# Lab 4: Multisensory integration

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## 1 Bayesian Cue Combination

### 1.1 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 $P(x|v)$ can be modelled using a gaussian distribution with mean $x_v$ and variability $\sigma_v = 4$ degree of visual angle.

We then remove the visual stimuli and present subjects with very briefs 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 $P(x|a)$ can be modelled using a gaussian distribution with mean $x_a$ and variability $\sigma_a = 3$ degrees of visual angle.

### 1.2 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.

- 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 bimodal distribution corresponds to the multiplication of the unimodal 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 $\sigma_{v1} = 1$ deg. Then we try a very blurry stimulus $v_2$ for which we measure $\sigma_{v2} = 20$ 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 system which can also achieve such optimal combination of different cues (based on information for two types of captors), how would you do? What questions/ challenges are you going to face? Do you have ideas how this could be implemented with neurons and networks of neurons? What's the difficulty / the implications ?

### 1.3 Probabilistic Population codes – Ma, Beck, Latham and Pouget (2006)

Wei Ji Ma and colleagues [4] have proposed that populations of activity automatically probability distributions and that, due to Poisson noise, multisensory integration could be realised very simply just by summing the activity of the two populations of activity.

Here we try to verify this (using code you should already have from assignment 1).

We consider 2 populations of neurons. Population 1 encodes cue 1, which for simplicity will be thought of as motion direction. Population 2 encodes cue 2, which similarly describes motion direction for the same object but relying on different inputs (auditory vs visual for example).

Each population is described by $N = 50$ neurons with tuning curves $f_i(\theta)$ describing the mean spike count of each neuron in 1 second as a function of the stimulus direction $\theta$. The cells have preferred directions $\theta_i$ equally spaced between $-180$ deg and 180 deg. The tuning curves are circular normal distributions[1]:

$$f_i(\theta) = G_\alpha.\exp(\beta(\cos(\theta - \theta_i) - 1)) + K \tag{1}$$

where $G_\alpha$ is the maximal firing rate for population $\alpha$ (we start with $G_1 = 50$ spikes and $G_2 = 20$ spikes) which controls the strength of each cue, $\beta = 3$ controls the width of the tuning curves and $K$ denotes spontaneous activity ($K = 5$ spikes). The variability of the spike count is Poisson. We denote by $\mathbf{r}^\alpha(\theta) = \{r_1^\alpha(\theta), .., r_N^\alpha(\theta)\}$ the response of population $\alpha$ on a given trial of 1 sec for a stimulus $\theta$.

- Plot the mean response $\mathbf{f}(\theta_0)$ of the two populations of neurons to stimulus $\theta_0 = 0°$.
- Plot an example of the population responses $\mathbf{r^1}(\theta_\mathbf{0})$ and $\mathbf{r^2}(\theta_\mathbf{0})$ to stimulus $\theta_0 = 0°$ for one trial for both populations.
  Tip: You will need to use a Poisson random number generator in matlab, for eg. `http://homepages.inf.ed.ac.uk/pseries/CCN/poirv.m`
- Now we construct another population of neurons which has also 50 neurons and where the activity of each neuron is just the sum of the activity of the neurons in the two populations with the same index. For each neuron i in population 3:
  $$r_i^3 = r_i^1(\theta_1) + r_i^2(\theta_2)$$
  Plot this population activity.

**Decoding**

- Leaving cue 1 at 0° , and using 100 trials, using Maximum likelihood, decode the stimulus from the population response for population 1. What is the mean estimate $\mu_1$ and variance of the estimate $\sigma_1^2$?
- Do the same for population 2. What is the mean estimate $\mu_2$ and variance of the estimate $\sigma_2^2$?
- Now do the same again for population 3. What is the mean estimate $\mu_3$ and variance of the estimate $\sigma_3^2$?
- Does that fall onto the Bayesian prediction?

[1]These functions are similar to Gaussian functions but they are periodic, so that they wrap around the circle of stimulus directions naturally.

- Introduce a conflict between the two cues. Does the mean estimate follow the Bayesian prediction?

# References


[1] David Alais and David Burr. The ventriloquist effect results from near-optimal bimodal integration. *Curr Biol*, 14(3):257–262, Feb 2004.

[2] M.O. Ernst and M.S. Banks. Humans integrate visual and haptic information in a statistically optimal fashion. *Nature*, 415:327–348, 2002.

[3] David C Knill and Alexandre Pouget. The bayesian brain: the role of uncertainty in neural coding and computation. *Trends Neurosci*, 27(12):712–719, Dec 2004.

[4] Wei Ji Ma, Jeffrey M Beck, Peter E Latham, and Alexandre Pouget. Bayesian inference with probabilistic population codes. *Nat Neurosci*, 9(11):1432–1438, Nov 2006.