Phenotypic Noise and the Cost of Complexity
Charles Rocabert, Guillaume Beslon, Carole Knibbe, Samuel Bernard

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

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
Phenotypic Noise and the Cost of Complexity

Charles Rocabet\textsuperscript{1,2}, Guillaume Beslon\textsuperscript{1,3}, Carole Knibbe\textsuperscript{1,4}, Samuel Bernard\textsuperscript{1,5}

\textsuperscript{1}. Inria, France  
\textsuperscript{2}. Synthetic and Systems Biology Unit, BRC, Szeged, Hungary  
\textsuperscript{3}. CNRS UMR5205 LIRIS, INSA Lyon, France  
\textsuperscript{4}. INSEER U1060 CarMen, INSA Lyon, France  
\textsuperscript{5}. CNRS UMR5208 Institut Camille Jordan, Univ Lyon 1, France

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)

\textbf{1. PHENOTYPIC NOISE EFFECT ON FITNESS DEPENDS ON THE SHAPE OF THE FITNESS LANDSCAPE (SINGLE CHARACTER)}

Generalized fitness function: \( w(z) = (1+\beta)\exp\left(-ax^2\right) + \beta \) (5)

- \( Q > 2 \)
- \( \beta > 0 \)

\textbf{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 \( \sigma \) (mutable),
- Rotation angles \( \Theta \) (mutable),
- Covariance \( \Sigma \) built from \( \sigma^2 \) and \( \Theta \),
- Phenotype \( z = N_n(\mu, \Sigma) \)

\textbf{3. PHENOTYPIC NOISE DIMENSIONALITY REDUCTION}

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

\textbf{Example:}
Simulation for two phenotypic characters:
- Initial distance: 4 units,
- Population size: 1,000,
- Mutation rate: 1e-3,
- Mutation size: 0.01.

\textbf{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:

- Phenotypic noise: variability in phenotypes of siagenic organisms in constant environment, aka developmental noise, phenotypic heterogeneity, cellular noise, biological noise, intra-genotypic variability, ...
- Directional selection: selection far from fitness optimum characterized by a convex (positive second derivative) fitness landscape.
- Stabilizing selection: selection close to fitness optimum characterized by a concave fitness landscape.
- Adaptive evolution: capability of increasing mean population fitness as measured by the rate of increase of the log-fitness with respect to the mean phenotype.
- Cost of complexity: Reduction of the fraction of beneficial mutations when the number of phenotypic characters under selection increases.
- 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 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.