Deep Learning Gravitational-Wave Searches for Cosmic Strings

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Introduction

- About me: a PhD candidate in gravitational waves
- Overview of today's presentation
- Interaction is encouraged, feel free to ask questions

Cosmic Strings

Cosmic strings as a general concept

- **Cosmic strings** find their origins in quantum field theory, where they appear as 1-dimensional **topological defects**
- Such defects arise as a result of spontaneous symmetry breaking
- Specifically local symmetry, so the **topology** of a **gauge group** is inspected

M. Sakellariadou, *Cosmic Strings and Cosmic Superstrings*, https://doi.org/10.1016/j.nuclphysbps.2009.07.046

Cosmic strings as physical phenomena

- Cosmic strings would be very thin **strings**, but with massive density
- Remnants of phase transitions associated with **grand unification**
- Classes of cosmic strings arise in **string theory**

Question: How can such objects generate gravitational waves?

Cosmic string detection

- Cosmic strings are dynamic and produce **gravitational waves**
- String **cusps** produce **burst** gravitational waves
- Current state-of-the-art detection relies on matched filtering
- Because of drawbacks, **neural networks** are reasonable successors

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R. Abbott et al., *Constraints on Cosmic Strings using Data from the Third Advanced LIGO-Virgo Observing Run*,

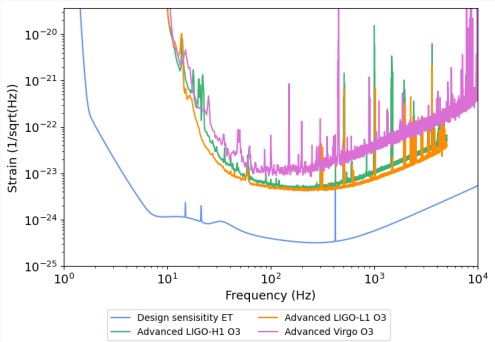
https://doi.org/10.1103/PhysRevLett.126.241102

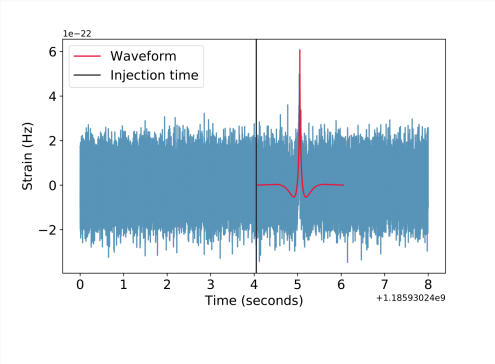
WaveNet

The data

- The input consist of **simulated cusp signals** and **artificial blip glitches**
- The waveforms were injected into coloured Gaussian noise time series

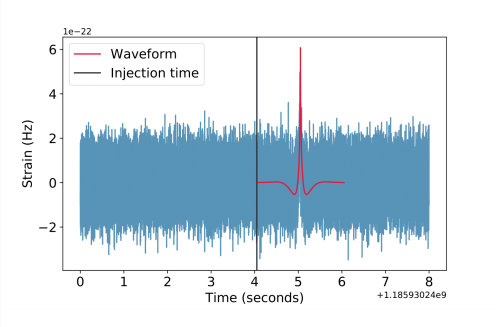
M. Lopez, *Simulating Transient Noise Bursts in LIGO with gengli*, https://doi.org/10.48550/arXiv.2205.09204

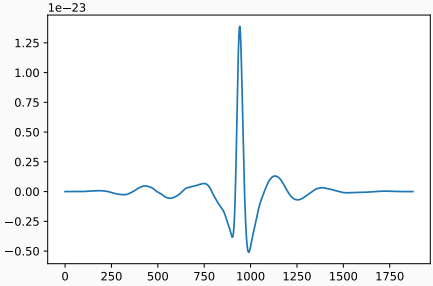




Figures: Detector sensitivities (left) and an injected cusp signal (right)

Question: What problems could arise from the shape of this waveform?





Figures: A worst case comparison between a signal (left) and a glitch (right)

Dilation

The architecture chosen for the convolutional neural network is based on **WaveNet**, originally designed for the generation of audio waveforms. The main motivation for this choice is the use of **dilations**.

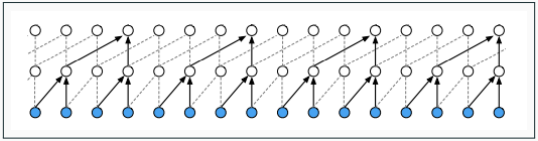


Figure: Dilations with different step values

A. van den Oord et al., *WaveNet: A Generative Model for Raw Audio*, https://doi.org/10.48550/arXiv.1609.03499

Modules

The following residual module is an important building block of WaveNet:

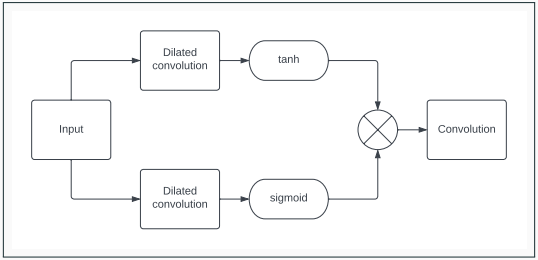
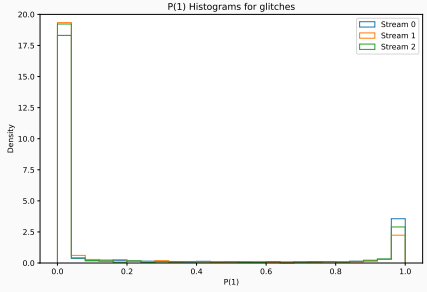


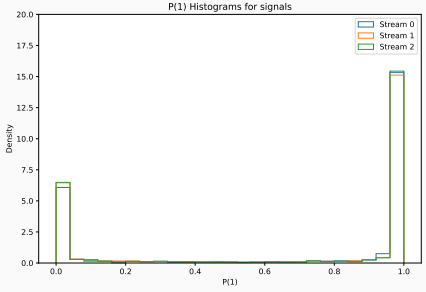
Figure: A WaveNet module

Results

Numerical results

- The classifier has an **accuracy** of 0.846, **TPR** of 0.76 and **FPR** of 0.068
- On average, classifying a two second strain takes 10 milliseconds





Figures: Histograms showing the probability densities for glitches (left) and signals (right)

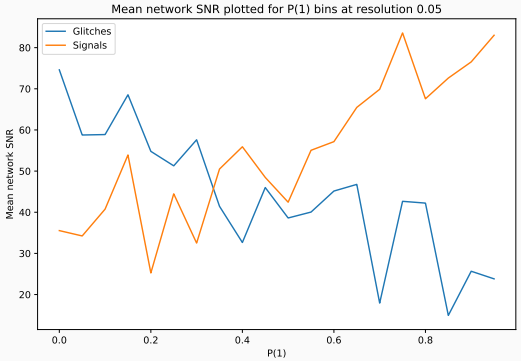


Figure: Mean network SNR versus probability

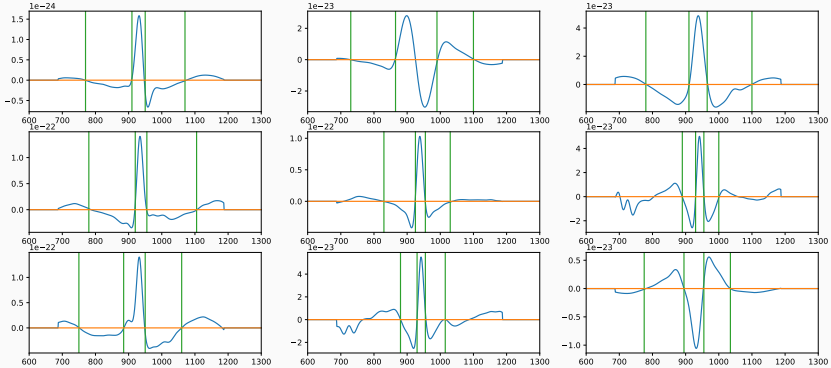


Figure: Glitch surgeries

Future

- A paper detailling this work is upcoming
- Evaluating performance on current datastreams
- Inclusion of other signal generating mechanisms

Questions