General relativity predicts the emission of gravitational waves by any mass distribution which has a time-dependent quadrupole (or higher order multipole) moment. Gravitational waves are perturbations of the background metric traveling at the speed of light. A gravitational wave induces strain in spacetime which affects the relative distance between two freely-falling test masses. Gravitational waves emitted from astrophysical sources can be detected with modern day interferometric gravitational wave detectors. One such detector is Virgo which is located in Italy near the city of Pisa. The Virgo detector is a Michelson interferometer with 3 km long Fabry-Perot resonant cavities as arms. The entire detection band runs from approximately 20 Hz to 10 kHz (sensitivities about $10^{-20}$ Hz$^{-1/2}$ and $10^{-21}$ Hz$^{-1/2}$ respectively), and the best sensitivity of the Virgo detector per 1-10-2009 was $6 \times 10^{-23}$ Hz$^{-1/2}$ for gravitational waves of 200 Hz.

Due to the losses in the mirrors of the arm cavities, the stored laser power will cause these mirrors to heat up. This heating will cause variations in the optical path length which change the properties of the Fabry-Perot cavities. This causes adverse effects in the stable operation of the interferometer (e.g. loss of lock) and will limit the laser power which can be injected in the interferometer.

Chapter 3 of this thesis describes a three dimensional finite element model of the Virgo input mirror, including the recoil mass, which is used to simulate the heating effects. It has been shown that in the steady state situation, the average temperature of the mirrors increase by 8.52 mK. Furthermore, the simulation shows that two principal eigenmodes of the input mirror (the drum and butterfly modes) increase in frequency with 0.42 Hz/K and 0.29 Hz/K, respectively. These results can be used to monitor the mirror temperature by extracting the resonance frequency of the modes from the detector output data. It has been shown that the mirrors have an even higher fractional absorption value than expected. In the case of the West End input mirror the losses are about an order of magnitude higher than previously thought. Also, the finite element analysis shows that in the transient situation, the average temperature increase is governed by a time constant which is computed to be 4 hours. Finally, due to the shape of the beam, the mirrors will heat up in a non-uniform way resulting in an effective radius of curvature of 21 km.

One of the sources of gravitational waves are non-axisymmetric rotating neutron
stars. Due to the high magnetic fields of these stars, cones of electromagnetic radiation can be emitted from their magnetic poles. If such a neutron star is oriented favorably with respect to Earth, these cones of radiation can be observed as pulses. These neutron stars are known as ‘pulsars’. From observing many of these pulsars and taking the observational biases into account, about $10^5$ active pulsars are expected to exist in our Galaxy. Furthermore, it has been observed that the majority of the observed pulsars with rotational frequencies above 20 Hz are in binary systems. Since the emission of gravitational waves is not limited to just the magnetic poles, the unobserved neutron stars could be seen as potentially observable gravitational wave sources. The amplitude of the gravitational waves emitted by such systems is weak. However, they are also continuous in nature, meaning that observing such systems over longer stretches of time will increase the signal-to-noise ratio with the square root of the observation time.

In order to take full advantage of the long integration times of a potential continuous gravitational wave signal, despite the fact that the locations of the majority of the neutron stars in our Galaxy are unknown, so-called all-sky searches have been developed. A fully-coherent search (i.e. the data are integrated over the entire observation time) has been shown to be computationally limited. The most sensitive search for isolated neutron stars required $10^4$ CPU years and was limited to 30 hours of data. In order to increase the observation time with limited computational resources, sub-optimal analysis methods have been developed. These so-called ‘semi-coherent’ analysis methods are based on taking multiple short coherent stretches of data and combining them in an incoherent way. What these searches lack in sensitivity, they partially make up in decreased computing requirements making it possible to consider longer stretches of data. When attempting to apply such semi-coherent searches to signals from neutron stars in binary systems, the initial coherent integration time can be increased by an order of magnitude with respect to the isolated neutron star case. This short integration time will limit the sensitivity of the semi-coherent analyses when applying them to binary systems.

A new data analysis algorithm, called ‘Polynomial Search’ has been developed and is described in Chapter 5. Polynomial Search is designed to be an all-sky search for gravitational waves from neutron stars in binary systems. Since Polynomial Search employs a bank of polynomial phase templates up to 4th order in time, the initial coherent integration time can be increased by an order of magnitude with respect to applying a traditional semi-coherent search to this signal. It has been shown that the increase in coherence time is about 25 for neutron stars in a Keplerian orbit, where the orbital period ($P$) is larger than 2 hours for circular orbits (eccentricity $e = 0$). A filter bank has been constructed which has been shown to cover all gravitational waveforms of which the orbital parameters obey $P > 2$ hours for circular orbits and $P > 6$ hours for eccentric orbits with $0 < e < 0.6$. These filters can be applied to the data with a coherence time of 600 seconds (whereas the coherence time of a semi-coherent search for circular orbits with $P = 2$ hours would be limited to 20 seconds). Furthermore, a strategy for combining the results from the individual coherent stretches, called ‘the consistent filter criterion’, has been developed. When applying Polynomial Search to white noise and to simulated gravitational wave signals, the projected sensitivity of the new search method has been presented.
Finally, in chapter 6 the developed framework is presented in which Polynomial Search has been implemented. This so-called ‘AnaPulsar’ framework has been developed for implementing various types of gravitational wave data analysis algorithms. Furthermore, the computing requirements of Polynomial Search have been discussed. It has been shown that in order to perform Polynomial Search on all gravitational wave signals originating from neutron stars in a Keplerian orbit with parameters $P > 2$ hours and $e = 0$, or $P > 6$ hours and $0 < e < 0.6$, for an analysis of 1 month of data approximately 36 CPU years are required.