Reconstructing an Ancestral Bat Echolocation Call

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Acknowledgements

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Related Research

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The analysis of acoustic phonetic data: exploring differences in the spoken romance languages.  
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The analysis of acoustic phonetic data: exploring differences in the spoken romance languages.

Nathaniel Shiers, John AD Aston, Jim Q Smith, and John S Coleman.
Gaussian tree constraints applied to acoustic linguistic functional data.

Nick S Jones and John Moriarty.
Evolutionary inference for function valued traits: Gaussian process regression on phylogenies.
Get Call Recordings

Sample of Bat Echolocation Calls

![Sample of Bat Echolocation Calls](image)
Time-Frequency Representation

A Time-Frequency Representation - Spectrogram
A model for Spectrogram Surfaces

“Functional Data Analysis is a branch of Statistics providing information about curves, surfaces, or anything else varying over a continuum” - Wikipedia
A model for Spectrogram Surfaces

“Functional Data Analysis is a branch of Statistics providing information about curves, surfaces, or anything else varying over a continuum” - Wikipedia

\[ S_{lm}(t_j, \omega_k) = G_{lm}^S(t_j, \omega_k) + \epsilon_{lm}^S(t_j, \omega_k) \]

Spectrogram = Underlying Surface + Noise
A model for Spectrogram Surfaces

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\[ G_{lm}^S(t_j, \omega_k) = C_{lm}^S(t_j, \omega_k) + \epsilon_{lm}^S(t_j, \omega_k) \]

Spectrogram = Underlying Surface + Noise

\[ G_{lm}^S(t_j, \omega_k) = S_{lm}^S(h^{-1}(t_j), \omega_k) + \epsilon_{lm}^S(t_j, \omega_k) \]

Spectrogram = Surface mapped from absolute to individual time scale + Noise
A model for Spectrogram Surfaces

“Functional Data Analysis is a branch of Statistics providing information about curves, surfaces, or anything else varying over a continuum” - Wikipedia

\[ \mathcal{G}_{lm}^S(t_j, \omega_k) = G_{lm}^S(t_j, \omega_k) + \epsilon_{lm}^S(t_j, \omega_k) \]

Spectrogram = Underlying Surface + Noise

\[ \mathcal{G}_{lm}^S(t_j, \omega_k) = S_{lm}^S(\mathcal{h}^{-1}(t_j), \omega_k) + \epsilon_{lm}^S(t_j, \omega_k) \]

Spectrogram = Surface mapped from absolute to individual time scale + Noise

\[ \mathcal{S}_i(t, \omega) = \mu_i(t, \omega) + \delta Z_i(t, \omega) \]

Sample surface = Group Mean Surface + Noise Process
Statistical Analysis

Given a set of Surfaces $\bar{Y}_1, \ldots, \bar{Y}_N$
Statistical Analysis

Given a set of Surfaces $\bar{Y}_1, \ldots, \bar{Y}_N$

Mean Surface Estimator

$$\bar{\mu}(t, \omega) = \frac{1}{N} \sum_{i=1}^{N} Y_i(t, \omega)$$
Statistical Analysis

Given a set of Surfaces $\bar{Y}_1, ..., \bar{Y}_N$

**Covariance Operator Estimator**

$$\bar{C}(t, t', \omega, \omega') = \frac{1}{N-1} \sum_{i=1}^{N} \{ Y_i(t, \omega) - \bar{\mu}(t, \omega) \} \{ Y_i(t', \omega') - \bar{\mu}(t', \omega') \}$$
Statistical Analysis

Given a set of Surfaces $\bar{Y}_1, ..., \bar{Y}_N$

Covariance Operator Estimator

$$\tilde{C}(t, t', \omega, \omega') = \frac{1}{N-1} \sum_{i=1}^{N} \{ Y_i(t, \omega) - \bar{\mu}(t, \omega) \} \{ Y_i(t', \omega') - \bar{\mu}(t', \omega') \}$$

Require a Simplifying Assumption – Separable Covariance Operators

$$C(t, t', \omega, \omega') = C(t, t')C(\omega, \omega')$$
Statistical Analysis

Given a set of Surfaces $\bar{Y}_1, ..., \bar{Y}_N$

\[
\bar{C}(t, t', \omega, \omega') = \frac{1}{N-1} \sum_{i=1}^{N} \{ Y_i(t, \omega) - \bar{\mu}(t, \omega) \} \{ Y_i(t', \omega') - \bar{\mu}(t', \omega') \}
\]

Require a Simplifying Assumption – Separable Covariance Operators

\[
\bar{C}(t, t', \omega, \omega') = \bar{C}(t, t') \bar{C}(\omega, \omega')
\]

\[
\bar{C}_t(t, t') = \frac{1}{N-1} \sum_{i=1}^{N} \int_0^F \{ Y_i(t, \omega) - \bar{\mu}(t, \omega) \} \{ Y_i(t', \omega) - \bar{\mu}(t', \omega) \} \, d\omega
\]

\[
\bar{C}_\omega(\omega, \omega') = \frac{1}{N-1} \sum_{i=1}^{N} \int_0^T \{ Y_i(t, \omega) - \bar{\mu}(t, \omega) \} \{ Y_i(t, \omega') - \bar{\mu}(t, \omega') \} \, dt
\]
Time expansion of an Actual Echolocation Call

Time expansion of an Approximation for the Mean Echolocation Call 1

Time expansion of an Approximation for the Mean Echolocation Call 2
Canonical Function Analysis

Given a set of Surfaces from $G$ groups, \{${Y_{ij}: i = 1, ..., N_i; j = 1, ..., G}$\}
Given a set of Surfaces from $G$ groups, $\{Y_{ij}: i = 1, \ldots, N_i; j = 1, \ldots, G\}$

find orthogonal basis functions which maximise the ratio of between group variation to within group variation

$$(B - \lambda_k W)f_k = 0$$
 Canonical Function Analysis

Given a set of Surfaces from $G$ groups, \{\(Y_{ij}: i = 1, \ldots, N_i; j = 1, \ldots, G\}\)

find orthogonal basis functions which maximise the ratio of between group variation to within group variation

\[(B - \lambda_k W)f_k = 0\]
WAP WAP WAP

CALVIN! WHAT ARE
YOU DOING TO THE
COFFEE TABLE?!?

* IS THIS SOME SORT OF
TRICK QUESTION, OR WHAT?