Metzger et al. 2015) suggest that phenotypic noise evolves faster than mean phenotype.

Selected references: