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JGD

Model Answer: Neural Computing, Question 3. 2001

1.

A neural network that learns a model for a process or a data set is estimating a small(ish) set of parameters that describe its main trends and dependencies. This is similar to the process of fitting a curve, such as a polynomial function, to data by the methods of statistical regression analysis or of least-squares (finding that set of parameters that minimizes the sum of the squared deviations between the model and the available data). Although an exact solution can be found for the coefficients of models such as polynomials which produce a system of linear equations in the same number of unknowns, more generally we wish to fit non-linear parameters that do not lead to systems of linear equations. Training such models requires slow iterative adjustment of all parameters while seeking to minimize an error function by gradient descent. This is basically how neural network training procedures work.

[4 marks]

The parameters of a neural network model can be set by the minimisation of an appropriate error function. However, the goal of training is not to give good performance on the training data, but instead to give the best performance (in terms of smallest error) on independent, unseen data drawn from the same distribution as the training data. The ability of a neural network to give good results on unseen data is called generalisation. If all of the available data were used in the training set and the model were made too large in order to fit all of it well, then it may become "over-trained" on this one set and will not generalize well to other sample sets. A simpler model trained just on a subset of the available data may actually show better generalisation. More complex models can fit the training data better, but do so at the expense of fitting the noise on the data as well as its underlying trend. Since the noise component of the validation data is independent of that on the training data, the result is an increase in the validation set error. Therefore the optimal model complexity would be somewhere between these two cases, and it should grow only slowly with the amount of data from which the neural net is trying to learn.

[6 marks]

2.

1. The capacitance of nerve cell membrane is approximately 10,000 microFarads per cm^2. This largely determines the nerve cell membrane time-constant and hence the neural response speed, as well as the velocity of nerve impulse propagation.

   [2 marks]

2. When generating a neural impulse, the voltage across a nerve cell membrane moves from about -40mV to +70mV (the inside relative to the outside of the neuron). The Nernst equilibrium potential determines the resting potential of -40mV based on the relative concentrations of K^+, Na^+, and Cl^- ions. The net positive polarisation of the membrane when Na^+ ions have flowed into the cell down their osmotic gradient, due to the voltage-dependent opening of Na^+ conductance channels in the membrane, balanced by the outward flow of K^+ ions, determines the peak spike potential of about +70mV.

[2 marks]

3. Nerve impulse generation is based on the existence of voltage-dependent conductances for Na^+ and K^+ ions, with differing time constants, and osmotic gradients of different sign. Positive feedback exists because the more the trans-membrane voltage rises, the lower the resistance becomes (the greater the conductance becomes) for Na^+ ions. This causes still more Na^+ ions to flow in, and the voltage to rise still more. The positive feedback process halts only when Na^+ equilibrium has been reached. (Then the opposite flow of K^+, with a slower time constant, brings the voltage down again until voltage-dependent conductance levels are restored, and ion pumps can restore the original ion separations and concentration gradients.)

[2 marks]

4. The retina develops embryologically from brain tissue, of which the eye itself is a collapsed ventricle. Retinal photoreceptors are derived from hair cells, as indeed are the transducers along the basilar membrane which are basis for hearing, and similarly the somatosensory receptors.

[2 marks]

5. The need to restore ionic equilibrium by the action of ion pumps is the reason for the 1 msec refractory deadtime after each nerve impulse. Collapse of ion-specific resistances during the nerve impulse allowed Na^+ and K^+ ions to flow down their osmotic gradients until reaching equilibrium with charge gradients. Restoring these to resting levels limits the highest frequency of nerve impulse generation to a few 100 Hz.

[2 marks]