How to Bring the Next Quantum Revolution

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A major obstacle when trying to construct a quantum computer is that the components of the computer are extremely sensitive to noise from various sources. One way to protect against noise is by using a so-called error correcting code. This thesis investigates the performance of a particular error correcting code, called the Steane code.

In technology, it is not uncommon to hear mentions of the 'first quantum revolution'. This refers to the invention and development of the transistor and semi-conductor electronics, as these devices make clever use of quantum mechanical effects such as tunnelling. In 1965 Moore proposed, based on observation, that the number of transistors that can fit on a chip will double every two years. Remarkably, almost 60 years later, the so-called 'Moore's law' still seems to hold. The advances in chip manufacturing have powered our modern information society, making devices such as the smart-phone part of our every day life, something which would have seemed like pure science fiction when the law was first formulated. This development cannot continue forever though, as the minimum size of a transistor is ultimately limited by the laws of physics.

To circumvent this problem, scientists have proposed not only using the effects of quantum mechanics, but actively manipulating these effects to create a *quantum computer*. Such a device would not only make use of quantum mechanical effects, but actively manipulate the quantum states of individual atoms to perform calculations. This would be the second quantum revolution. It turns out however, that building a quantum computer is exceedingly difficult. A major obstacle turns out to be that individual atoms are extremely prone to picking up environmental noise. This can be likened to the way in which an incorrectly calibrated TV-antenna scrambles what is shown on the TV, or what happens when your favourite radio station is incorrectly tuned in.

This thesis deals with protecting quantum computers from such noise, using something called a *quantum error correcting code*. The basic idea of quantum error correction is that a quantum computer can be protected from noise by introducing redundancy in a clever way. There is a major problem however: getting access to a quantum computer to try the code on! Luckily, we can use normal computers to simulate quantum error correction at a small scale. An inescapable problem when using an error correcting code is that the code cannot be used to correct an infinite amount of errors in the data. What this means in practice is that underlying hardware needs to have a basic tolerance of noise before such a code can be used, and even then one has to be careful as using the code can itself introduce errors. The main focus of this thesis has been to find out how much noise can be present in the computer hardware before a specific error correcting code fails, but also how much the code can reduce the noise level. It was found that the highest noise level that can be tolerated before error correction fails is close to the noise levels that can be expected to be achieved in the rare-earth materials targeted by the quantum information group at Lund University. Somewhat surprisingly though, it was found that a lot more can be gained from using error correction if the noisiness of the hardware is much lower from the start.