Uncertainty in Neural Perceptual Systems

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Summary

Organisms face different kinds of uncertainty when perceiving their environment and they have to cope with this fact to survive. Such uncertainty might stem from unreliable sensors, ambiguities in the limited data about the physical world, or other imponderables. In order to enable optimal inferences from observed information, such uncertainty has to be taken into account and recent studies provide empirical evidence that this is realised in perceptual systems. In most cases recurrent processing structures form the basic machinery for dealing with this problem.

This work examines how we can formally analyse example problems of perception in terms of information processing and how they can be solved by a consistent model of neural functioning. To provide a sound foundation for this goal, we describe basic facts about the underlying biological systems and the mathematical methods to analyse them. We start by reviewing existing approaches suggesting how recurrent processing architectures can deal with uncertainty and use the formal frameworks of Bayesian inference and information theory to enable a quantitative treatment.

In more detail, we then describe different probabilistic interpretations of neural processing that represent uncertainty in the activation patterns of both single units and populations. We discuss how properties observable at the system level can be traced back to properties of its constituent elements.

In the core part of this work, we describe and analyse a concrete model for the dynamics of a single processing unit that enables a direct interpretation of its variables in terms of an inference process. We derive implications for signal transmission in single units and how effects of attention can be accounted for. Single units of this type can be arranged in simple circuits to improve information transmission and results from computer simulations illustrate the properties of such circuits.

The approach described in this work establishes a probabilistic interpretation for a simple dynamical system to enable a *functional* interpretation of its characteristics. Beyond precisely describing dynamical properties of perceptual systems this provides an answer to the question *why* it might "make sense" for a system to implement dynamics of a specific form. Interpreting perception as an inference task and showing that the specific dynamics solve this task in an optimal manner provides such an explanation.