Morphospace Approaches to Evolution: Geometric and Developmental Considerations

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Synopsis

The biological notion of morphospace is examined from its conceptual and analytical dimensions. We review the diverse morphospace geometries encountered in the literature and their implications for the interpretations of morphological patterns. We also show how considerations of organismal development suggest novel mathematical structures to endow the set of morphological variants with evolutionarily meaningful notions of accessibility.

Main text

The notion of morphospace is both of conceptual and empirical importance in biology and paleobiology. Conceptually, it has entailed critical discussions about the relative prevalence of selective forces, variational constraints, and historical contingencies in shaping patterns of morphological evolution. Empirically, morphospaces have proven powerful quantitative tools to document and analyze morphological patterns in various research areas, from comparative anatomy and systematics, to functional morphology and large-scale studies of clade dynamics.

A morphospace is generally understood as the depiction of morphological variants as points in an abstract space in such a way that the relative proximity of points expresses the morphological similarity of variants. Here, we discuss whether this way of conceiving morphospace is always warranted in empirical studies or even adequate for all research questions. Two main aspects pertaining to morphospace geometry are considered: (i) the potential misinterpretation of the geometry induced by some morphometric descriptors and (ii) a notion of evolutionary accessibility among variants derived from the developmental representation of morphological traits.

Morphospace narratives often include statements about distance (between morphological variants) and direction (of morphological change) indicating that an inner-product geometry (generally the dot product of Euclidean geometry) is assumed for the morphospace. However, not all morphospaces are equipped with the metric properties that one tends to intuitively attach to the notion of ‘space’ [1,2]. So-called ‘theoretical morphospaces’ are particularly

prone to such non-metric geometries [2]. Raup's iconic shell coiling morphospace is taken as an example to illustrate this phenomenon and discuss its implications for biological inferences.

In paleobiology, the use of discrete character data does lead to metric morphospaces (assuming no missing data), but their Hamming-like geometry is sometimes overlooked [3]. In particular, the morphospace and its multivariate ordination are often confused for one another, inviting the use of inappropriate methodologies for their analyses (Fig. 1A).

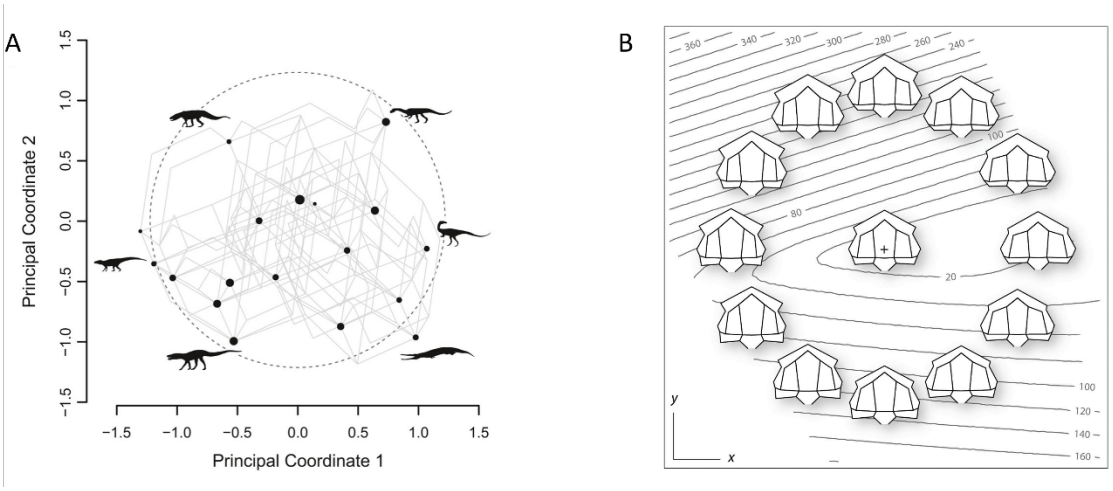

Figure 1. (A) Morphospace representation from discrete character data; (B) Accessibility structure mapped onto a morphospace.

Historically, methodological approaches to morphospace construction have typically aimed for metric topologies defined at the morphological level, organizing variants according to their morphological similarity. This choice may be suboptimal for addressing some important evolutionary questions however, since morphological distance among variants can be a poor predictor of their evolutionary accessibility (Fig. 1B). We show how a genetic or developmental representation of morphological characters allows the definition of accessibility among variants and enriches the explanatory power of morphospace with regards to the role of constraints and selection in morphological evolution [4].

References

[1] Huttegger, S. M., & Mitteroecker, P. (2011). Invariance and meaningfulness in phenotype spaces. *Evolutionary Biology*, *38*, 335-351.

[2] Gerber, S. (2017). The geometry of morphospaces: lessons from the classic Raup shell coiling model. *Biological Reviews*, *92*(2), 1142-1155.

[3] Gerber, S. (2019). Use and misuse of discrete character data for morphospace and disparity analyses. *Palaeontology*, *62*(2), 305-319.

[4] Gerber, S. (2014). Not all roads can be taken: development induces anisotropic accessibility in morphospace. *Evolution & Development*, *16*(6), 373-381.