Morphometrics
(Quantitative Morphology)

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Introduction

• Morphometrics:
  – The study of (1) form, (2) variation in form, and (3) change in form among organisms.
    • Size (scaling)
    • Shape

• Serves as a basic methodological tool in:
  – Systematics, phylogenetics, paleontology
  – Evolutionary and theoretical morphology
  – Ecomorphology
  – Developmental biology
  – Quantitative genetics
  – Functional and constructional morphology
  – Forensics
• Morphometric methods are used to investigate three basic kinds of problems:

(1) **Patterns of variation**
- Variation among individuals
- Geographic variation
- Interspecific variation
- Effects of selective forces on morphology
  - E.g., evolutionary, agricultural, orthodontic
- Growth (normal or abnormal)
- Genetic basis: quantitative genetics
Three kinds of problems:

(2) Differences among “populations”
   - Populations defined \textit{a priori}
   - Discrimination:
     - How large is the difference?
     - What is the nature of the difference?
     - Is the difference statistically significant?
   - “Classification”:
     - Allocation of “unknowns” to known groups.

(3) Levels of similarity
   - Hierarchical relationships with respect to some criterion:
     - Overall similarity (phenetic)
     - Derived similarity (cladistic)
   - Basis for phylogenetic methods
• Some **basic premises** underlying morphometric methods:

  (1) Morphometry involves **geometric abstraction**.
• Premises:

(2) Underlying all morphometric analysis is the concept of form-change as a **deformation**.

– Concept dates from German Renaissance artist Albrecht Durer (1524):

– Elaborated and formalized by the mathematical biologist D’Arcy Thompson (1917, 1942):
• Premises:

(3) Comparisons limit descriptions:
  • One form can be described arbitrarily to any degree of resolution.
  • For sets of forms, the choice of descriptors can greatly affect the conclusions.
  • Analogous to distinction between description and diagnosis.

(4) Morphometrics can be used both for exploration and for hypothesis-testing.

(5) Question + geometric abstraction = method.
• Premises:

(6) Biologically informative morphometry is based on two fundamental biological principles:

(a) Homology:
- Evolutionary correspondence of structures among taxa.
- Extrapolates to correspondence of points (anatomical “landmarks” among taxa.
- Provides the basis for biological comparisons.
Premises:

(6) Two fundamental biological principles:
(b) Allometry:
   - Systematic change in shape (proportions) with increasing body size.
   - Provides a basis for size/shape decompositions.
• Premises:

(7) The most informative morphometric analysis separates the roles played by biology, geometry, and statistics:

- Biology → landmarks
- Geometry → relationships among landmarks
- Statistics → comparisons of sets of forms
• How to quantify and compare forms:

(1) **Rank their shapes:**
- Form a transition series with respect to one or more traits, and rank the individuals.

• Problem: the **Shape Monotonicity Theorem:**
  - For any three outlines \{A, B, C\}, there exist indefinitely many shape measures for which A and C have exactly the same value, so that B, no matter what it looks like, cannot be in between.
• Moral: any ranking of forms is arbitrary, because there can be no “natural” ranking.
• Applies to phylogenetic ‘character states’.
• How to quantify and compare forms:
  (2) Rely on **meristic (countable) features**.
    • E.g., vertebrae, scales, eye facets, trichomes, etc.
    • Too crude.

(3) Use **measurable (mensural) features** that characterize the size and shape of the organism.
    • E.g., lengths, angles, etc.
    • Problems: Which to use? How to compare? Homologous? Analogous?
• How to quantify and compare forms:
  (4) Estimate shape difference directly, without measuring original shapes.
  • Procrustes mappings

  • Biorthogonal grids

  • Thin-plate splines
### Morphometrics: historical context

<table>
<thead>
<tr>
<th>Factor analysis</th>
<th>Allometry</th>
<th>Deformations</th>
<th>Shape spaces</th>
<th>Self-similar systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pearson, Wright, Spearman, Hotelling, Fisher, Mahalanobis, Mosteller (1890s – 1930s)</td>
<td>Huxley (1924, 1932)</td>
<td>Thompson (1917, 1942)</td>
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</table>
• A taxonomy of morphometric methods for describing forms:

(1) **Boundaries only**
- Geometric modeling and description
- Radius and tangent-angle functions
- Medial axes
- Fourier and wavelet decompositions

(2) **Landmarks only**
- Homology maps (e.g., Procrustes superimposition)
- Deformation methods
- Finite-element analyses
- Inter-landmark distance methods
- Multivariate statistics
- Path analysis, factor analysis

(3) **Boundaries + landmarks**