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Divergence alone cannot guarantee stable sparse activity patterns if connections are dense

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Introduction

It is quite well known, and we have recently confirmed it for the olfactory system in insects [1], that sparse activity is necessary for efficient pattern recognition and memory formation. In many brain centers, including the olfactory system, strongly divergent connections with high-threshold post-synaptic neurons are believed to generate these sparse patterns. We have shown in a generic model that this interpretation rests on the assumptions that the connections are not only divergent but also sparse. However, in locusts the connections from the antennal lobe to the mushroom bodies have been found to be not sparse. To the contrary, experimental observations seem to imply connectivities with 50% of all-to-all connections [2]. Our generic model elucidates how such dense connections lead to instabilities with respect to noise and fluctuations in the incoming signals. We then suggest a hypothesis how the original coding idea can be rescued by appropriate feed-forward gain control mechanisms.

Results

There are three minimal requirements for a successful sparse coding strategy: (1) The response patterns should be sparse for the whole range of expected input patterns, (2) different input patterns should not elicit identical responses (confusion), and (3) the baseline activity of input neurons should not trigger any responses. To investigate these requirements we formalized the idea of a divergent layered neuronal system with a set of minimal assumptions. We then investigated for which combinations of two crucial parameters, the density of connections

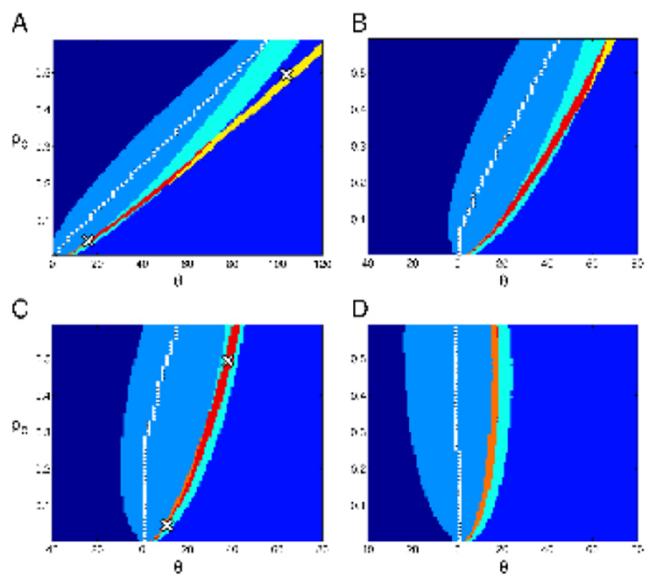

Figure 1

Regions where our criteria 1–3 are fulfilled. Dark blue: none are fulfilled, blue: (3) is true, light blue: (2) is true, cyan: (2) and (3) are true, yellow: (1) and (3) are true, orange: (1) and (2) are true, and red: all three are true. Note that for no gain control (A), the red region is located between $p_c = 0.1$ and $p_c = 0.3$ and is very thin. It then moves to higher p_c with increasing gain control (B), (C) and (D), where it disappears. The strings of white dots in each of the panels mark the locus of the minimum of the probability of confusion with respect to the threshold θ_{KC} for each given value of p_c Depending on the density of connections, a different degree of gain control is necessary to be able to fulfill all three criteria for a suitable sparse activity.

p_c and the firing threshold θ_{KC}, these conditions can be fulfilled. Without additional mechanisms of gain control all three conditions cannot be fulfilled simultaneously for dense connections (Figure 1A) while an appropriate gain control mechanism allows it (Figure 1C).

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