5. **Fisher information of heterogeneous spiking networks.**

**Background.** Cells in the primary visual cortex are orientation selective, which means that the orientation of a stimulus can be inferred from their spiking activity as long as their preferred orientation is known. The Fisher information is a measure for the statistical efficiency of the orientation estimate: the higher the Fisher information the more precise the estimate. Another key concept is the tuning function, the firing rate as a function of stimulus orientation. The location of the peak of the tuning function indicates the neuron’s preferred orientation. Orientation selectivity can emerge in a feedforward way or as a result of recurrent cortical connections. It has been demonstrated that the correlations caused by recurrent connections reduce the Fisher information (Series et al *Nat Neurosci* 2004). In most computational studies the tuning functions of different neurons were identical except for the peak location. However, heterogeneity can be introduced by varying the peak amplitude and the shape of the tuning function across neurons. A recent paper holds that heterogeneity of tuning functions improves the Fisher information compared with a network with identical tuning functions (Chelaru & Dragoi, *PNAS* 2008). It is not clear what type of heterogeneity improves and what type of heterogeneity reduces the Fisher information, and by which correlations (spike count versus spike time) these changes are mediated.

The overall goal of this project is to study using a neural network how and in what way heterogeneity affects the Fisher information.

The learning goals for this project are to (1) gain a familiarity with the concept of Fisher information and learn how to calculate it analytically and numerically; (2) construct a coupled network of firing rate neurons using Matlab and obtain peaked tuning functions; (3) learn how to vary the degree and type of heterogeneity of the tuning functions obtained from the network; (4) determine the impact of tuning-function heterogeneity on the Fisher information.

The obvious extension of this project is to replace the firing rate neurons by spiking neurons, which will provide insight into the role of spike-to-spike correlations between neurons, which is topic of current interest.
6. Constructing and validating statistical models for spike patterns

**Background.** Half a century ago Hubel & Wiesel characterized the response properties of individual neurons in the visual cortex using a microelectrode. They found that cells were orientation-selective, for which they won the Nobel prize. Currently, the responses of multiple neurons are simultaneously recorded using multi-electrode arrays or two-photon microscopy. In order to understand these extremely complicated data sets it is necessary to develop statistical models. Recently two methods were proposed, one based on the Ising model of statistical physics (Scheidman et al *Nature* 2006) and one based on generalized linear models (Pillow et al *Nature* 2008). The Ising model is very powerful because it reduces the number of parameters, it fits the experimentally obtained cross correlation functions based on the principle of maximal entropy. The Ising model explains the data in terms of pair-wise coupling constants that could be interpreted as the presence of excitatory or inhibitory synapses for the pair in question.

The overall goal is determine how well pair-wise coupling constants represent the synaptic connectivity matrix under different states of the cortical network. This study will be conducted using model simulations of networks of spiking neurons and is relevant because it will help the interpretation of experimental results.

The learning goals are: (1) Gain familiarity with the Ising model for describing spike patterns; (2) Understand methods used to fit Ising models to experimental or simulation data; (3) Learn how to develop network models and simulate them using matlab, C or python; (4) Learn how to setup a simulations

There are a number of extensions that could lead to scientific publications. First, the Ising model is based on the optimization of the so called Shannon entropy, which is extensive – the question is whether there are other optimality principles that account better for the data. The Ising model presently does not include temporal interactions, but they could be included in a fairly straightforward way. The question in that case is whether including temporal interactions leads to a better description of the experimental data. Third, these techniques could be applied to real experimental data and lead to publishable insights.
7. Population models for motion sensitivity in the primary visual cortex of the Ferret

**Background.** The response of neurons in primary visual cortex (V1) can under certain circumstances be described as the output of a spatiotemporal energy (SE) filter, for instance as a space-time Gabor function (Basole et al *Nature* 2003; Mante & Carandini *J Neurophys* 2005). Our perception of the direction of motion is based on the population response in V1, which can thus be modeled as an array of SE filters. Because neurons are direction selective, the information about object motion is present in two types of responses: the preferred direction of motion of the neurons that are activated by the object and the change in time of the receptive field centers that are activated by it (position tracking). The waterfall illusion is a well known illusion: if you focus on a waterfall for a minute or so and then move your gaze to the rock wall next to the waterfall, the rock wall will appear to move upwards. Recent experiments in Ferret indicate that during a sudden shift in direction of motion of an object, certain aspects of the motion transition are misinterpreted perceptually (Wu et al, unpublished). Logic dictates that this shift could be due to either the adaptation of neurons (like for the waterfall illusion); short term plasticity of the synapses that connect them or specific features of the synaptic connectivity.

The **overall goal** is to construct a population model to account for the perceptual effects during a motion transition using a firing rate model with neurons that have a Gabor type receptive field and are connected through plastic synapses (meaning synapses with activity-dependent strength).

The **learning goals** are: (1) Learn how spatiotemporal energy filters extract stimulus features using Fourier space analysis; (2) Learn how to simulate in matlab the response of SE filter model to an arbitrary stimulus movie; (3) Design a network model with neurons that behave like SE filters and connected by plastic synapses; (4) Learn how to extract the direction of motion from the model response using either the motion selectivity or position tracking; (5) Compare these model results to experimental results obtained using voltage-sensitive dye imaging.

As there is presently no good model to account for these experimentally observed effects, a model-based explanation with clear predictions is publishable.