

Machine Learning in Ultra-High Energy (UHE) Neutrino Analysis

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Introduction**What are UHE Neutrinos?**

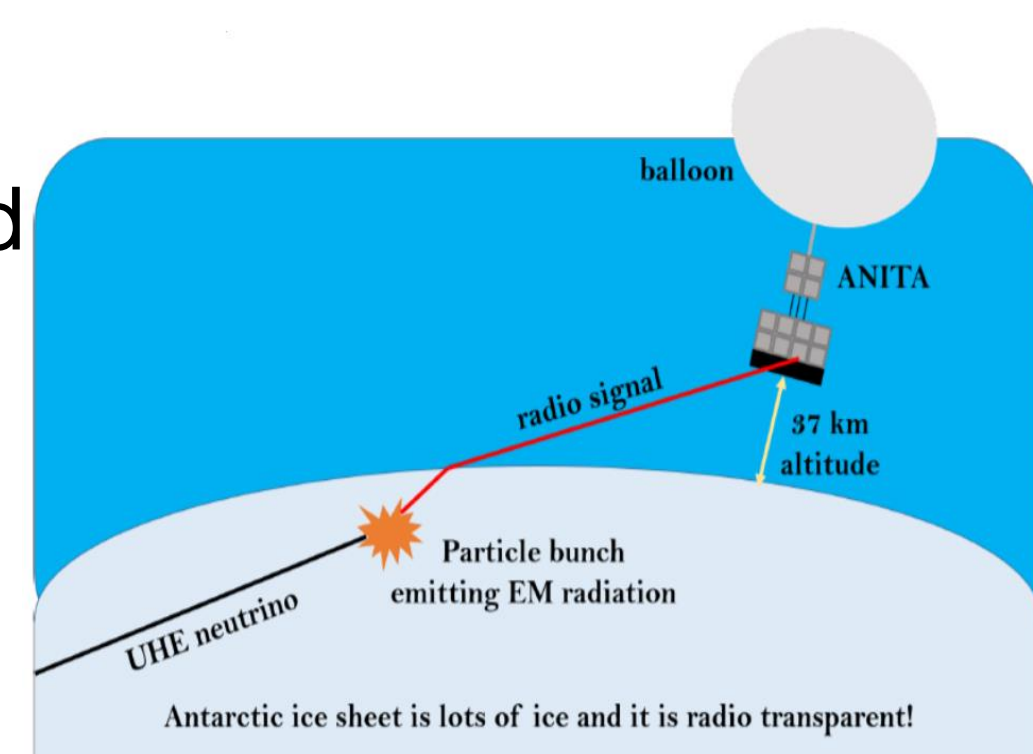
- Neutrinos are fermions with no charge and negligible mass. UHE neutrinos reside on ($>10^{18}$ eV) of the energy spectrum.
- UHE neutrinos are theorized to exist by that when cosmic rays interact with the cosmic microwave background, they produce UHE neutrinos.

Askaryan Effect:

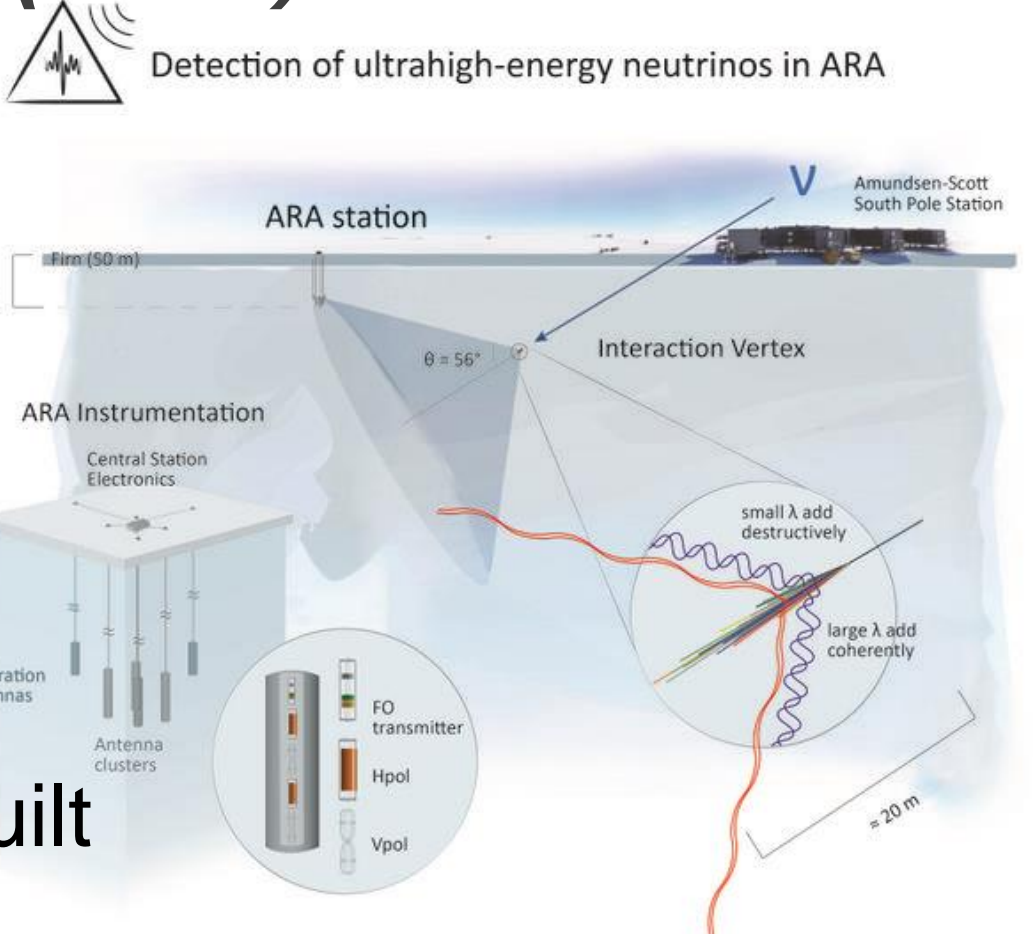
- When neutrinos interact in a medium, they produces a particle bunch that propagates through ice. The particle bunch gives off EM radiation that is coherent for wavelengths greater than the 10-cm bunch size, equivalent to light frequency of around under 1 GHz.

Radio Detectors**The Antarctica Impulsive Transient****Antenna (ANITA)**

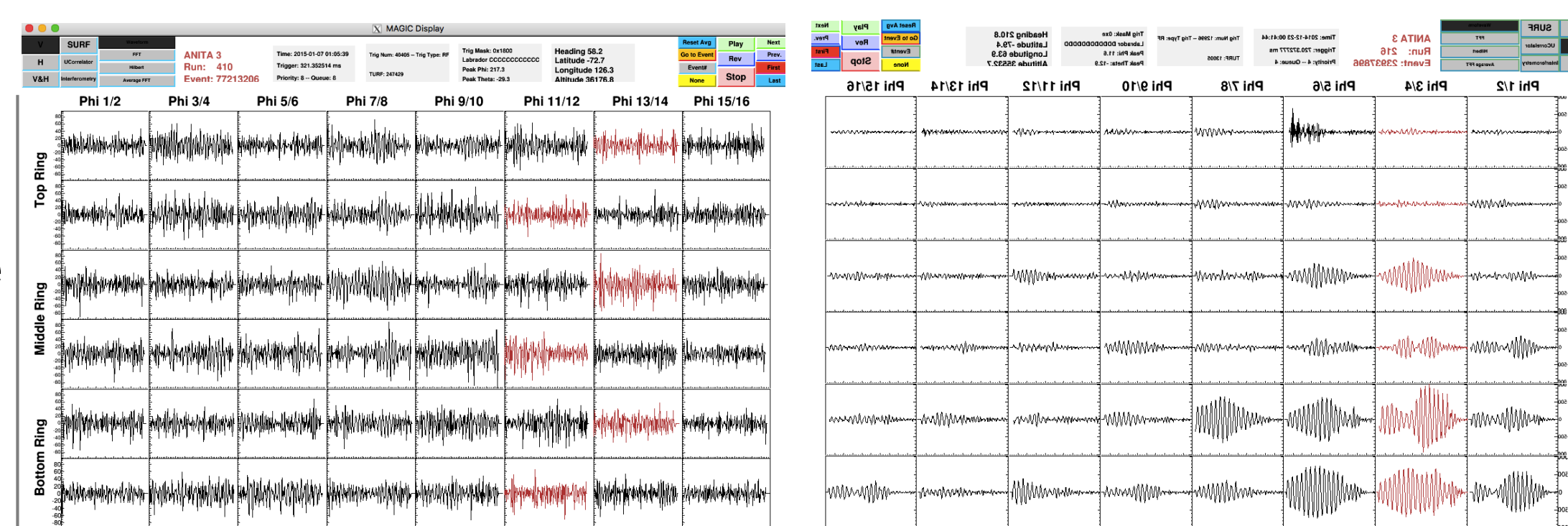
- Radio detector suspended by a balloon in Antarctica.
- Surveys a large area of ice and records potential neutrino events.
- 4 flights each about one month long each

**Fig. 1. The setup of ANITA****Askaryan Radio Array (ARA)**

- 37 Radio Array Stations
- Each Consists of an array of radio antennas drilled into the ice.
- Each station separated by approximately 2 Km
- 3 of the planned 37 stations have already been built

**Fig. 2. The setup of ARA****Payload Blasts**

- Payload Blasts are background noises caused by the equipmentmen of ANITA flight.
- They are problematic as they pass the final analysis cuts that only UHE Neutrinos and cosmic rays are meant to.
- Payload blasts have a very unique waveform and are easy to distinguish.

**Fig. 3. Payload blast event (right) Vs. other event (left)****Why Machine Learning****Convolutional Neural Network (CNN)**

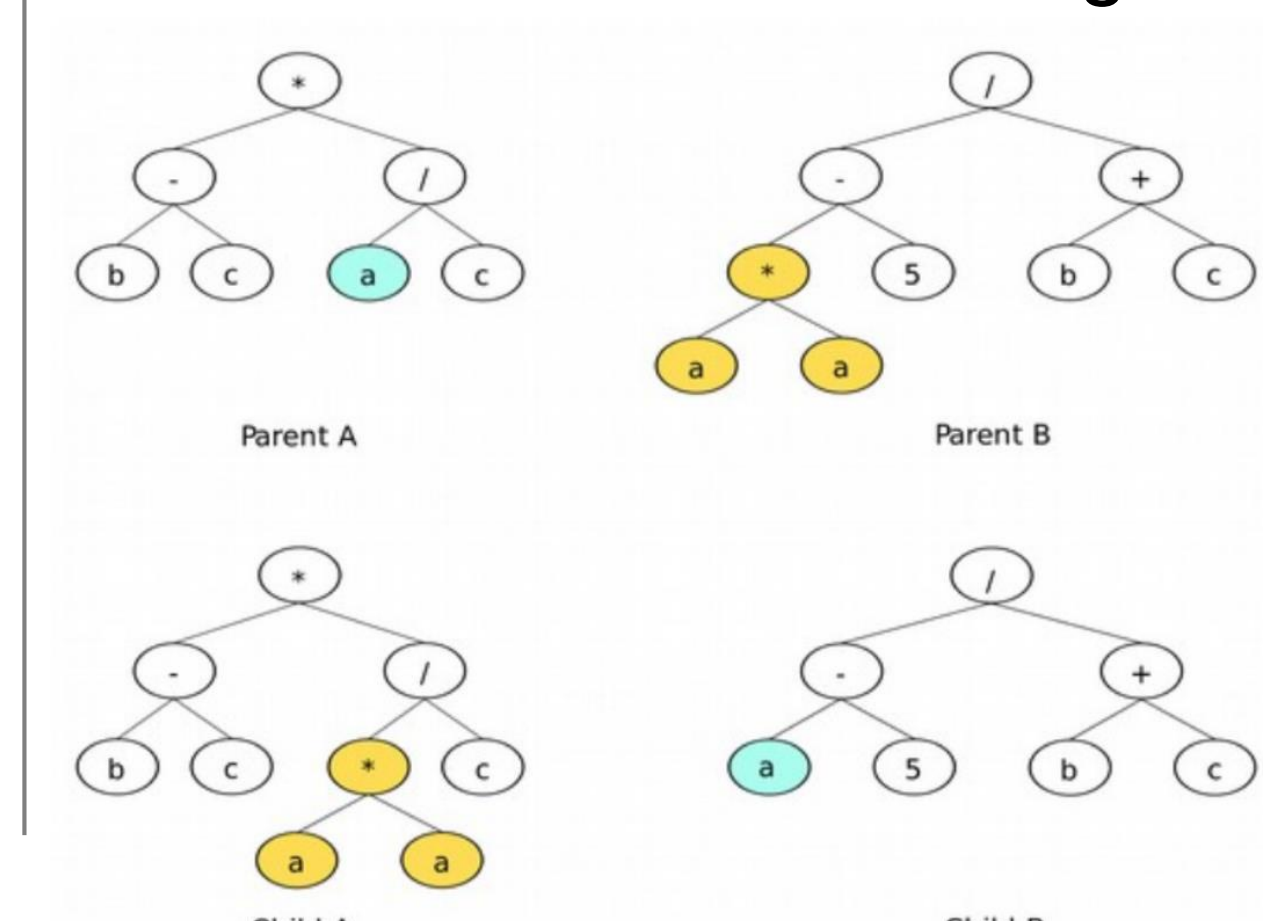
- CNN is a proven method in classifying images of different classes and works extremely well given enough training data.
- Goal: is to able to classify payload blasts and remove them from data

Regression

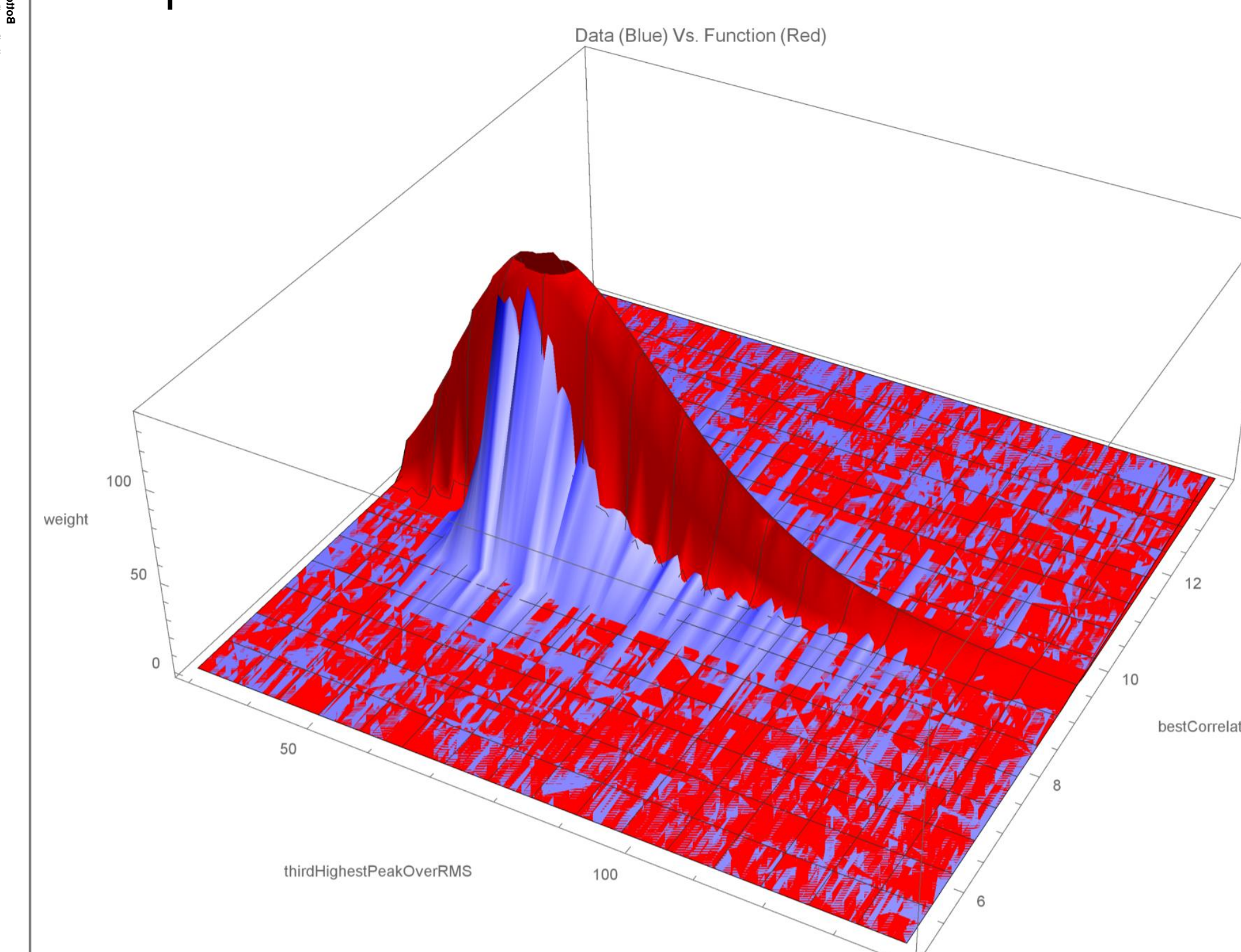
- Regression analysis is used to describe a data set by a simple function.
- Goal: is to model all background noise data and hence filter these events from the data set.

Regression explained

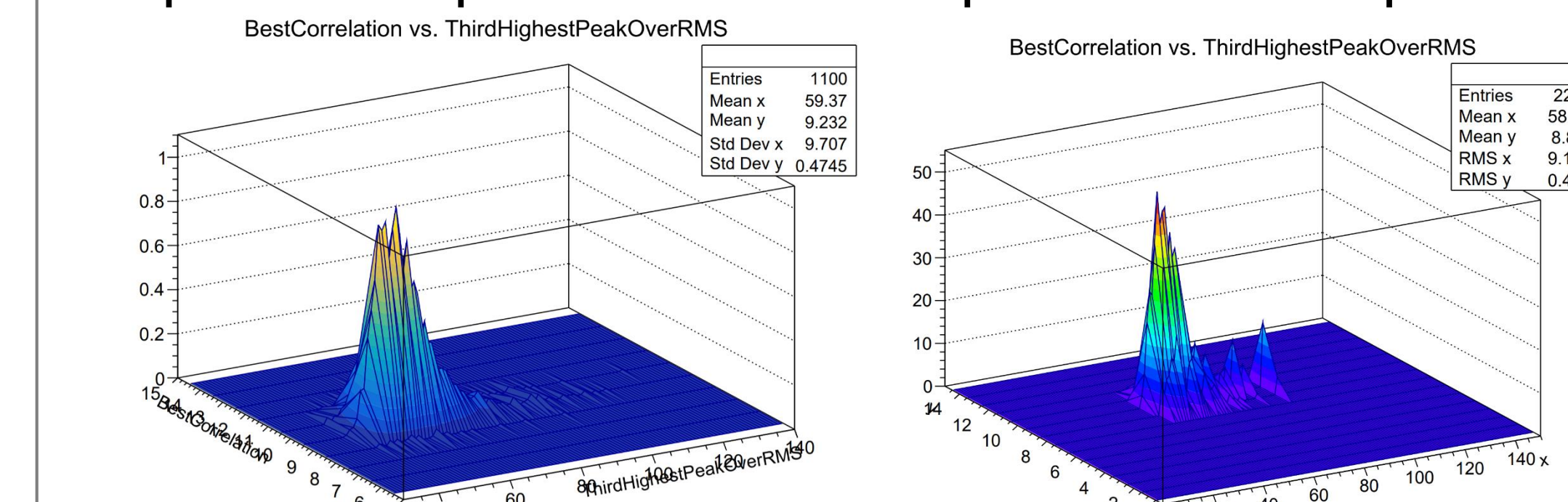
- The process starts with the selection of random functions.
- These functions are tested for their fitness score against the data and functions with the best fitness score are selected to parent the next generation.
- The functions are then evolved by either of the following:
 - Reproduction: the tree is copied without mutation to the next generation
 - Point/Branch mutation: a single node/branch mutates before added to next generation
 - Crossover: 2 trees parent are selected to produce 2 offspring by mutation as summarized in Fig. 4.

**Fig. 4. An example of a crossover mutation process****Results**

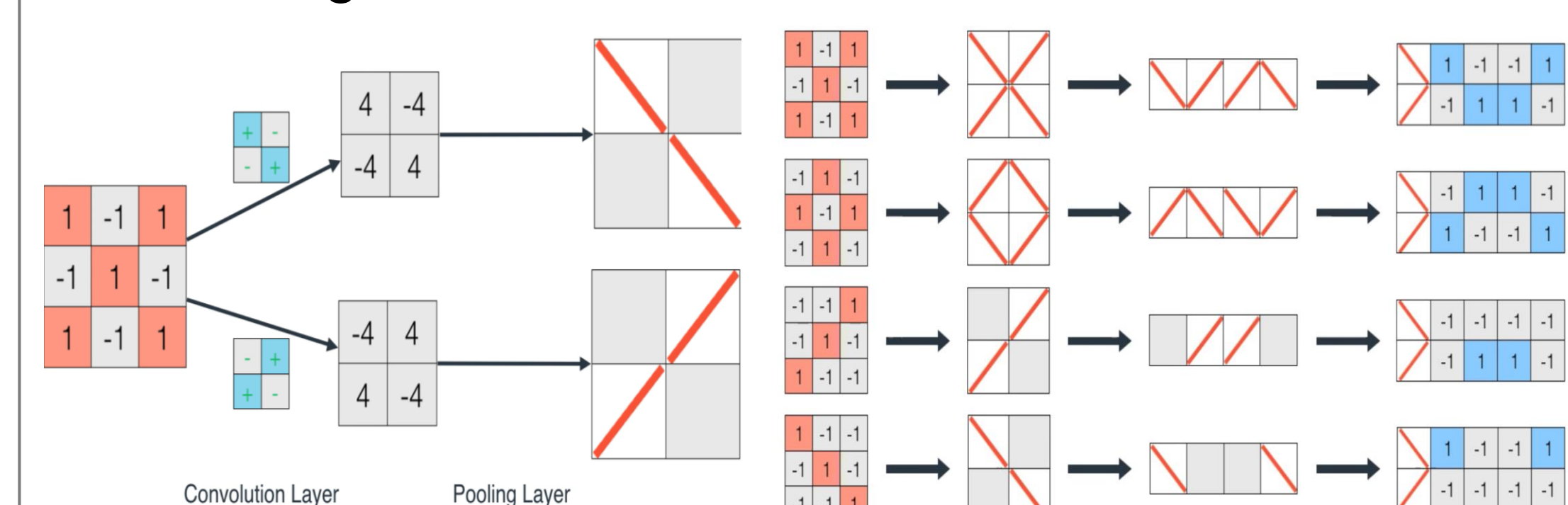
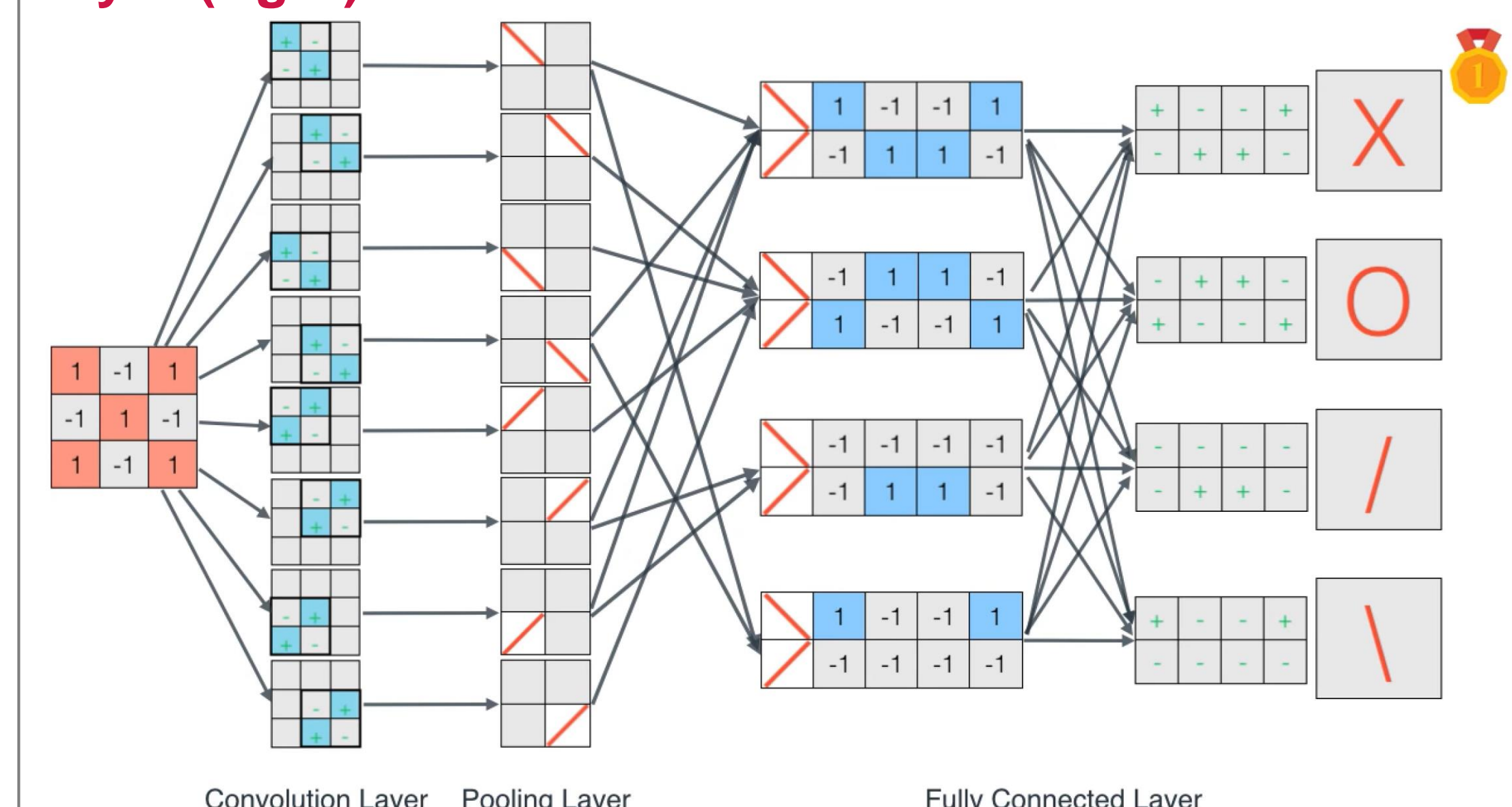
- Various implementation of regression analysis were used. Some of these were Karoo-GP, Eureqa, and HeuristicLab.
- Eureqa yield the best result and in the shortest time.
- A plot of such model is shown below.

**Fig. 5. A plot of the Background data (Blue) and the Eureqa model (Red)****Verifying the model**

- It is very common for such models to be over trained, to verify that this was not the case; a pseudo experiment was conducted based on the model and compared with the data.
- This consisted of converting the Probability Density Function (PDF) from Eureqa to a Cumulative Density Function (CDF) by numerical integration.
- The data from the CDF were then used to generate a PDF plots by random selection of points from the CDF data.
- If the resulting PDFs were similar to the original, we conclude that there was no over fitting.
- The last step was to compute the likelihood for each pseudo experiment and compared to the expected.

**Fig. 6. A plot of the data normalized (left) Vs. pseudo (right).****CNN Explained**

- The concept is best explained by 3*3 pixels model where only 4 characters are allowed; \, /, O, and X.
- We start by picking up filters, for this example we pick / and \ filters.
- We pass the two filters over the characters and see how they fit (Convolution Layer).
- Based on a threshold value we decide whether we found something or not, here either characters / or \ (Pooling Layer).
- We build filters by encoding our character as matrix in / and \ vector space (Fully Connected Layer)
- The whole process of evolving filters is done by a gradient descent of an error function starting by a random guess.

**Fig. 7. Convolution/Pooling Layer (left) Fully Connected Layer (right)****Fig. 8. The steps followed in classifying the X character Results**

- Building the CNN was met with success with the ability to classify over 1000 classes some of which are special classes.
- To train the CNN to classify the payload blasts, data is being collect and it should be straight forward to classify there after.

Acknowledgements

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