where the effects of potential drugs are tested indirectly in test tubes and in animals, followed by the clinical phase where therapeutics are tested directly in human volunteers. Medicine that passes both nonhuman and human testing is approved for sale to consumers.

Researchers have begun to construct models that optimize each part of the drug discovery process. For example, molecular deep learning has been applied to problems such as predicting the potential toxicity of putative medications and to chemical problems involved in the synthesis and design of drug-like molecules. Other researchers and companies are using deep convolutional networks to design new experiments that closely track cellular behavior on massive scales to obtain stronger understanding of novel biology. These applications have had some impact on the pharmaceutical world, but nothing dramatic yet since it isn't possible to build one drug discovery model that "designs" a novel drug. However, as more data gathering efforts continue and more biological and chemical deep learning models are designed, this state of affairs could change drastically in the next few years.

Deep Learning in Law

The legal industry relies heavily on precedent in the legal literature to make arguments about the legality or illegality of new cases. Traditionally, legions of paralegal researchers have been employed by large law firms to perform the needed lookups into the legal literature. In more recent years, legal search engines have become standard fare for most sophisticated firms.

Such search algorithms are still relatively immature, and it's likely that deep learning systems for neurolinguistic processing (NLP) can offer significant improvements. For example, a number of startups are working on building deep NLP systems that offer better querying of legal precedent. Other startups are working on predictive methods that use machine learning to predict the outcome of litigation, while a few are even experimenting with methods for automated generation of legal arguments.

In general, these sophisticated applications of deep models will take time to mature, but the groundswell of legal AI innovation likely heralds a dramatic shift in the legal profession.

Deep Learning for Robotics

The robotics industry has traditionally avoided deploying machine learning since it's not easy to prove that machine-learned systems are safe to deploy. This lack of safety guarantees can become a major liability when building systems that need to be safe for deployment around human operators.

In recent years, though, it's become clear that deep reinforcement learning systems, combined with low data learning techniques, can offer dramatic improvements in

robotic manipulation tasks. Google has demonstrated that reinforcement learning can be deployed to learn robotic object control, using a factory of robotic arms to enable large-scale training on real robots (see Figure 10-1). It's likely that such enhanced learning techniques for robots will begin filtering into the larger robotics industry over the next few years.

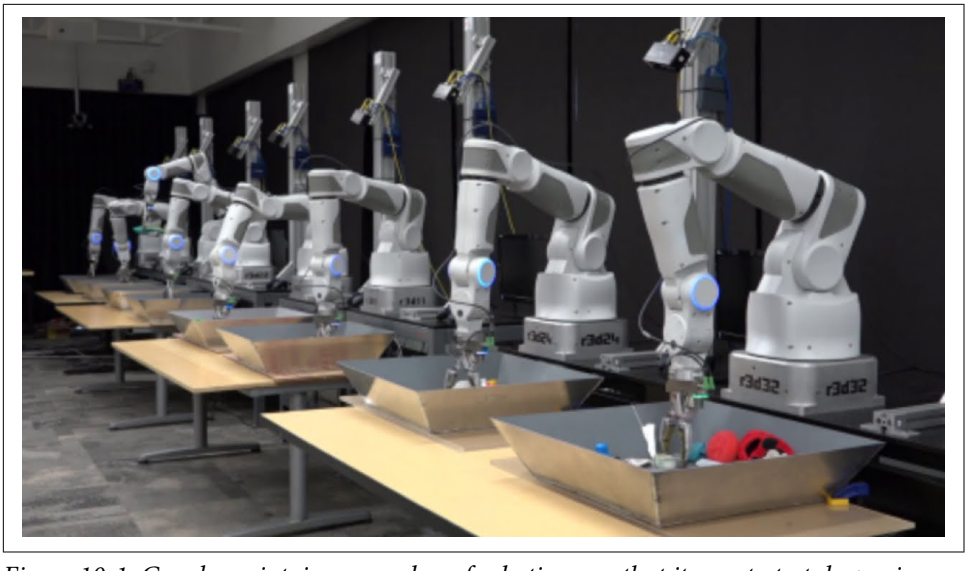

Figure 10-1. Google maintains a number of robotic arms that it uses to test deep reinforcement learning methods for robotic control. This fundamental research will likely find its way to the factory floor in the next few years.

Deep Learning in Agriculture

Industrial farming is already heavily mechanized, with sophisticated tractors deployed to plant and even pick crops. Advances in robotics and in computer vision are accelerating this trend toward automation. Convolutional networks have already been employed to identify weeds for removal with less pesticide. Other companies have experimented with self-driving tractors, automated fruit picking, and algorithmic crop yield optimization. These are mainly research projects for the time being, but these efforts will likely blossom into major deployments over the next decade.

Using Deep Learning Ethically

Most of this book has focused on the effective use of deep learning. We've covered many techniques for building deep models that generalize well on different data types. However, it's also worth spending spending some time thinking about the societal effects of the systems we build as engineers. Deep learning systems unleash a host of potentially unsettling applications.