Computer simulations of a neural network model of 1-D and 2-D brightness phenomena are presented. The simulations indicate how configural image properties trigger interactions among spatially organized contrastive, boundary segmentation, and filling-in processes to generate emergent percepts. They provide the first unified mechanistic explanation of this set of phenomena, a number of which have received no previous mechanistic explanation. Network interactions between a Boundary Contour (BC) System and a Feature Contour (FC) System comprise the model. The BC System consists of a hierarchy of contrast-sensitive and orientationally tuned interactions, leading to a boundary segmentation. On and off geniculate cells and simple and complex cortical cells are modeled. Output signals from the BC System segmentation generate compartmental boundaries within the FC System. Contrast-sensitive inputs to the FC System generate a lateral filling-in of activation within FC System compartments. The filling-in process is defined by a nonlinear diffusion mechanism. Simulated phenomena include network responses to stimulus distributions that involve combinations of luminance steps, gradients, cusps, and corners of various sizes. These images include impossible staircases, bull's-eyes, nested combinations of luminance profiles, and images viewed under nonuniform illumination conditions. Simulated phenomena include variants of brightness constancy, brightness contrast, brightness assimilation, the Craik-O'Brien-Cornsweet effect, the Koffka-Benussi ring, the Kanizsa-Minguzzi anomalous brightness differentiation, the Hermann grid, and a Land Mondrian viewed under constant and gradient illumination that cannot be explained by retinex theory.