Deep Learning Applications in Space & Solar Physics

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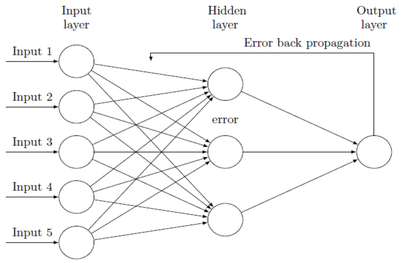
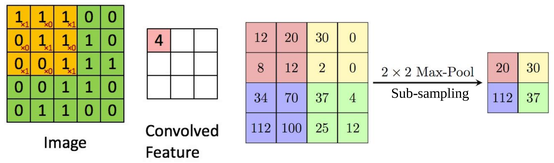
Neural Networks

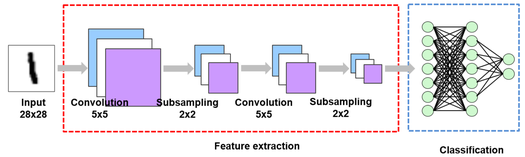
Neural Network (NN) is a specialized machine learning algorithm "trained" to perform a specific task. The training is being done by introducing numerous data several times to the NN and by then optimizing the NN's parameters according to these examples ("back propagation"). The basic idea behind neural networks is that after parametrizing a network to classify known data, the network can be used to perform tasks on some new unknown given information.



Convolution Neural Network (CNN) is an advanced neural network that works ideally when dealing with images. It consists of different layers and parameters that try to obtain features originating from the input images in order to perform a specific task.



For problems with inputs of higher dimensions (e.g. images), one can combine the traditional neural networks along with convolution and subsampling layer to create a **CNN**.



In this work, we look at **three** different **applications** of deep learning, featuring both **regression** and **classification** tasks.

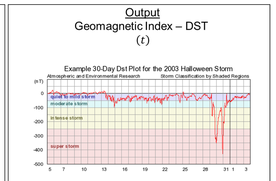
Predicting Geomagnetic Index

Find value of DST index using past solar wind measurements

Input
Solar Wind Data (OMNIweb)
$(t-4, t-1)\ h$

- Absolute Magnetic Field
- Dynamic Pressure
- Mach Number
- Beta Parameter
- Electric Field
- Velocity
- Density
- Temperature
- DST Index

Output
Geomagnetic Index – DST
(t)



Dst index is used to show the difference between the perturbed and the unperturbed geomagnetic field. A value of zero means that there is no disturbance, while negative values indicate phenomena ranging from sub-storms to super **geomagnetic storms**.

In this work, we are using solar wind data from the **ACE** space mission, in order to solve the "**regression** problem" of predicting the time-series of Dst index using a **deep neural network**.

Prediction time: 1 hour
Dominant features: $\rho_{dyn}, B_Z, Dst_{t-1}$
Result: Cross validation, Mean Square Error: -0.04 (0.01)

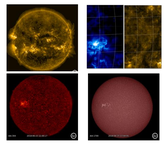
For better results and longer predictions times one can use:

- **LSTM** (**Long short-term memory**) neural networks
- Extra input features by using **GPS** data.

Forecasting CMEs

Forecast the emerged CMEs using solar images taken from SDO and CNN

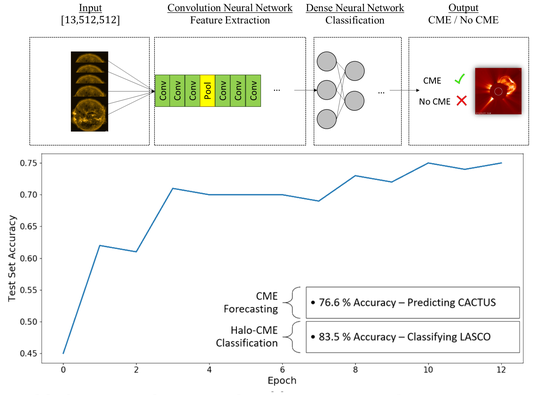
Input
SDO Images during 2014



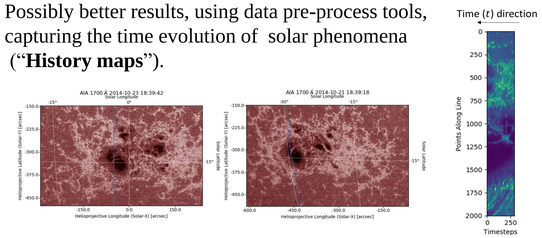
Output
LASCO/CACTUS Catalogs

Date	Characteristics					
2014/01/02 13:48:06	184	57	894	959	825	711
2014/01/03 00:24:05	264	18	225	272	169	0
2014/01/03 02:24:06	51	24	657	637	674	720
2014/01/03 03:47:05	61	44	1132	1303	961	965
2014/01/03 07:36:05	62	17	250	193	306	615
2014/01/03 10:36:05	65	21	316	273	358	627
2014/01/03 12:36:05	265	25	277	287	267	34
2014/01/03 18:00:06	154	60	208	114	295	430
2014/01/03 18:48:05	90	31	89	179	0	0
2014/01/03 19:36:05	222	112	286	331	237	0

By applying a **CNN** and images from **SDO**, we tackle this "forecasting **classification** problem", predicting the automatic **CACTUS** catalog and classifying **Halo-CME**s of the manually derived **LASCO**.



Possibly better results, using data pre-process tools, capturing the time evolution of solar phenomena ("**History maps**").



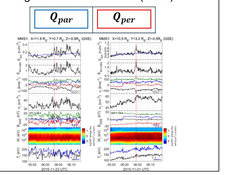
Classifying Magnetosheath Jets

Find class of magnetosheath jet found by MMS using solar wind data

Input
Solar Wind Data (OMNIweb – Bow Shock)

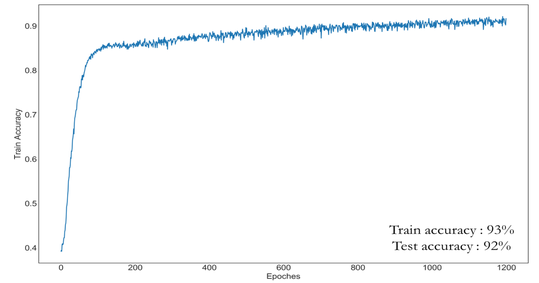
- Absolute Magnetic Field
- Dynamic Pressure
- Average Dynamic Pressure (10 min)
- Mach Number
- Beta Parameter
- Electric Field
- Velocity
- Density
- Temperature

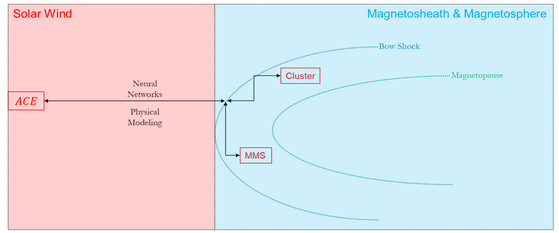
Output
Magnetosheath Jet Class (MMS)



Magnetosheath jets are enhancements of dynamic pressure above the general fluctuations level and they are a key component to the coupling between solar wind and the magnetosphere.

With a neural network, we **classify** the jets measured by **MMS** using solar wind data, therefore confirming a connection between the particle populations before and after bow shock interaction.





Conclusion

Machine learning techniques have been proven to be extremely useful with various tasks, in many different fields. In the last few years, they have been introduced to space and solar physics and already achieved very promising results. Although, these techniques might not replace human's physical understanding, they can aid us in creating more accurate models and investigate patterns, previously considered to be too complex to study.

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