Finding gravitational wave signals from binary black hole collisions with convolutional neural networks

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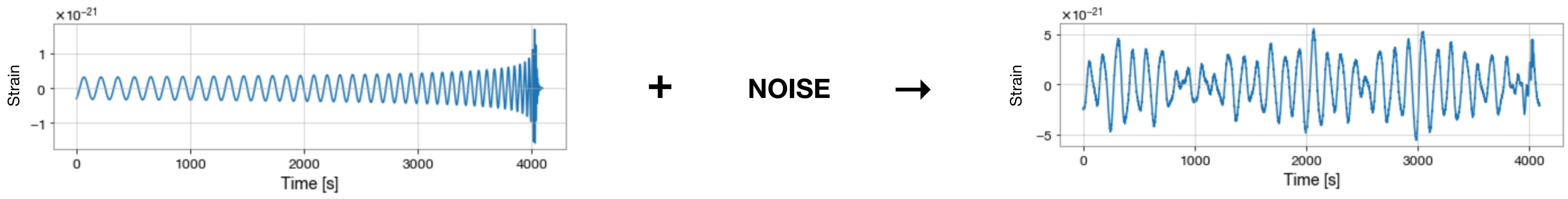
INTRODUCTION

In 2015, the first gravitational wave signals from colliding binary black holes were detected. Subsequent detections of gravitational waves lead researchers to observe a new population of massive, stellar-origin black holes. These signals are tiny ripples of the fabric of space-time. Even though the global network of gravitational-wave detectors is one of the most sensitive instruments on the planet, the signals are buried in detector noise. Analysis of gravitational-waves data and the detection of these signals is a crucial mission for the gravitational-waves community.

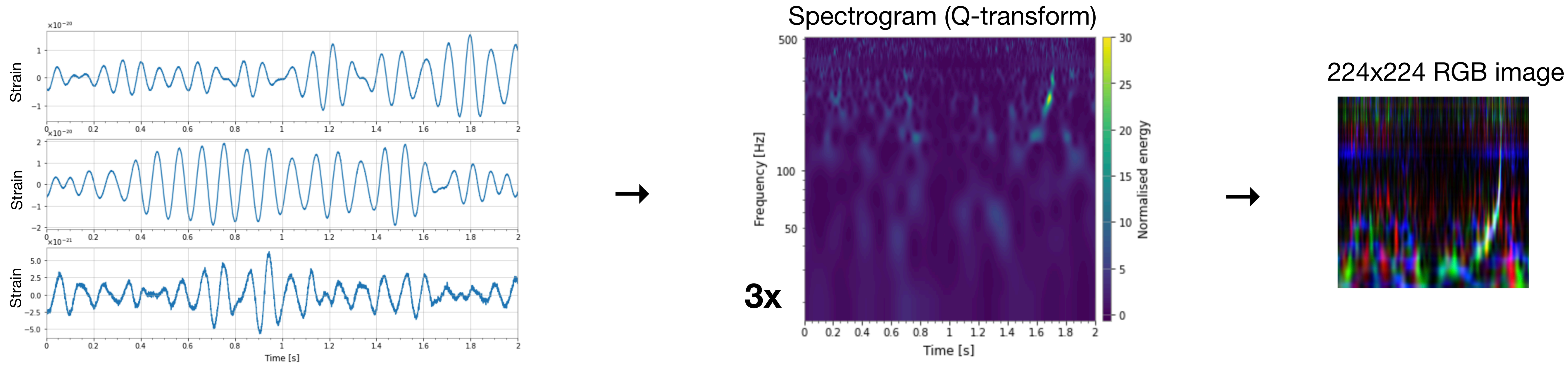
In this project, I used a machine learning technique to analyse simulated gravitational-wave time-series data from a network of ground-based detectors released by the G2Net Kaggle data challenge of the European Gravitational Observatory [1]. More precisely, time-series data from three detectors were converted into spectrograms using a constant Q-transform and combined into a single RGB figure. Subsequently, I used transfer learning to train a state-of-the-art convolutional neural network (CNN) to detect gravitational-wave signals from the merger of binary black holes.

METHODS & RESULTS

Example of a gravitational wave signal from the merger of two black holes with chirp mass $M_{\mathrm{chirp}} = 21.1\,\mathrm{M}_{\odot}$, mass ratio $q = 0.8$ at a distance of $D = 100\,\mathrm{Mpc}$ similar to the first detection of GW150914 (left) versus the same signal embedded in the detector noise.

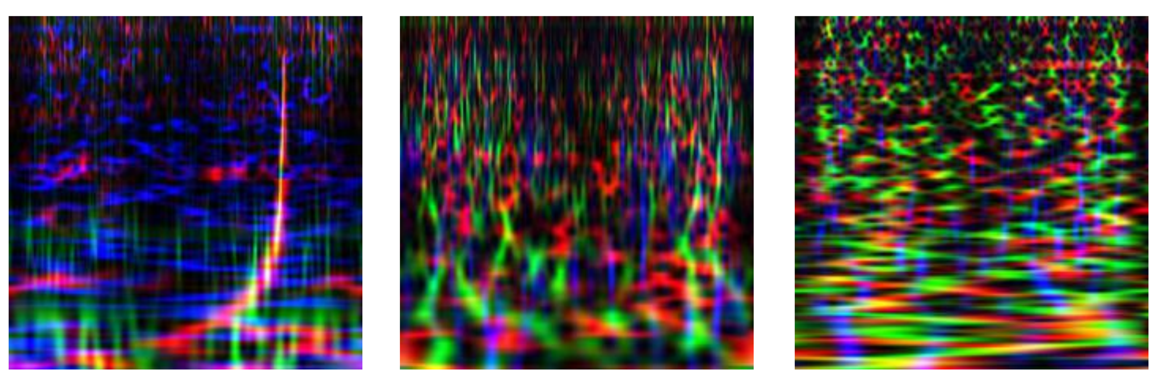


The dataset contains 560,000 simulated signals detected by a network of 3 detectors. Each signal is transformed into a composted RGB image where each colour channel corresponds to the spectrogram obtained by applying a Tukey window function and a Q-transform to the signal time-series in the frequency range [16,512] Hz.

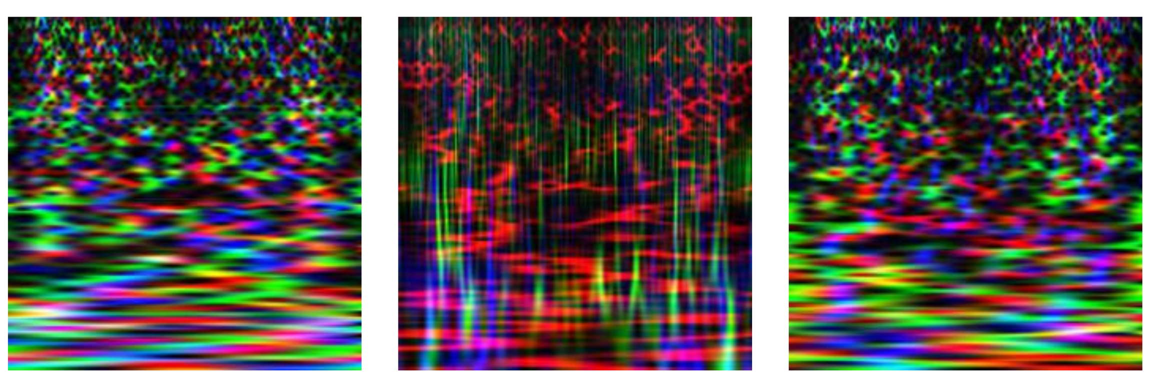


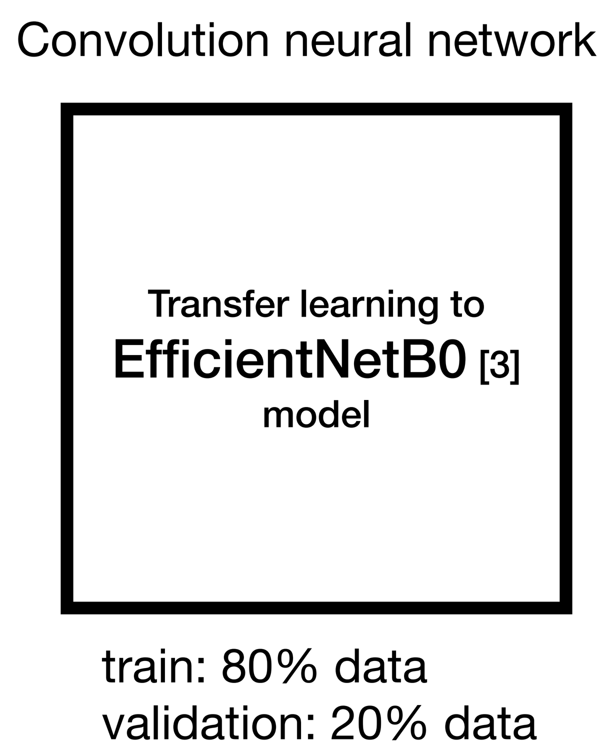
We used transfer learning to train the state-of-the-art model EfficientNetB0 [3] previously trained on the ImageNet dataset [4] to recognise spectrograms with gravitational wave signals. In the above spectrogram the gravitational wave signal can be stopped "by eye", this is not always the case (see the examples below).

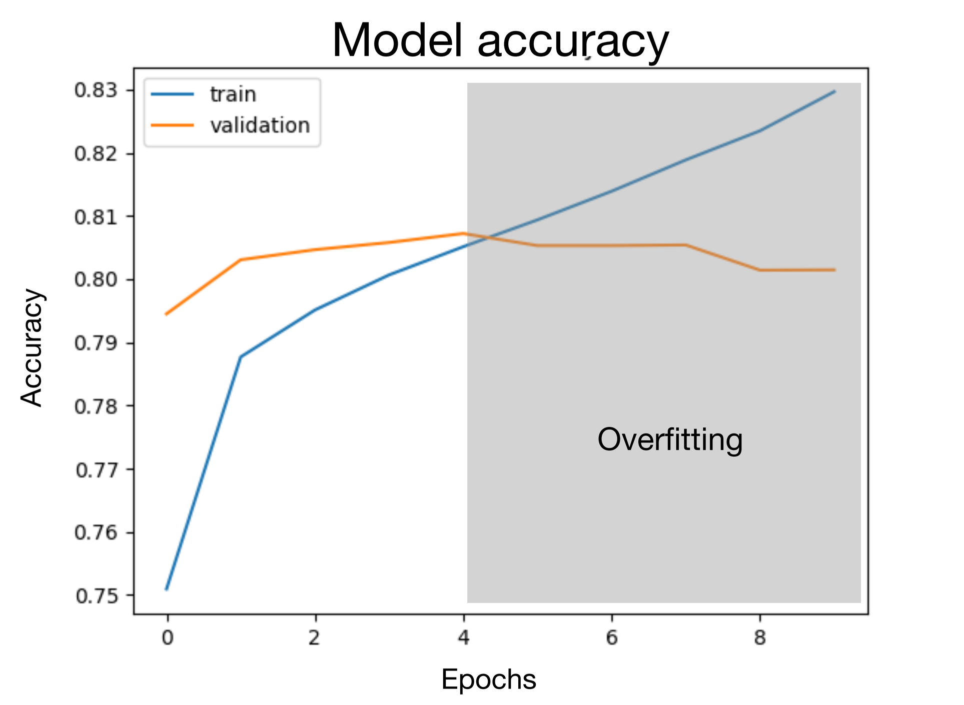
Spectrograms with a gravitational wave signal (target 1)



Spectrograms without a gravitational wave signal (target 0)







Training time: ~ 3.5 hours per epoch on an NVIDIA TITAN RTX (batch size 64 images)

The Kaggle competition also provides an unlabelled dataset of 260,000 signals to evaluate the score of the model. On this dataset the model scores 81% accuracy (similar to our validation accuracy). As a reference, the best model submitted to the Kaggle competition scored 88.5% accuracy [5].

BIBLIOGRAPHY

[1] G2Net Kaggle challenge https://www.kaggle.com/c/g2net-gravitational-wave-detection/

[2] LIGO Scientific Collaboration and Virgo Collaboration, Phys. Rev. Lett. 116, 061102

[3] Tan M. & Le Q. V., ICML 2019, arXiv:1905.11946

[4] https://www.image-net.org

[5] G2Net Kaggle leaderboard https://www.kaggle.com/c/g2net-gravitational-wave-detection/leaderboard