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To cite this version:
Charles Rocabert, Guillaume Beslon, Carole Knibbe, Samuel Bernard. Phenotypic Noise and the Cost of Complexity. EvoLyon 2019, Nov 2019, Lyon, France. hal-02402443

HAL Id: hal-02402443
https://hal.archives-ouvertes.fr/hal-02402443
Submitted on 10 Dec 2019

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Phenotypic Noise and the Cost of Complexity

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This work was supported by the European Commission 7th Framework Programmes 659 (FP7-ICT-2013.9.6 FET Proactive: Evolving Living Technologies), and EvoEvo Project 660 (ICT-610427)

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)

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 \(z = N_{\mu, \Sigma}\)

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%,
- Mutation size: 0.01.

4. PHENOTYPIC NOISE PROMOTES ADAPTIVE EVOLUTION AND DECREASES THE COST OF COMPLEXITY

Phenotypic noise mutation rate, compared to mean phenotype mutation rate:
- 1) Lower
- 2) Equal
- 3) Higher
- 4) No noise

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:
(1) Lande (1980); Pal (1998); Kawecki (2000); Panniket al. (2007); Zhang et al. (2009) Mol Sys Biol 5:299;
Bruijning et al. (2019)
(2) Böld et al. (2017) PLOSBiol 15:e2000646; Dureau et al. (2018) Eilibr. 7.e17272
Nature 521:344-347
(5) Zhang et al. (2009) Mol Sys Biol 5:299; Draghi et al (2019);

- **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 plateaus.
  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 promote adaptive evolution in flat regions of the fitness landscape.