

the advent of general purpose GPUs (described in section 12.1.2), faster network connectivity and better software infrastructure for distributed computing, is one of the most important trends in the history of deep learning. This trend is generally expected to continue well into the future.

1.2.4 Increasing Accuracy, Complexity and Real-World Impact

Since the 1980s, deep learning has consistently improved in its ability to provide accurate recognition or prediction. Moreover, deep learning has consistently been applied with success to broader and broader sets of applications.

The earliest deep models were used to recognize individual objects in tightly cropped, extremely small images (Rumelhart *et al.*, 1986a). Since then there has been a gradual increase in the size of images neural networks could process. Modern object recognition networks process rich high-resolution photographs and do not have a requirement that the photo be cropped near the object to be recognized (Krizhevsky *et al.*, 2012). Similarly, the earliest networks could only recognize two kinds of objects (or in some cases, the absence or presence of a single kind of object), while these modern networks typically recognize at least 1,000 different categories of objects. The largest contest in object recognition is the ImageNet Large Scale Visual Recognition Challenge (ILSVRC) held each year. A dramatic moment in the meteoric rise of deep learning came when a convolutional network won this challenge for the first time and by a wide margin, bringing down the state-of-the-art top-5 error rate from 26.1% to 15.3% (Krizhevsky *et al.*, 2012), meaning that the convolutional network produces a ranked list of possible categories for each image and the correct category appeared in the first five entries of this list for all but 15.3% of the test examples. Since then, these competitions are consistently won by deep convolutional nets, and as of this writing, advances in deep learning have brought the latest top-5 error rate in this contest down to 3.6%, as shown in figure 1.12.

Deep learning has also had a dramatic impact on speech recognition. After improving throughout the 1990s, the error rates for speech recognition stagnated starting in about 2000. The introduction of deep learning (Dahl *et al.*, 2010; Deng *et al.*, 2010b; Seide *et al.*, 2011; Hinton *et al.*, 2012a) to speech recognition resulted in a sudden drop of error rates, with some error rates cut in half. We will explore this history in more detail in section 12.3.

Deep networks have also had spectacular successes for pedestrian detection and image segmentation (Sermanet *et al.*, 2013; Farabet *et al.*, 2013; Couprie *et al.*, 2013) and yielded superhuman performance in traffic sign classification (Ciresan