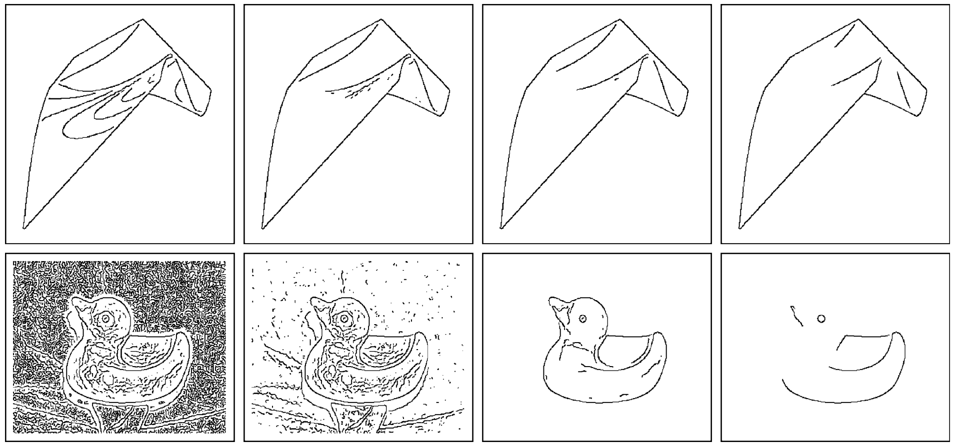

Fig. 4. Geometric problems in edge detection using the Canny operator (Matlab implementation). The different edge maps depict the results of the edge detection process using different parameter values. Note that at some levels non-boundaries are signaled as edges while at other levels genuine edges are missed or broken. Often proper but distinct boundaries are inappropriately connected (e.g., the boundary of the duck's back and the one of its neck).

iso-oriented cells, are the "outliers" to this simply noise? Is the correct abstraction for the majority co-linear facilitation, or is something else going on? And, how should the majority be defined; in particular, what is the proper spread in the distribution of connections in the orientation domain?

Finally, there are questions that arise from the interface between physiology and computer vision: are horizontal facilitations only participating in edge detection, or might they also be implementing other functional roles? If so, what might these be and are they consistent with the given data about connections?

We shall consider each of these groups of questions in this paper. To set the stage, we note that a closer examination of the physiological data suggests the story is more complex than co-aligned contour facilitation (Fig. 5). For example, while Kapadia et al. [26] stress iso-orientation facilitation, they also provide examples of facilitation between cells with up to 50° orientation difference (their Fig. 10). The distributions provided by Bosking et al. [7] clearly show non-negligible portion of anatomical connections even between cross orientations (their Fig. 6). And from the findings of Ts'o et al. [43] it is evident that there are facilitory functional interactions between iso-oriented cells whose receptive fields are parallel to one another, rather than co-aligned (see top pair in their Fig. 5). Interpreting such pairs as participating in collinear contour integration is awkward. Instead, we shall argue that such exceptions are naturally explained from a series of computational tasks, including curved contour integration, texture, shading, and stereo processing.

To develop this argument, we shall have to consider how early visual information processing can be structured on orientation hypercolumns. We do this in two stages. First, we briefly review a model that captures enough of the structure of the columnar architecture that it can be related to neurophysiology and neuroanatomy, but is sufficiently abstract that it can be analyzed mathematically and computationally. We then proceed to the analysis of curves, textures, shading, and stereo in it, and how these relate back to (certain aspects of) scene structure. As we show, facilitory interactions can be involved in all of them, but co-aligned facilitation by itself is insufficient. Differential geometry, and

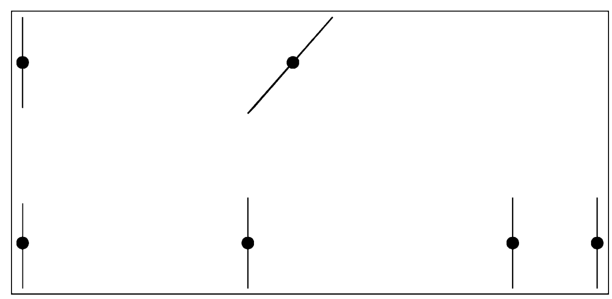

Fig. 5. The fact that the majority of connections are between iso-orientation columns does not necessarily imply co-aligned facilitation; similarly, orientation good continuation does not necessarily imply only iso-orientation interactions. Three different pairs of cells are shown, with position corresponding to the relative placement of receptive fields and the short bar corresponding to the preferred orientation of the cell. (Left) Co-aligned facilitation is a natural implication of boundary detection and a common interpretation of iso-orientation interactions. (Center) An "outlier" to co-aligned facilitation, with about a 50° rotation over a short (retinotopic) distance. This example is not iso-orientation facilitation although it reflects a possible receptive field arrangement along a coherent boundary curve. (Right) An "outlier" to co-aligned facilitation that is iso-orientation facilitation. While this example may contribute to the majority of iso-orientation interactions, it cannot be interpreted as serving curve integration. The question is whether this and other "outliers" can support useful visual information processing.