Multi-sensory cue integration with reliability encoding, using Line Attractor Dynamics, searching for optimality

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Introduction
A key requirement for any systems, including biological or man-made systems is their capability to estimate physical properties of the real world through partially reliable observations to interact properly with their environment. Apart from intrinsic variability of neural activity in the brain, accessible sensory cues are often uncertain and ambiguous. The human brain can combine these noisy and partially reliable pieces of information to optimally estimate the state of the world and gives us a coherent representation of the environment in order to efficiently handle cognitive tasks [1]. Physiological experiments show that human performance Bayesian model averaging over sensory observations based on relative variability of stimuli [1] [2]; but underlying neural mechanisms to encode and internalize the relative reliabilities of cues is still addressed as a central issue [2].

Neural activity modulation like Gain Field Modulation, is a well-known mechanism in brain to highlight information under specific internal or external constraints e.g. attention-based modulation of striate cortex by higher cortical feedbacks [3]. In this work in a sensory convergence problem and using an attractor network, we have investigated if modulating neural activity according to relative reliability of connected cues can bias the dynamics of the network in favor of more reliable cue, and consequently integrate cues in an optimal fashion. We have evaluated our methodology in a three-modal heading estimation experiment using an omnidirectional mobile robot [4]. We have compared the outcome of the network with Maximum-Likelihood-Estimator (MLE) and it is shown that the network can realize a near optimal solution for reliability based multi-sensory cue integration.

Encoding and Network Dynamics

\[ P(x_i) = \frac{\Phi(K,x_i)^\alpha}{\Phi(K,x_i)^\alpha + \nu} \]

- Poisson variability of \( n \) neurons activity given to a stimulus
- \( \Phi(K,x) = \exp(\beta x) \)
- \( \beta \)
- \( \alpha \)

Input variable (stimulus) subject to encoding by population vector \( R \)

Fig.3 Real: The activity of \( n \) neurons in response to stimulus \( c \) (blue: \( n \) neuron tuning curve centered at \( c \))

Multi-sensory Heading Estimation Experiment

\[ \mu_{\theta} = \frac{s_k + \sum_{i,j} s_{ij} \theta_i}{s_k + \sum_{i,j} s_{ij}} \]

Robot Reference Trajectory

Fig.4 The reference trajectory of the omni-directional mobile Robot

Network Architecture

- The Attractor Network consists of three input populations each for single input cue, and three intermediate populations of multi-modal neurons (Fig.1).
- Input cues are encoded by the activity of input populations through overlapping Gaussian tuning curves.
- All input neurons are reciprocally connected to intermediate neurons using Von Mises function (Fig.1).
- Modulating input populations strongly effect the dynamics of the network (Fig.2).

Conclusion and Remarks

- From Psychological experiments it is clear today that human observer performs a near-optimal Bayesian model averaging over partially reliable noisy sensory observations to achieve an estimation of the observed cues [2].
- In this work we have investigated how possibly modulating neural activity in an Attractor Network can describe reliability-based weighted cuing. The Attractor Network consists of three input populations each encoding single cue and three intermediate populations conducting the Dynamics of the network (Fig.1).
- The outcome of proposed methodology is compared with MLE estimator and voting based integration algorithm [5] and it is demonstrated that the network can integrate input cues in near optimal fashion if it is modulated according to relative reliability of connected cues (Fig.6).

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