Bayesian integration of information

A team-based learning project

(written by G. Blohm for NSCI 401, October 2012)

The goal of this project is to acquire theoretical knowledge about Bayesian integration of information, i.e. the statistically best way to combine evidence. You will also get some hands-on experience through a movement decoding exercise.

Learning objectives: By the end of this project, you should be familiar with the following notions.

- Bayes law and what likelihoods, priors, marginal and posteriors mean
- Why and where Bayes law is useful in neuroscience
- How to use Bayes rule

Step 1: individual knowledge acquisition

Every group member should read the papers in the **portfolio** and familiarize her-/himself with the following concepts (feel free to do some research in the library, on the internet, etc):

- Reading portfolio (online): Deneve & Pouget (2004), Körding & Wolpert (2006)
- Optional: probabilities primer (online)
- Bayes law: likelihoods, priors, marginal, posteriors
- Conditional probabilities
- Statistical optimality

Step 2: collaborative learning – problem solving

These are the questions you are ultimately required to answer in your final written report. Answer them ALL **before** you start writing your report (step 3).

- Why is Bayes law useful for neuroscience? State at least 3 examples of applications.
- What does "statistically optimal" mean?
- How can ventriloquism be explained by Bayesian integration?
- Provide an intuitive explanation of what the following terms mean: likelihood, prior, marginal and posterior.
- **Practical application of Bayesian statistics**: *Optimal decoding of movement intention from multiple simultaneously recorded neurons in M1*
  - Suppose we simultaneously record from neurons in primary motor cortex (M1). We measure average spike rate for each neuron right after the onset of a reach instruction. Subjects can move either left or

right, but we don't know what they intend to do. How can we infer their intentions from neuronal recordings? Here are the measured firing rates of 10 neurons for one single reach intention:

- $\begin{pmatrix} 40.8084 \\ 44.3164 \\ 34.1953 \\ 75.3335 \\ 43.4339 \\ 50.6627 \\ 49.4592 \\ 47.3496 \\ 38.5744 \\ 14.9380 \end{pmatrix}$ Hz
- From previous reaches, we know that on average, all neurons fire at μ=50Hz for right-ward reaches and 60Hz for left-ward reaches, with a standard deviation of σ=10Hz. The likelihood function for observing a firing rate (x), given it would be a rightward movement would thus look like (and similar for a leftward movement, only with a different μ): $P(x|R) = \frac{1}{\sqrt{2\pi}\cdot\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}}$ (Gaussian Probability Density Function, PDF). Use this function to compute your likelihoods.
- To start with, suppose you only measure from the first neuron. How could you apply Bayes rule to compute the posterior? Note, you have to choose whether you compute the posterior P(L|x) or P(R|x). What would your prior be when you don't have evidence yet? What would your marginal look like? Hint: for the marginal, remember you have to sum over all options, i.e. P(x)=P(x|L)*P(L)+P(x|R)*P(R).
- Now that you have your posterior for the first neuron, you want to add evidence from a second neuron. How could that be done? But you already have knowledge from a first neuron. How does that change your prior?
- Once you have figured out how to add evidence from a second neuron, you can continue that way to add evidence from all other neurons in an iterative way.
- What happens to your posterior when you keep adding neurons (i.e. evidence)?
- Finally, based on this example, how do you think our brains can determine priors?

Step 3: project report

Please answer all above questions and justify your answers! Include a **1-page summary** of Bayesian integration. This summary should be like an introduction to Bayesian integration for a naïve reader. The total project report should **not exceed 5 pages** (12pt fond size, single spaced).

Important! Include your names on the report. Also, please provide a breakdown of work performed by the group (who did what?) on an additional page.

Email the final report to gunnar.blohm@queensu.ca by the deadline!!!