# Sound Localization by Self-Supervised Time Delay Estimation

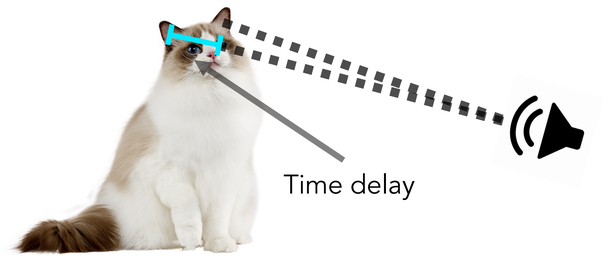
Ziyang Chen, David F. Fouhey, Andrew Owens
University of Michigan

ECCV TEL AVIV 2022

Webpage

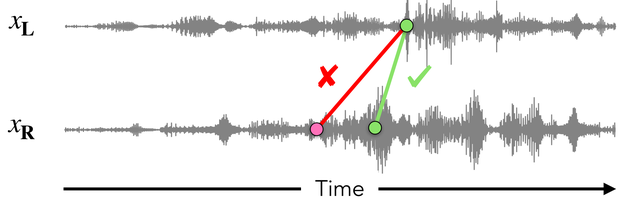
## Introduction

**Goal**: Localize sounds by estimating how much sooner they arrive at one ear than the other. We'll learn to do this *using only unlabeled recordings*.




## Time Delay Estimation

**Idea**: Treat it like a self-supervised tracking problem! Find **interaural correspondences,** pairs of sounds from different channels that correspond to the same underlying events.

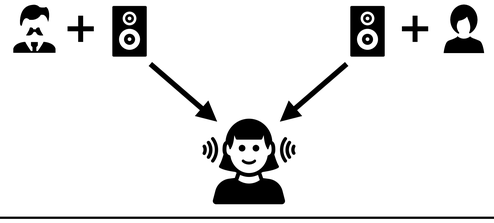



**Generalized cross-correlation:** find a time delay $\tau$ that maximizes [Knapp & Carter, 1976]:

$$R_{\mathbf{x}_1,\mathbf{x}_2}(\tau) = \mathbb{E}_t\left[\mathbf{h}_1(t)\cdot\mathbf{h}_2(t-\tau)\right]$$

We'll learn audio (or audio-visual) features $\mathbf{h}$.

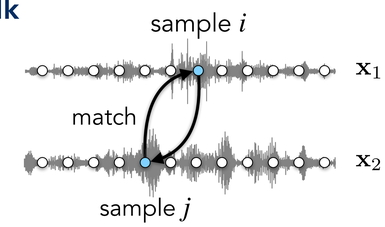
**Visually-guided sound localization**: localize a sound from a mixture, guided by the appearance of a speaker.

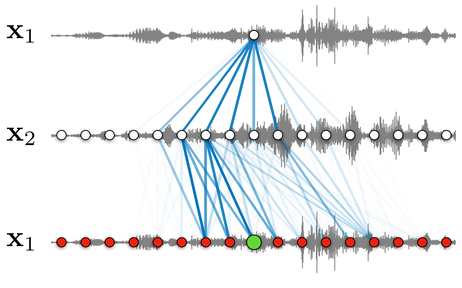


## Method

### Binaural Contrastive Random Walk

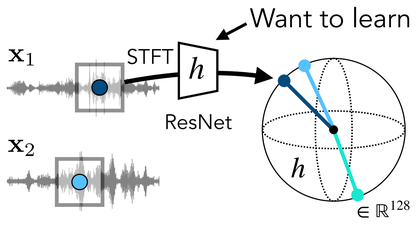
**Idea**: learn a representation that leads to *cycle-consistent* matching.




Transition probability from sample $s$ in $x_i$ to sample $t$ in $x_j$ :

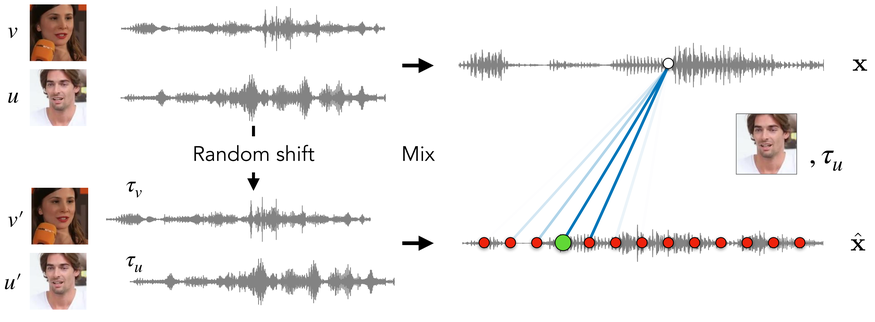
$$A_{ij}(s,t) = \frac{\exp(\mathbf{h}_i(s)\cdot\mathbf{h}_j(t)/c)}{\sum_{k=1}^{n}\exp(\mathbf{h}_i(s)\cdot\mathbf{h}_j(k)/c)}$$




**Objective**: maximize the return probability of a walk moves between channels [Jabri et al. 2020]:

$$\mathcal{L}_{\text{crw}} = -\operatorname{tr}(\log(A_{12}A_{21}))$$

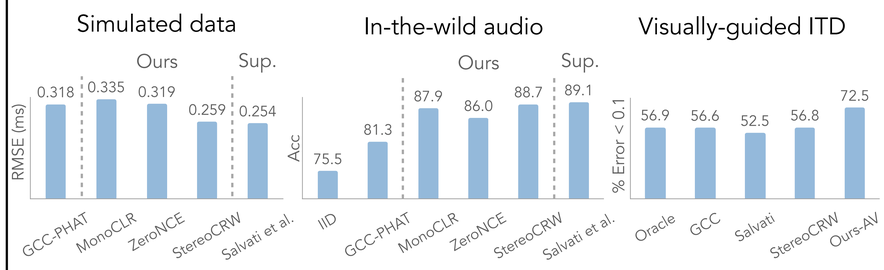
### Visually-Guided Time Delay Estimation



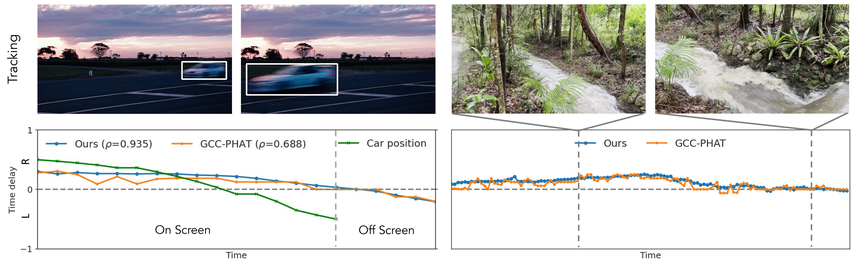

Learning audio-visual features $\mathbf{g}$ by optimizing:

$$\mathcal{L}_{\text{av}} = -\log\frac{\exp(\mathbf{g}_1(t)\cdot\mathbf{g}_2(t-\tau_u)/c)}{\sum_{k=1}^{n}\exp(\mathbf{g}_1(t)\cdot\mathbf{g}_2(k)/c)}$$

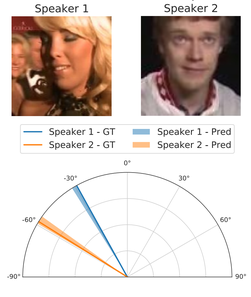
## Experiments



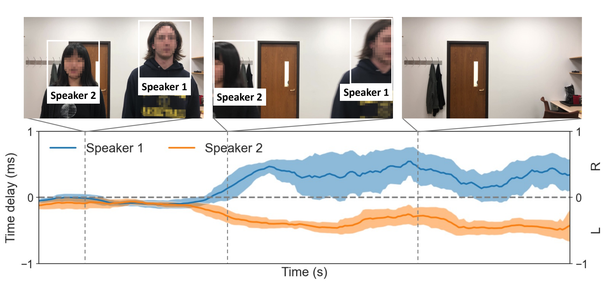

In-the-wild examples


Simulated examples




Real-world visually-guided time delay estimation




## Conclusions

- We propose a simple, **self-supervised** method for learning to estimate interaural time delay via cycle-consistent random walks.
- Visual signals allow our models to localize specific speakers within mixtures.