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Future developments in computing technologies

The transition of computers from low capacity, room-sized machinery to extremely powerful, ubiquitous pocket-sized devices has been a gradual process. These changes in hardware, along with developments in the software which runs on them, have already made possible a complete transformation of many aspects of our daily lives. However, **the speed with which our lives are being transformed continues to increase**. Partly, **this** is because the power of AI, machine learning and neural networks has advanced greatly in recent years. As a result, computers are now capable of even more tasks which previously could only have been completed by humans. **Accurate speech recognition and near instantaneous translation from one language to another** are now increasingly common. **These** advances, along with facial recognition, object recognition and tracking are examples of how learning algorithms are changing our lives.

Artificial neural networks (ANNs) have played a significant role in increasing the capabilities of computers. As a subset of AI and machine learning, the algorithms **they** use mimic the human brain. The neural network model is based on a 1949 book by Donald Hebb (*The Organization of Behaviour: A Neuropsychological Theory* [1]) which outlines the relationship between **different neurons** and how **these** create intelligence. Artificial neural networks simulate these relationships and, as a result, they are particularly useful for **algorithms for pattern recognition**. A good example of **these** is the nearest neighbour algorithm, first conceived in 1967, which uses similarities between features to create **clusters**. Depending on which features can be identified, **they** can be used to provide detailed information about the patterns within an object. As Shneider and Xhafa [2] point out, a major advantage of systems using **this algorithm** is that **it** is data-driven, rather than supervised by humans. Since neural networks can use many layers to improve performance, they can **find patterns which are too complex for humans to discover unaided**. A good example of **this** is *AlphaGo*, which used pattern identification to create winning strategies which expert Go players were unable to predict. More recently, **AlphaFold** has used pattern identification to predict structures for over a hundred million proteins, something which human efforts alone could not match. **This** development opens the way for the creation of a wide range of new materials and drugs.

Developments are also underway which have the potential to radically increase the capabilities of computer hardware. Current computers are based on what is referred to as **'classical computing'**, based on binary values of 1 or 0 and using the Turing model of input, process and output. As a consequence, all of the work carried out by **these** types of computers is limited by the speed with which their hardware can process the stream of binary values. While **the speed and size of devices continues to increase** in line with Moore's law, there are signs **this** is likely to change, limiting future increases in processing power. However, **quantum computing** is very different to classical computing. **It** relies on principles of quantum mechanics, principles which apply to very tiny particles. **It** uses a tiny particle called a **qubit** as a basic unit of information. Two features of quantum mechanics make qubits particularly useful. The first is a property called **superposition**, where the qubit can simultaneously have any of a range of values and only has a specific value when **it** is measured. The other useful property is called **entanglement**. **This** means that two particles can be physically separate, yet linked together, so any change in the state of one is reflected in the state of the other. Despite the fact that entanglement has been discovered and measured, physicists still do not fully understand how it works. Nevertheless, **entanglement** is important for quantum computing as it means that information can be moved around, even when its state is not known. **These** features are extremely important in making quantum computing powerful.

The idea of developing quantum computers is not a new one, but practical developments are relatively recent. **It** was first suggested by Richard Feynman in 1981, but the science which underpins the idea goes back much further. The term 'quantum mechanics' was first used in 1924. Subsequently, a textbook outlining the theories (*The Principles of Quantum Mechanics* [3]) was published in 1930; it is still in use. The idea of 'superposition' values was described by Schrodinger in 1935 and 'quantum entanglement' was described by Einstein in 1947. However, there was a considerable wait before a functioning quantum computer was produced. The first commercially available quantum computer was offered by D-Wave Systems in 2011. By 2019, Google was able to report that its 53-qubit Sycamore processor had outperformed a traditional supercomputer, taking 3.3 minutes to complete a task that would take a conventional supercomputer at least 2.5 days. In 2021, a Chinese 66-qubit computer was able to complete the task 1 million times faster. IBM announced plans to create a 1,000-qubit processor in 2023, which would result in even higher speeds.

Quantum computers which could be used for general purposes would represent a major step forward for computing. Although this is likely to take some time, the development of working computers shows rapid progress is being made. **General purpose quantum computers** could have many uses. In the same way machine learning has been able to advance drug discovery and materials development, **general purpose quantum computers** could have a similar impact. **They** could also carry out calculations in mathematics and physics which could greatly expand human understanding of our world. It is also likely **they** could decode almost all existing cryptography, making it possible to read all types of secret communications. Twenty years ago, it was difficult to imagine that computers would have the capabilities they now have. It is even more difficult to predict the future capabilities of quantum computing and the changes that this could make possible.