Chapter 2

Inevitability of Illusions

This chapter primarily concerns a very general constraint on brains: that they take time to compute things. This simple fact has profound consequences for the brain, and vision in particular. I will put forth evidence that it is the visual system's attempting to deal with this computing delay that explains why we experience the classical geometrical illusions. Figure 2.1 shows a sample such illusion; basically, the illusions are those found in any introductory Psychology course. I will also, along the way, briefly discuss a general approach to modeling brain computation: that approach is decision theory, wherein the brain, or some portion of it, is modeled as an ideal rational agent acting to maximize its expected utility on the basis of probabilities concerning the nature of the uncertain world. This is referred to as the Bayesian framework for visual perception, and with it researchers have made some important breakthroughs. We will need to understand it, and its shortcomings, to understand how the visual system copes with the time it takes to compute a percept. I also discuss the difficulties of one of the older and more established inference-based theories of the geometrical illusions. Before proceeding, it is important to understand why there may be computing delays in perception.

Computation is sometimes slow, sometimes fast, but never instantaneous. Computation takes time. Running software on your computer takes time. For example, it takes about one second to start Microsoft Word on my lap top, over two seconds to start Adobe Acrobat, and over half a minute to run LaTex with this book as the input. Despite the orders of magnitude increase in computation speed over the last twenty years since the advent of the personal computer, there seems to always be significant delays for contemporary software. This is presumably because software producers have figured out the time delays

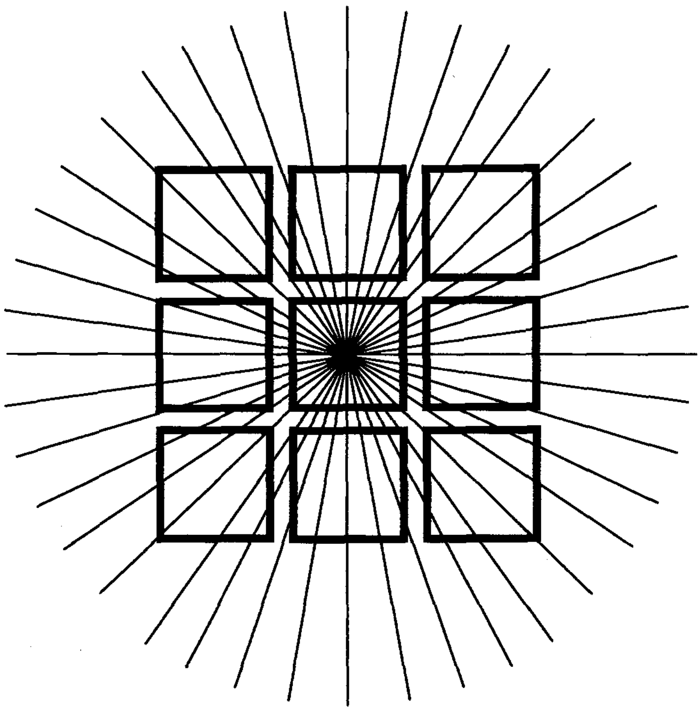

Figure 2.1: Nine perfect, identical squares on a radial display induce an illusion, which is a version of the Orbison illusion.

consumers are willing to put up with and can use this time to carry out more sophisticated computations for the consumer.

Brain computation takes time as well. In addition to the computation delays due to simply traveling through individual dendrite and axon arbors, and to the time it takes signals to traverse synapses, computation delays are also due to the complex time course and pattern of neural firings that actually implement the computation. How much time can the brain afford to take in carrying out its computations? To answer this, consider the brain (and evolution) as the software producer, and the animal (and his genes) as the consumer. The brain will presumably have figured out the time delays the animal is willing to put up with—i.e., delays that the animal is able to deal with without compromising survival too much—so as to be able to use this time to compute more powerful functions of use to the animal. More exactly, the brain and evolution presumably will have discovered how to optimally trade off computation time with computational power. How much time is given to computations in this optimal trade-off will depend on the details of the animal's ecology, but it seems *a priori* unlikely to be exceedingly long—e.g., 10 second delays—or microscopically short—e.g., 0.001 seconds. Because the world changes too much and too unpredictably during a long, say 10 second, interval, long delays will lead to computational solutions that are moot by the time they are computed. Nearly instantaneous computations would avoid this problem, but would leave the brain with too little time to compute much of interest to the animal. Somewhere in between these extremes will be an optimal middle ground, allowing sufficient time for powerful computations, but the time is short enough that the computations are still applicable to the changing world. These considerations are relevant for any brain—Earthly or not—having to deal with an uncertain and dynamic world, so long as they are not literally infinite in computational speed.

One effective possible strategy for a brain to use in its attempt to increase its computation time is to attempt to *correct* for the computation delay (De Valois and De Valois, 1991; Nijhawan, 1994, 1997, 2001; Berry et al., 1999; Sheth et al., 2000; Schlag et al., 2000; Khurana et al., 2000; Changizi, 2001). That is, suppose it would be advantageous to have a time interval Δt to carry out some useful computation, but suppose that Δt is long enough that the world typically has changed to some degree during this time, making the computation moot. What if, to deal with this, the brain took a different tact? Rather than trying to compute something that is useful for dealing with the world the way it *was* when the computation started, the brain might try, instead, to compute

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