EMPIRICAL SHAPE SPACE REPRESENTATIONS AND SHAPE MODELING OF FOSSILS FROM LANDMARK-REGISTERED 2D OUTLINES, 3D OUTLINES, AND 3D SURFACES, WITH A COMMENT ON THE INDETERMINACY OF EMPIRICAL "MONO-MORPHOSPACE" ANALYSIS

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Although a large number of tools are currently available for landmark-based morphometric analysis, there continues to be a need for outline and surfaced-based representations of morphologic variation. This need is especially evident in the field of synoptic empirical shape space analysis, where researchers are often confronted with a complex array of skeletal morphologies and a corresponding scarcity of landmark points common to all specimens under consideration. In such instances it is possible to take advantage of the analytic formalism supplied by an outline-based approach to morphologic characterization, while at the same time retaining the homology and/or structural correspondence information supplied by available landmarks, through a few simple modifications to the traditional eigenshape procedure.

These modifications extend the range of objects susceptible to eigenshape analysis from 2D closed curves to include 2D open curves, 3D closed curves, 3D open curves, and 3D surfaces. The unique shape modeling and shape morphing abilities of traditional eigenshape analysis are fully compatible with the "extended" eigenshape procedure. These 2D and 3D modeling and morphing capabilities are especially useful in gaining insight into the nature of shape spaces within which degrees of phenetic similarity and difference between specimens can be portrayed. The shape modeling abilities of the extended eigenshape procedure are essentially identical in sensitivity and systematic information content to various "Raupian" theoretical shape modeling techniques. Moreover, landmark registration of the constituent outlines enables the extended eigenshape procedure to control the degree of shape resolution in such a way as to differentially weight regions of high shape variability in the overall analysis. This, in turn, leads to more accurate and more efficient summarization of variational modes on the resulting shape axes.

Examples of applying different forms of the extended eigenshape procedure to test datasets drawn from the vertebrate, plant, invertebrate, and microfossil records show that inferred similarity/dissimilarity patterns are highly sensitive to the manner in which the underlying morphology has been sampled. Consequently, it is inappropriate to assume that results of an eigenshape-based (or any other type of) single-space or "mono-morphospace" analysis are necessarily valid for all possible shape space representations. Given the inherent indeterminacy of single shape space approaches to the characterization of observed shape variation, results based on such studies should not be regarded as valid for alternative shape spaces unless it can be shown that those results are robust to the inclusion of additional data and to the use of alternative shape space metrics. However, single shape space approaches can be used to test hypotheses that address specific aspects of inter-taxic morphological variation.