Computational Cognitive Neuroscience. Lab 4

Multisensory integration. March 2025

Lecturer: Peggy Seriès
Teaching Assistant: Lars Werne

Tutorial Objectives

In this tutorial, you will:

- Learn about a Bayesian theory on how humans localize the source of sounds / noisy visual cues.
- Explore a probabilistic model for the integration of multisensory information describing the same object.

Bayesian Cue Combination

Background

We are interested in understanding how humans localize sound sources, when they can use both hearing and vision. We are also interested in illusions that arise in situations where there is a conflict between the two signals, for example as in ventriloquism (1).

We first present subjects with visual stimuli v: a low contrast Gaussian blob, very quickly flashed at some position in space x_v. The subjects are asked to localize the stimulus position x. We find that the subjects estimates are unbiased on average but display some variability from trial to trial. Their estimates $P(x_v|v)$ can be modelled using a Gaussian distribution with mean x_v and variability $\sigma_v = 4$ degrees of visual angle.

We then remove the visual stimuli and present subjects with very brief auditory stimuli a ("clicks") originating from different positions in space x_a. We again ask the subjects to localize the source of the sound, and find that their estimates $P(x_a|a)$ can be modelled using a Gaussian distribution with mean x_a and variability $\sigma_a = 3$ degrees of visual angle.

Cue Combination

Now we present the visual and auditory stimuli at the same time and at the same location in space.

- If humans are Bayesian optimal in integrating the information from both sources, how precise are they going to be in their localization performance now? Express mathematically the distribution of the subjects' estimates – explaining how this is derived.

  Hint: You are allowed to assume that the brain has no prior knowledge / bias on the true source location before sampling the stimuli.

- Plot the three distributions (based on vision alone, based on audition alone, and based on both vision and audition) on the same graph. Check that the bisensory distribution corresponds to the multiplication of the unisensory distributions.

Now we trick the subjects. We tell them that the 2 stimuli come from the same point in space and corresponded to a single event (like a ball hitting the screen), but actually we introduce a small displacement between the stimuli: the visual stimulus is displaced 5 deg rightwards and the auditory stimulus displaced 5 deg leftwards ($x_v - x_A = 10$ deg, where x_v and x_a are the spatial positions of the visual and auditory stimuli)

- How is this affecting the response? Plot the 3 distributions on the same graph.
- Now we keep the auditory stimulus unchanged but vary the blurry-ness of the visual stimulus, we use first a very precise stimulus v_1 and repeat the experiment. We measure in this case σ_{v_1} = 1 deg. Then we try a very blurry stimulus v_2 for which we measure $\sigma_{v_2} = 20$ deg. Where do subjects localize the source in these 2 cases ? Illustrate these examples and comment on your results.

These predictions were precisely tested by (1) and they found that human behaviour is consistent with the Bayesian predictions. As described in class, this seems to be a general result, with evidence from a number of experimental protocols, in different modalities (1; 2; 3).

- If you were to construct an artificial neural network that solves the above task – the optimal combination of two cues relating to different senses – how would you do it? Do you have ideas on how one group of neurons may encode a probability distribution? How may the activity of two such populations then be combined? What would be the difficulties / implications?

References

[1] Alais D, Burr D. The ventriloquist effect results from near-optimal bimodal integration. Current biology. 2004;14(3):257-62.

[2] Ernst MO, Banks MS. Humans integrate visual and haptic information in a statistically optimal fashion. Nature. 2002;415(6870):429-33.

[3] Knill DC, Pouget A. The Bayesian brain: the role of uncertainty in neural coding and computation. TRENDS in Neurosciences. 2004;27(12):712-9.