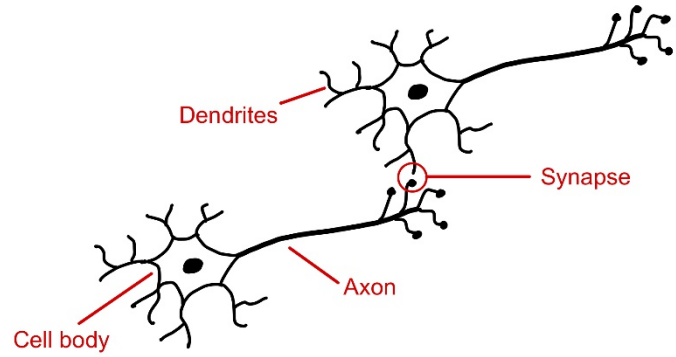

Figure 1.12 Schematic illustration showing two neurons from the human brain. These electrically active cells communicate through junctions called synapses whose strengths change as the network learns.

1.3. A Brief History of Machine Learning

Machine learning has a long and rich history, including the pursuit of multiple alternative approaches. Here we focus on the evolution of machine learning methods based on neural networks as these represent the foundation of deep learning and have proven to be the most effective approach to machine learning for real-world applications.

Neural network models were originally inspired by studies of information processing in the brains of humans and other mammals. The basic processing units in the brain are electrically active cells called neurons, as illustrated in Figure 1.12. When a neuron 'fires', it sends an electrical impulse down the axon where it reaches junctions, called synapses, which form connections with other neurons. Chemical signals called neurotransmitters are released at the synapses, and these can stimulate, or inhibit, the firing of subsequent neurons.

A human brain contains around 90 billion neurons in total, each of which has on average several thousand synapses with other neurons, creating a complex network having a total of around 100 trillion (10^{14}) synapses. If a particular neuron receives sufficient stimulation from the firing of other neurons then it too can be induced to fire. However, some synapses have a negative, or inhibitory, effect whereby the firing of the input neuron makes it less likely that the output neuron will fire. The extent to which one neuron can cause another to fire depends on the strength of the synapse, and it is changes in these strengths that represents a key mechanism whereby the brain can store information and learn from experience.

These properties of neurons have been captured in very simple mathematical models, known as *artificial neural networks*, which then form the basis for computational approaches to learning (McCulloch and Pitts, 1943). Many of these models describe the properties of a single neuron by forming a linear combination of the outputs of other neurons, which is then transformed using a nonlinear function. This