Challenges and Opportunities in Array Processing for Bioacoustics

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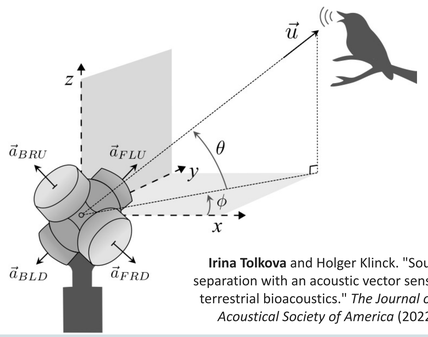
Acoustic arrays are used extensively for biodiversity monitoring — for localizing wildlife, improving automated classification, and estimating abundance. Below are **practical applications** of arrays in terrestrial and marine bioacoustics, followed by a few **further research directions** that could benefit conservation efforts.

Source Separation of Birdsong with Small-Aperture Microphone Arrays

A common challenge of passive acoustic monitoring is the **overlap** of target vocalizations with other calls and environmental/anthropogenic noise.

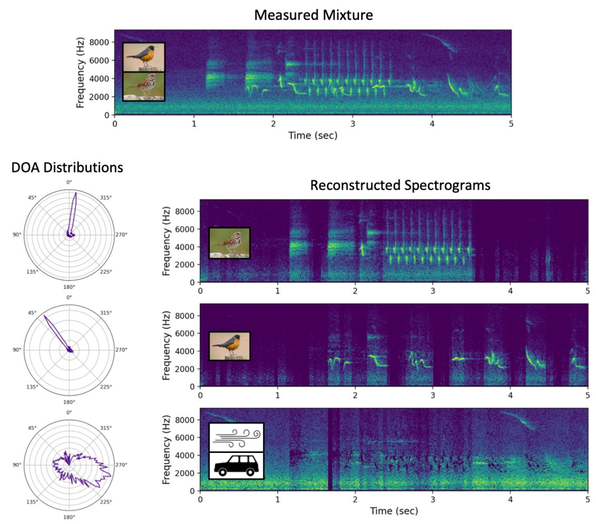
Using a small-aperture array, we can separate overlapping sound sources in a natural environment.

In particular, a **tetrahedral first-order ambisonic array** streamlines direction-of-arrival estimation.

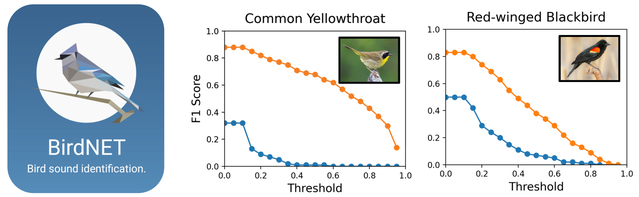


Irina Tolkova and Holger Klinck. "Source separation with an acoustic vector sensor for terrestrial bioacoustics." *The Journal of the Acoustical Society of America* (2022).

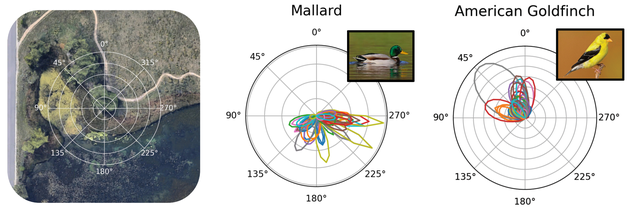
With this array, we can calculate **azimuth angles** corresponding to each spectrogram pixel.



When source separation is used for a natural recording, we obtain **improved species-level classification performance:**



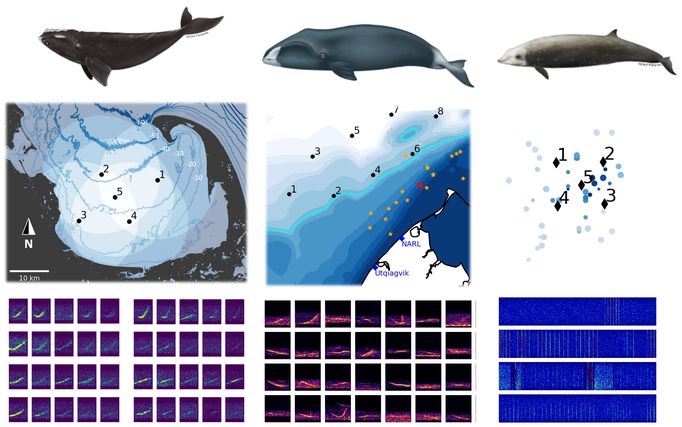
We can also examine the azimuth **distribution** of species in their habitat:



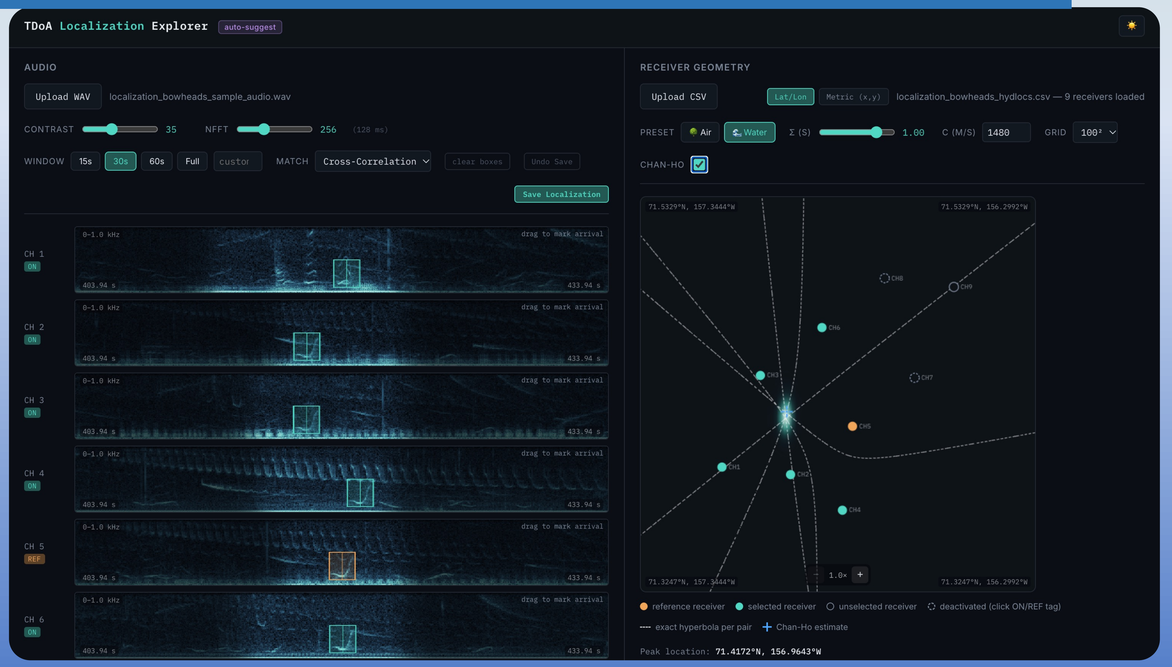
Furthermore, we can **track moving sources**, obtain **rough counts** of individuals, and, with two tetrahedral arrays, **calculate locations**.

Abundance Estimation of Whales with Wide-Aperture Hydrophone Arrays

Underwater, **acoustic localization** with wide-aperture arrays is an established methodology for **monitoring spatial distributions** and obtaining **abundance estimates** for marine mammal populations.



In these projects, we integrated **acoustic cues** with **visual sightings**, **aerial surveys**, or **call rate estimates** to estimate abundance or density, whether with distance sampling or a regression model.



Further Directions

Data-driven Clock Synchronization

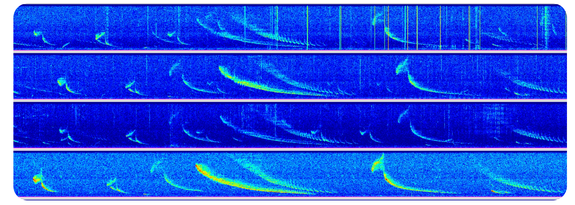
With enough spatially distributed calls, we can **solve for relative drift** alongside solving for optimal source locations in a least-squares framework:

$$\underset{s,\tau}{\operatorname{argmin}} \sum_{n=1}^{N}\sum_{j=1}^{K}\sum_{i=j}^{K}(||\vec{r_i}-\vec{s_n}||_2 - ||\vec{r_j}-\vec{s_n}||_2 - c\tilde{\Delta}t_{i,j} + c\tau_i - c\tau_j)^2$$

Can such data-driven clock synchronization be made more robust and annotation-agnostic?

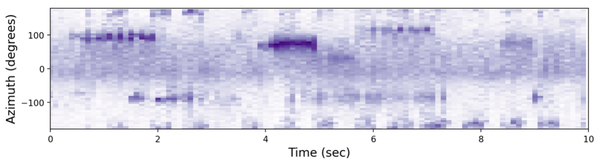
Joint Detection and Association

Frameworks for sound event detection focus on single-channel audio. How can these models be extended to **jointly detect and associate calls** for array applications?



Tracking Sound Sources

Natural soundscapes are characterized by high variability, overlap, low SNR, and movement.



What are robust approaches for **source separation and tracking** in this complex environment?

All of these directions would greatly benefit from **benchmark datasets** for evaluating localization, synchronization, association, tracking, and other array problems.

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