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Classifying LIGO Signals With CNNs

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Introduction:

LIGO (The Laser Interferometer Gravitational-Wave Observatory) is a pair of gravitational wave detectors in Hanford, WA and Livingston, LA.

When a gravitational wave passes through a detector, the relative length of the two perpendicular arms changes. This change in length can be measured by the interference of lasers.The deformation of the arm length is called gravitational strain, and is on the order of 10^{-21}.

Our goal is to classify gravitational wave sources using recordings of the strain over time.

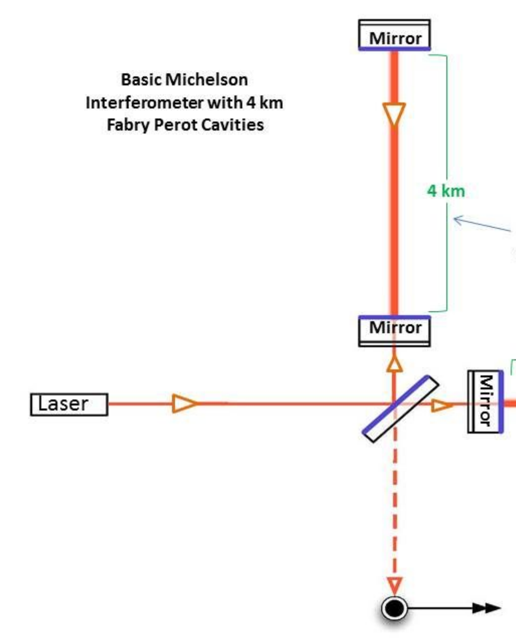
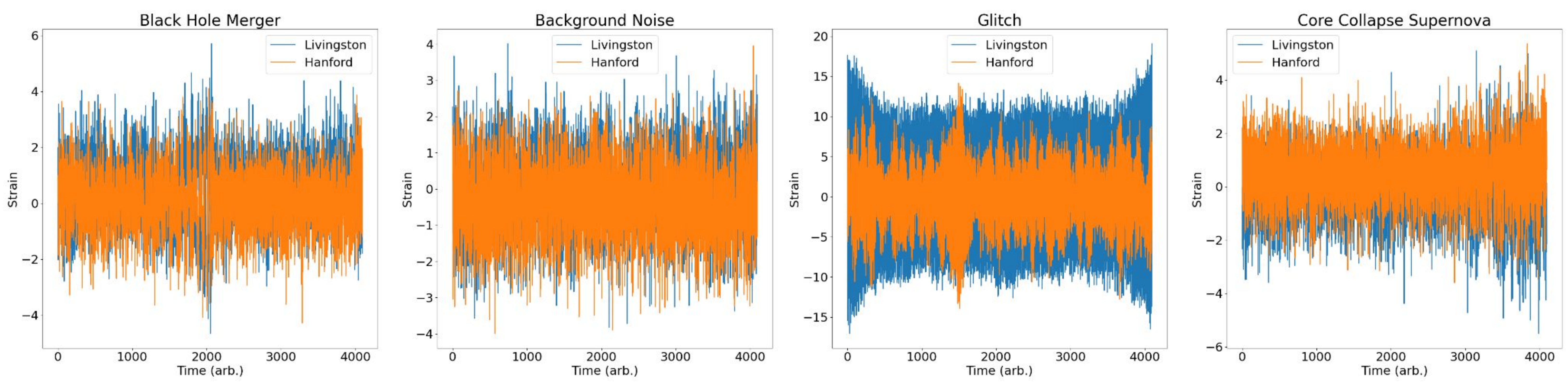


Diagram of the LIGO detector [5]

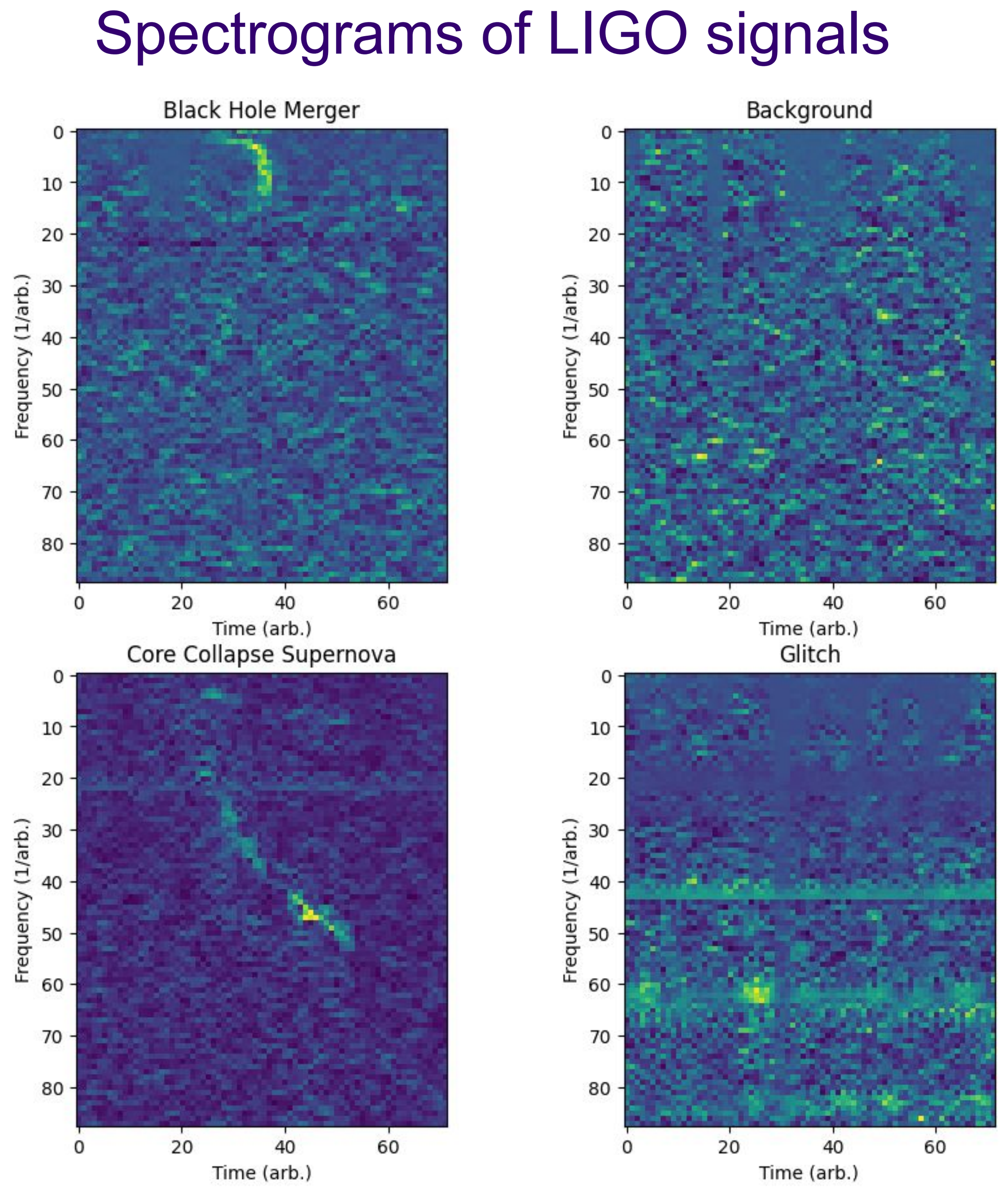


Strain vs Time plots from the LIGO detectors.

Convolutional Neural Networks (CNNs)

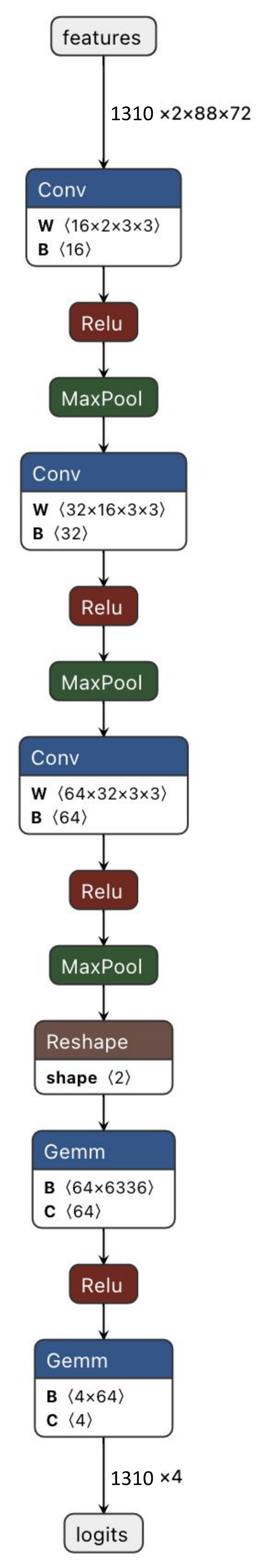
- Neural networks are a method for developing a general function from known inputs to known outputs such that the function is effective for similar inputs.
- CNNs are a type of neural network designed for images (3-D inputs including a color dimension).
- Previous research on gravitational wave classification has used CNNs on spectrograms [1], and we followed this method.
- Based on Al Mamun and Iqbal [2], we aimed for an accuracy of 95%.

Spectrograms of LIGO signals



Data Prep

- > Convert time-series data to spectrograms with `scipy.spectrogram`, combine spectrograms from both detectors to 2-channel image
- > Normalize images with scikit-learn `StandardScaler`
- > Label data
- > Shuffle data
- > Split into train, test, and validation (80:16:4)



Architecture

Convolution: convolves a filter with learned weights with the image to extract a feature map.

Pooling: reduces the dimension of the feature map.

Dense layers: learns how to map extracted features to objectives. [4]

Convolution parameters:
Kernel Size: 3, Stride: 1, Padding: 1

BatchNorm: applied after convolution

Dropout: 40%, applied after first linear layer

Training: 323 training samples, 15 epochs, batch size 32.

Note: Gemm is "general matrix multiplication," i.e. a linear layer

Results

- Fast-converging (8 epochs) gravitational wave classification model trained on 1310 samples.
- **Testing accuracy of 100%** on 410 samples.

References

[1] Morales et al. Deep Learning for Gravitational-Wave Data Analysis: A Resampling White-Box Approach.

[2] Al Mamun AM, Iqbal MA. Classifying the gravitational waves using the deep learning technique. Material Sci & Eng. 2022;6(2):41–46. DOI: 10.15406/mseij.2022.06.00178

[3] Xia et al. Improved deep learning techniques in gravitational-wave data analysis. https://arxiv.org/pdf/2011.04418.pdf.

[4] Amidi and Amidi. Convolutional Neural Networks cheatsheet. https://stanford.edu/~shervine/teaching/cs-230/cheatsheet-convolutional-neural-networks

[5] LIGO collaboration, Caltech. https://www.ligo.caltech.edu/system/media_files/binaries/701/original/Basic_michelson_with_FP_labeled.jpg?1632442159