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Extended abstract

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Towards a general probabilistic framework to predict human sound localization

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ABSTRACT

Our hearing system plays a significant role in understanding the space around us. Such a process is the result of the dynamic interaction between the listener and the environment. Yet, predicting how our hearing system drives space perception is still an open problem. In this work, we explore the possibility of employing Bayesian models as a quantitative method to predict human behavior in acoustic environments. We describe how perceptually relevant features can be used to estimate spatial quantities from the acoustic space (e.g., directional sound location). We further describe how the spatial information transmitted by such cues can be mapped to predict individual behavior in tasks related to spatial hearing. As result, we propose a unified probabilistic framework potentially able to integrate outcomes from various perceptual experiments to develop functional models of space perception. As a proof of concept, we show how to accommodate an already existing auditory model for the sound localization task in the proposed framework, discussing its advantages and its limits.

Keywords: sound localization, auditory model, space perception, Bayesian model

1 INTRODUCTION

In the psycho-acoustic field, human ability to perceive space with the hearing system is usually represented by computational models (1). These models mimic the auditory pathway with a pipeline of processing components (2) and they allow to test quantitative hypotheses such as analyze which spatial cue can best predict elevation perception (3). However, developing a model from scratch requires to define the interactions between deterministic components (e.g. computation of the spatial cues) and intrinsic uncertanties of the hearing process (e.g. internal noises).

A similar scenario can be identified in the cognitive sciences field where cumulative evidence supports the hypothesis that brain mechanisms can be modeled as inference processes implementing the Bayes' law (4). Importantly, this field has demonstrated how probability theory can extend signal detection theory and be an effective tool to test mechanisms thought to happen in the brain while taking into account the uncertainty inherited in the subject's data.

In this work, we introduce a software framework to develop auditory models leveraging the theory of Bayesian models of perception. Particularly, we show a first case study focusing on a model for the prediction of human behavior in the sound-source localization task.

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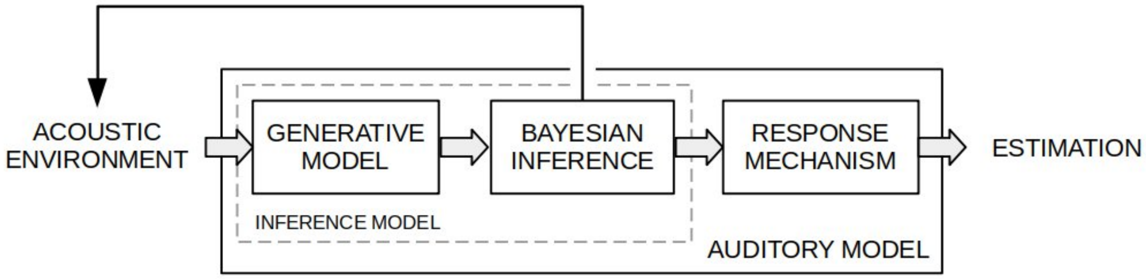
Figure 1: Framework structure implementing Bayesian inference.



2 THE FRAMEWORK

In order to develop auditory models as probabilistic models, we follow the architecture of Bayesian models of perception (4). These models hypothesize that the human brain infers the state of the world according to the Bayes' law. Following this theory, we identify four components within the structure shown in Fig. 1. In the following we introduce these components, describing their application to an auditory model of perceived direction (5).

The first component defines the *generative model* which describes how the sensory evidence is produced given a potential state of the environment. Within the task of sound source localization, the environmental state is identified by the source location and the sensory evidence by noisy spatial cues generated by the auditory periphery processing the binaural stream. Then, the *Bayesian inference* block hypothesizes the brain ability to estimate the actual state of the environment given the sensory evidence combined with an a-priori assumptions. When localizing a sound source, the state is linked with the evidence in a learned mapping between source directions and spatial cues (6). The interaction of these two first components – generative model and the Bayesian inference – is combined into the third component: the *inference model*. This model might consider a one-shot evaluation of the world like estimating the sound source position as in (5) or a dynamic interaction between subject and environment such as involuntary head movements to solve front-back confusions (7). Finally, the fourth element considers the *response mechanism* which transform the perceived direction available to the brain to an actual response as a real subject would point towards the estimated position of the sound source.

Following this organization, we defined a code scaffolding leveraging the model architecture and implemented it as a proof of concept in the Auditory Modeling Toolbox (8). The structure is shown in Table 1 and it can be easily extended to predict behavior in the estimation of other spatial quantities, e.g. sound externalization.

This structure provides two levels of code abstraction targeting two profiles of hearing scientists: model's *developers* seeking to write a model from scratch or to improve an already existing model and *users* interested in adopting an already existing model. Such a categorization might help in adapting other auditory models based on probabilistic approaches.

3 CONCLUSIONS

In this work, we introduced a framework for auditory models based on Bayesian inference. We described its general structure, with a sound-localization model as an example, and provide a code scaffolding for the integration of future models. The implementation of the framework is under development and available in the code repository branch *barumerli2023framework* of the Auditory Modelling Toolbox (8).

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Table 1: Code scaffolding for an auditory model organized as a Bayesian model.

File name	Functionality	Target group
author2022_generativemodel.m	Generative model	Developer
author2022_inference.m	Bayesian Inference	Developer
author2022.m	Inference model and response mechanism	Developer
exp_author20xx.m	Data analysis	User and Developer

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