Appendix B: Kohonen's Model of Retinotopic Mapping

INTRODUCTION TO PERCEPTUAL MAPS WITH CARDINAL NEURONS

Biological consideration. The computational model of so-called self-organizing ANN which adapt to perceptual data by evolving brain-maps with preserved input-data relations was established by Teuvo Kohonen in early eighties (Kohonen, 1982, 1995). For vision, it might have some biological significance for those levels where the "Mexican-hat" - like receptive fields were found: in retinal and LGN cells. Swindale (1996) presented in detail how this model could fit globally the experimental data on the visual-cortex topology, especially development of ocular-dominance columns and columns selective to orientation of stimuli, and also on global retinotopic mapping.

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The model should be used only as a "metaphor", although it performs very well in computer simulations. Namely, it might give us some rough intuition about global perceptual computation if applied to particular levels of a long multi-level computation along the retino-geniculo-striate visual pathway. However, it cannot be applied directly to any level of the visual pathway, and also not as an implementation model for the global retinotopic mapping onto V1 as a whole, because it neglects biological details in many stages (e.g., LGN), it ignores experimentally-supported V1-profiles of receptive fields (Gabor filters), and also phase-information has not yet been incorporated. This situation was not satisfactorily improved also after many followers of Kohonen (overviews in: Swindale, 1996; Kohonen, 1995) have extensively tried to fit particular biological details.

The main strength of the model is computational flexibility which approximates cortical map formation, i.e. e ectively reproduces it in simulations. Computational power is accompanied by mainly unjustified modularity (as with many popular and applicative computational models). The main weakness is lack of biological plausibility on the level of individual neurons and especially sub-neuronal processes. Therefore, there are significant differences between Kohonen-based mapping models and the holonomic theory, although some other models like the "infomax" perceptual-net model (Linsker, 1988) may suggest compromising relations.

Introduction to the model. Let us now present the basic ideas of the *self-organizing topology-preserving ANN* (Ritter, Martinetz & Schulten, 1992; Peretto, 1992). Encoding is constructed by *reducing the difference (error) between the external state and the network's internal representation of that state or similar previous states*. Both, internal and external states, are presented as activity patterns and are mathematically described by vectors. The individual components of each pattern-vector corresponds to an individual element of the pattern. The synaptic connections, where patterns are stored, change according to the rate of this disagreement between the prototype (internal representation) $\vec{w}$ and ordinary pattern (pattern of environmental stimuli detected by sensory cells) $\vec{x}$. Prototype can be prescribed by a "teacher", which could be provided by a higher-order cortical center (this is supervised learning), or can be established by a self-organizing procedure (unsupervised learning). In the second case, which is biologically more relevant, the prototype has been constituted by the previous experience and is encoded by the "winning neuron". This is the neuron which wins the competition between neurons and more-or-less individually takes the task of coding a specific pattern. The winning neuron is also called *cardinal neuron*, or *order-parameter cell* (because it orders the whole layer of neurons after it has "taken all the power") (Haken, 1991). To be more specific, as long as such a neuron competes with other dominant neurons we will refer to it as *potentially-cardinal neuron*. At that stage also its competitors are potentially-cardinal neurons. Only one of these potentially-cardinal neurons can win the com-

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