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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 adaptative evolution under directional and/or stabilizing selection if the **logarithmic fitness plateaus**.

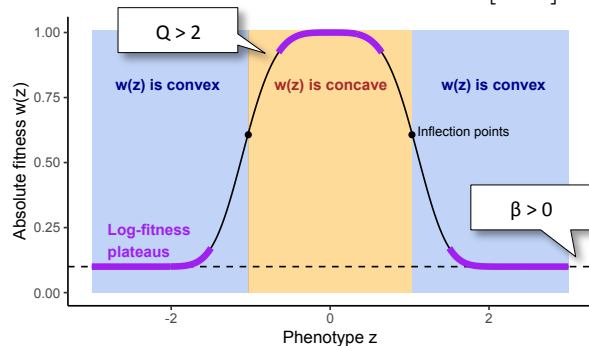
For multiple phenotypic characters under selection, the phenotypic noise evolves to a one-dimensional noise aligned with the direction of the fitness optimum.

• CONCLUSION

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

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

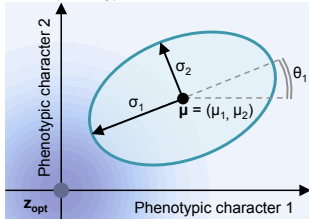
Generalized fitness function: $w(z) = (1-\beta)\exp[-\alpha z^Q] + \beta$ (5)



	Stabilizing selection (close to the fitness optimum)		Directional selection (far from the fitness optimum)	
Parameters	$Q = 2$	$Q > 2$	$\beta = 0$	$\beta > 0$
Shape of the absolute fitness function	concave (curvature < 0)	concave (curvature < 0)	convex (curvature > 0)	convex (curvature > 0)
Shape of the log-fitness function	does not plateau	plateaus	does not plateau	plateaus
Does noise increase mean absolute fitness?	No	No	Yes	Yes
Does noise promote evolution?	No	Yes	No	Yes

2. A MODEL FOR PHENOTYPIC NOISE EVOLUTION

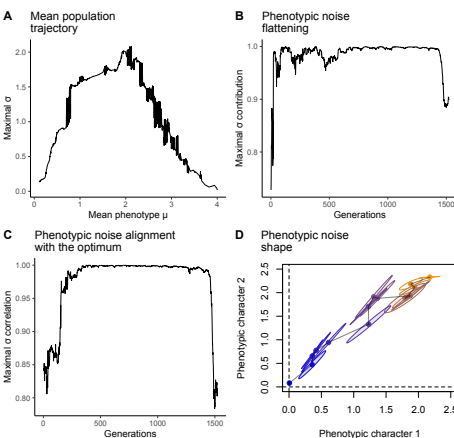
Evolvable phenotypic noise for two phenotypic characters



Multi-dimensional phenotypic noise is built from the mutable genotype $\{\mu, \sigma, \theta\}$:

- Mean phenotype μ (mutable),
- Variances σ^2 (mutable),
- Rotation angles θ (mutable),
- Covariance Σ built from σ^2 and θ .
- Phenotype $z \sim N_n(\mu, \Sigma)$

3. PHENOTYPIC NOISE DIMENSIONALITY REDUCTION

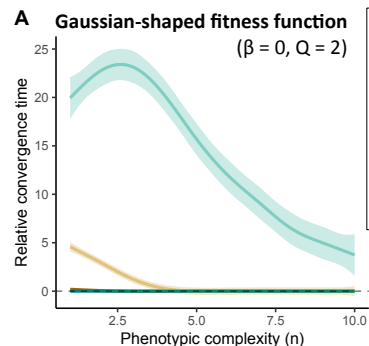


For multiple phenotypic characters under directional selection, we demonstrate that the best phenotypic noise configuration is **aligned and fully correlated with the direction of the fitness optimum**.

Example:

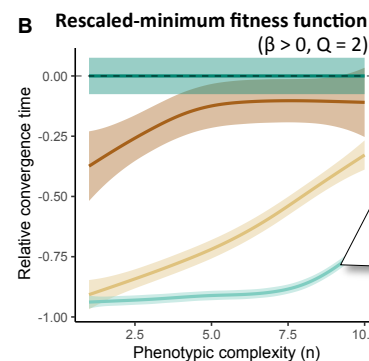
- Simulation for two phenotypic characters:
- Initial distance: 4 units,
 - Population size: 1,000,
 - Mutation rate: $1e^{-3}$,
 - mutation size: 0.01.

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.

- **Phenotypic noise**: variability in phenotypes of isogenic 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**: capacity 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.

Selected references:

- (1) Lande (1980); Pal (1998); Kawecki (2000); Paenke et al (2007); Zhang et al (2009) Mol Sys Biol 5:299; Bruijning et al (2019)
- (2) Bódi et al (2017) PLOS Biol 15:e2000644; Duveau et al (2018) Elife 7:e37272
- (3) Orr (2000) Evolution 54:13-20; Martin & Lenormand (2006) Evolution 60:893-907
- (4) Ito et al (2009) Mol Sys Biol 5:264; Pelabon et al (2010) Evolution 64:1912-1925; Viñuelas et al (2012) Prog Biophys Mol Biol 110:44-53; Shen et al (2012) PLOS Genetics 8:e1002839; Metzger et al (2015) Nature 521:344-347
- (5) Zhang et al (2009) Mol Sys Biol 5:299; Draghi et al (2019);