Solving The Particles Game Using Machine Learning

Divya Divkaran*
Homi Bhabha National Institute, BARC, Mumbai
Email: divdnair@gmail.com

People say that there are at least 7 people on earth who are identical to each other. But what if two of them are invited to the same party and decide to fool their spouses. The partners get confused as they look the same, wear the same dress and have the same mannerisms. A difficult situation! Isn't it? Now, if the partners are smart enough, they can check for some minute features which differentiate the two. If that also doesn't work, the only solution is to do fingerprint or DNA test. Just like the quantum numbers of electrons in an atom, every person in this world has a unique fingerprint and DNA.

Now think about such a situation in the particle physics world. Just like these two identical people being invited to the same party, two fundamentally different particles falling on the same detector can produce the same kind of signals. For instance, consider an electron and a proton. An electron gives rise to an 'electromagnetic shower' in the detector whereas a proton, which belongs to the group of fundamental particles called 'hadron' gives rise to a 'hadronic shower'. A shower is a cascade of secondary particles produced as a result of the interaction of a primary particle or incident particle with matter. In our case, both the showers look almost the same in their recorded digitised signal. Now, the experimenter here has to play the difficult role of the partner to identify the particles in spite of their identical nature. The first task is to find the fingerprint or DNAlike features which distinguish one from the other and then use that feature to identify the source of the shower. A lot rests on the shoulders of the spouse as for only if s/he can correctly identify the

---

* Ms. Divya Divkaran, Ph.D. Scholar from Homi Bhabha National Institute, BARC, Mumbai, is pursuing her research on "Neutrino Physics." Her popular science story entitled "Solving the Particles' Game using Machine Learning" has been selected for AWSAR Award.

sources and separate them can the data be used without doubt for further physics analysis. This is what I am trying to address in my PhD thesis. My work is on separating the showers produced by an electron and a hadron in a particle detector and use that information to improve the capability of detector and further physics studies using it. We are addressing the problem such that it can be applied to any detector with similar signals.

If we just delve a bit beneath the surface, we find that our experimenter bears the staggering task of separating out the showers, which unlike human, have no such unique fingerprints. All one has are digitised hits of the position and the time information of the passage of thousands of particles through the detector at a time for him to sort through. Well, fortunately all is not lost, and to her aide comes the application of advancement in technology in pure science. Machine learning algorithms, which have changed the face of the modern world, from self-driving cars to making financial decisions for big businesses to enabling the cameras to take better selfies, comes to her rescue. Machine learning, as the word implies, involves teaching a machine to perform some tasks from its 'experience' of previous exposures to similar problems. In our case, we teach the algorithm, how these two showers will behave in a detector using simulated results. Once they are trained with it, they can identify the source of the shower from any noisy set of data with considerable certainty. Just like once we know a person very well, we can identify him from any crowded place,these algorithms, especially the neural networks used in them, are inspired from how the human brain works.

Towards this endeavour, we simulate the detector using a software package GEANT4. The patterns of the electromagnetic and hadronic shower in the detector are obtained separately by making them fall on the detector in the simulation. Also, the hit information corresponding to each case is obtained. But, this raw information cannot be fed into the machine learning algorithms as such. As we have stated earlier, we need to get that DNA-like character or feature which can distinguish between the two showers under consideration. We extract these features after a number of trials and errors and feed them into the machine learning algorithm. The task of the algorithm now is to understand the feature corresponding to each class well and tune it for maximum efficiency. For us, efficiency is the ability to identify an electron signal correctly as an electron. Once the algorithm is ready after the training, the simulated data corresponding to realistic events in the detector where all these interactions happen at the same time will be passed through the algorithm. By then, the algorithm becomes able to separate the events based on the training it had received already, which in effect, now makes the detector even capable of giving information regarding electrons and hadrons.

But, we have told only a part of the story. Our original motive is not just to separate out the electron shower and hadron shower but to obtain the information regarding a mysterious and omnipresent particle called the neutrinos. It is natural to ask how neutrinos came into picture here all of a sudden? Well, for that we need to go back to our past. Trillions and trillions of neutrinos pass through human body every second without us having a clue to such a thing. It's because they are very weakly interacting with matter which also makes it extremely difficult to detect them. But, it is already known that when they interact, their interaction can be classified into two typescharged current interactions and neutral current interactions. In charged current interaction, these neutrinos produce electrons and hadrons at the output. While in neutral current interactions, they produce only hadrons. Detecting the products is the only way to predict about these interactions. Here, in our case, detecting electrons and hadrons will give us the information we were seeking, enabling us to address some open problems related to a particular fundamental particle the electron neutrinos and as such deepen our understanding of particle physics and also the universe as a whole. And that is why we are eager to address the difficult task of separating out the shower or cascade produced by electrons and hadrons in the detector.

I agree, it may seem a lot to wrap one's head around but that's what also makes it exciting. I hope I was able to give you a glimpse into it.

Physics is a discipline that comes with philosophy. Every new discovery leading to the enhancement of human knowledge will answer some fundamental existential questions like how did the universe come into existence? What happened in the initial stages? And how did everything evolve? Ultimately, we, the humans, seek these answers and, with time, also get better at finding them. Sounds familiar?