A New Quantitative Method to Analyze Geospatial Variations in Speech and Vocalization

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Abstract

Vocalizations play an important role in the social structure and development of many species of animals including hominins, apes and, especially, humans, in whom vocalization has evolved and diversified so far that it has become nearly 7000 informatically complex and immensely diverse languages. Studying how these vocalizations change and evolve is a central pursuit in understanding the social structure, behavior and evolution of many animals, including humans. Furthermore, spatial variation is a well documented, and often very pronounced, form of vocalization variation and may play a role in reproductive isolation and thus, speciation. Here, we present a new method for analyzing geospatial trends in animal vocalization using frog calls as a model organism to demonstrate the utility of our method. Unlike previous methods, ours does not rely upon the use of spectrograms. Rather, we analyze the signal directly, avoiding some of the issues with spectrograms.

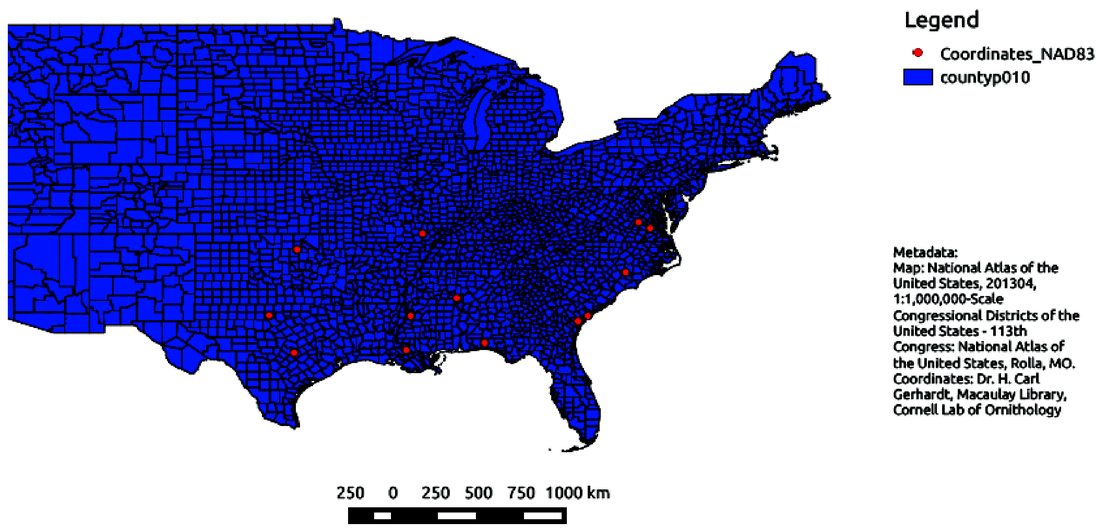
To develop and demonstrate our method, a sample of 187 mating calls of the Cope's Gray Treefrog (*Hyla chrysoscelis*) were downloaded from a Cornell repository. These calls were then aligned using a modified form of Generalized Procrustes Analysis after being cleaned to remove noise. The aligned calls were then run through a dimension-reduction method and related to the GPS coordinates in UTM format using spatial regression. Using both simulated test data, as well as the real data from our model organism, we show that our method is a reliable and powerful way to quantitatively analyze the geographic variation in vocalization patterns.

This study is indebted to the Macaulay Library of the Cornell Lab of Ornithology for generously allowing us to download and use their frog calls for our research.

Introduction

- Signal processing has become a very large part of field biology recently with the advent of techniques such as Spectrographic Cross-Correlation (SPCC) and Principal Coordinates Analysis (PCO) often abbreviated as SPCC-PCO by Cortopassi and Bradbury (2000) [1].
- This project attempts a different method based not on spectrograms, as has previously been common practice, but on the original signals. Here, we examine the shape of the waveform of a single pulse extracted from the overall waveform as and use a form of hierarchical clustering analysis to determine geographic variation in the calls.

Map 1: Map of Recording Locations



Map 1: This map displays the geographic locations of all of the recording sites from which samples were taken. These samples were collected between 1969 and 1990 by Dr. H. Carl Gerhardt and were licensed to this project and downloaded from the Macaulay Library of the Cornell Lab of Ornithology. The points in red are the coordinate locations while the map itself is from the U.S. National Atlas. It is in the Public Domain as it is a publication of a part of the USDOI.

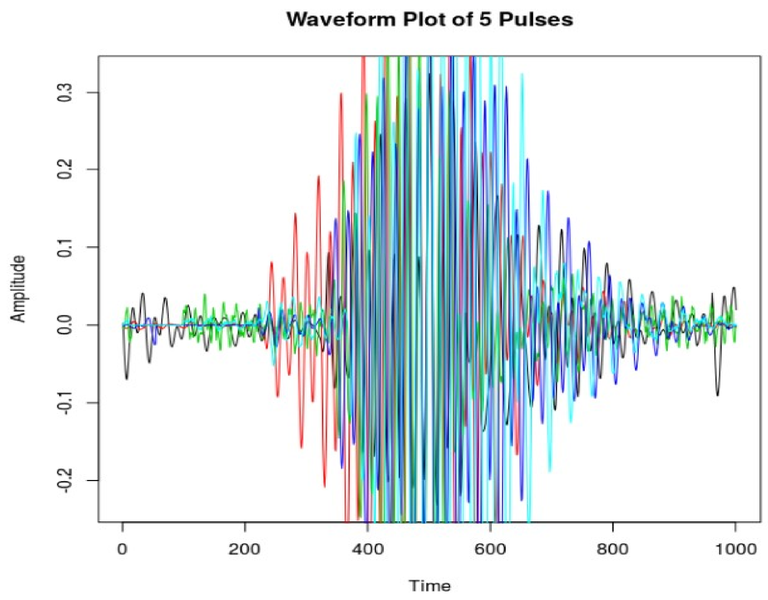


Figure 1: This figure shows a sample of 5 pulses overlaid on top of one another which were extracted from the original frog calls. Each color is a different pulse.

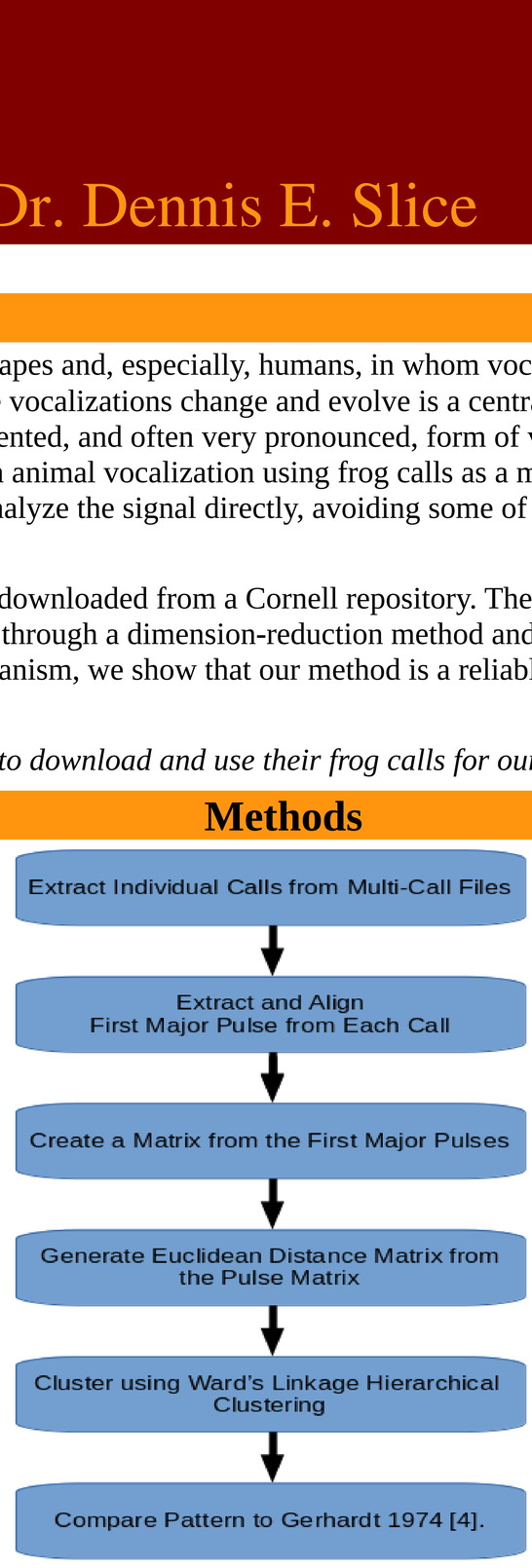
Hypothesis

- Show that analyzing the shape of a single pulse in the waveform of frog calls can be used to determine geographic relationships.

Single-Pulse Analysis

- In this project, a single pulse was extracted from each call for analysis. In each case, this was the first major pulse.
- The first major pulse is the first pulse in each call whose amplitude exceeds the threshold at which it and all subsequent pulses become self-similar. This is 4σ of the overall amplitude.
- Exactly 1000 timesteps around the first point of the call to exceed that threshold are extracted.
- Once extracted, the pulses were aligned by centering their peaks (maximum amplitude values).
- Once aligned, a Euclidean distance matrix is formed from the pulses and clustered.

Methods



Results

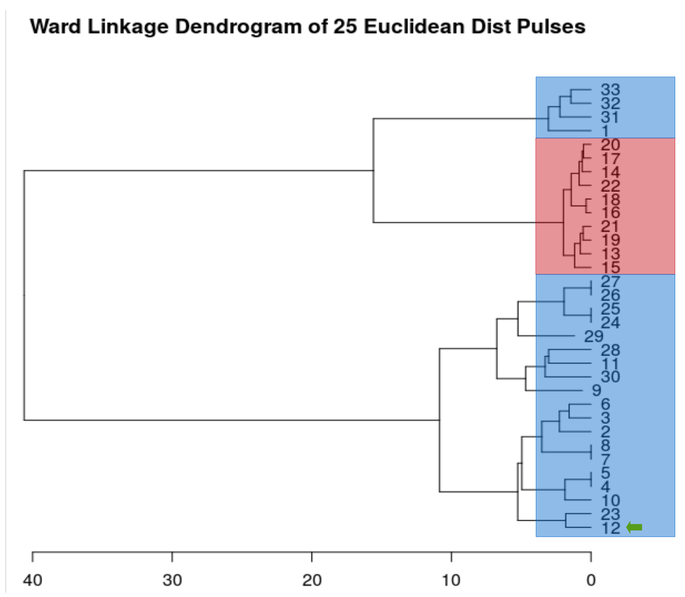


Figure 3: In the image to the left, the leaves numbered 1 through 11 are the Georgia population from coordinates 32.00522,-81.28441 while those numbered 12 through 22 are a Texas population from coordinates 32.33545,-98.82943 and the last set from 23 to 33 are a Florida population from coordinates 30.76013, -86.59498. The **RED** group is the Western group and the **BLUE** group is the Eastern group. **GREEN** arrows are ambiguous calls.

Conclusion

- The preliminary results shown here are promising as they clearly show the expected pattern of geographic variation and the clustering technique also is able to distinguish both groups.
- The pattern here, as shown in the dendrogram in Figure 4, is very clearly the east-west split in the calls detailed in Gerhardt (1974) [4].
- The pattern, as shown above, has a misclassification error rate of 3.03%. This could indicate that more fine-tuning of the methodology is needed or could simply indicate excessive noise in some of the individual pulses.
- Thus, in its present state, the Single Pulse Analysis method is a valid method for analyzing geographic variation in animal vocalizations.

Acknowledgements

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References

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