Transfer Learning and its applications in Solar Physics

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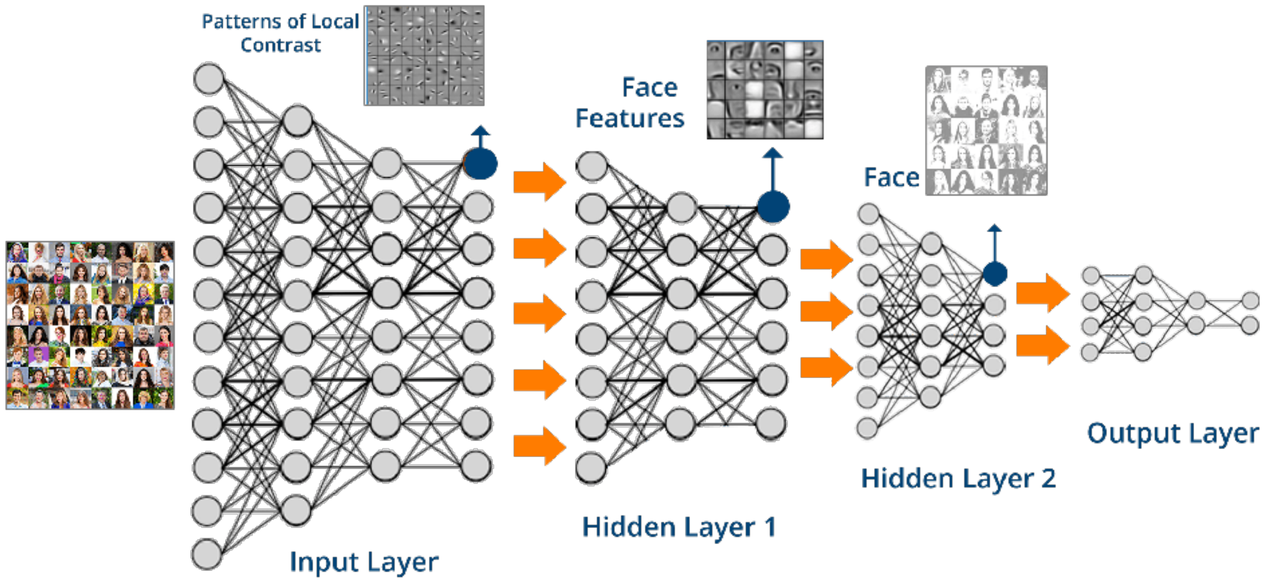
Overview

- What is transfer learning?
- How does transfer learning work?
- Why should we be using it in solar physics?
- Is a solar ImageNet feasible?

Very brief review of deep learning

- A deep neural network is one in which there are >1 hidden layers.
- Traditional deep neural networks e.g. CNNs, ANNs can only perform two tasks: classification and regression.
- **These will not give scientifically useful results unless used for one of these two purposes.**
- For anything more involved, generative networks are often the solution e.g. VAEs, GANs.

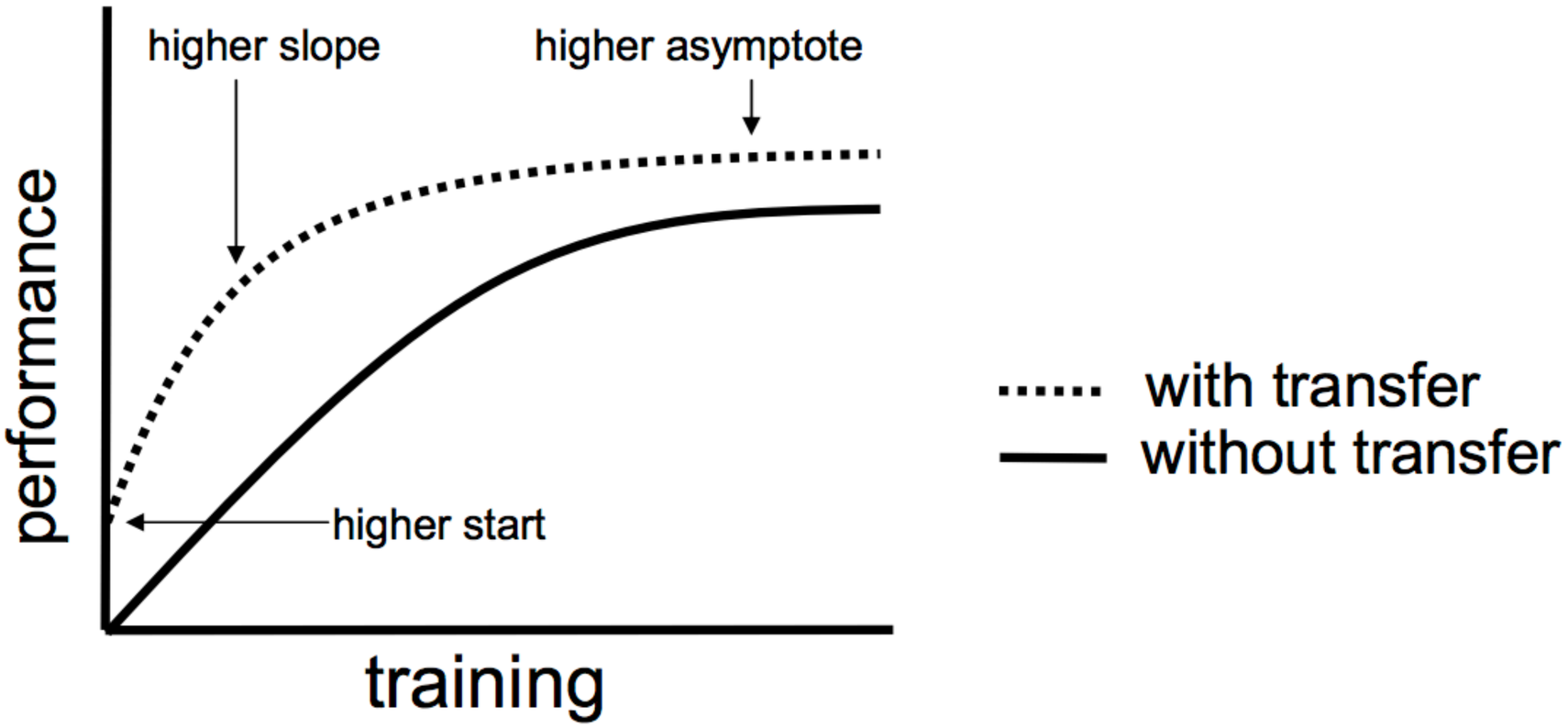


Source: https://bit.ly/2OHySYM

What is transfer learning?

- A trained ML algorithm passes its knowledge to a new model
- A technique to use the parameters from one deep neural network (DNN) for a different task without having to train an entirely new DNN
- An optimisation allowing for rapid progress and/or improved performance when modelling a new task
- Three main possible advantages:

    1. good initialisation
    2. reduced training time
    3. increased accuracy



Source: https://bit.ly/2ERtZT6

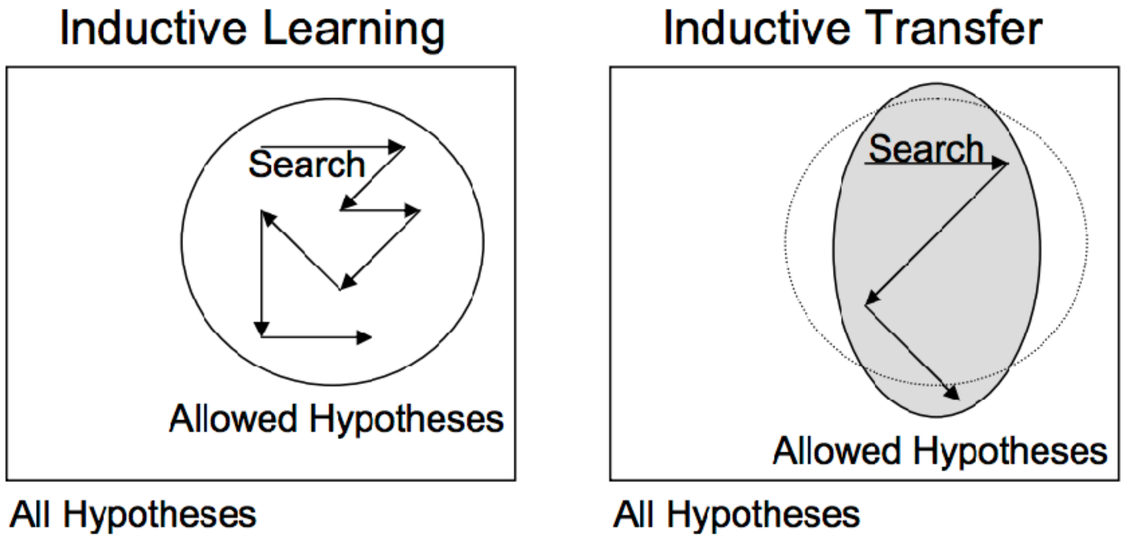
A bit more about neural networks….

- Neural networks are examples of supervised learning — a network will learn a predictive model from a set of labelled training examples
- This model needs to have a bias: assumptions about the true distribution of the training
- This is described by the loss function and initialisation
- e.g. L2 loss arises from assuming the training data has a Gaussian distribution

How does it work?

- Only works if the features learned by the first model are general and related to the second model

- The transfer of knowledge narrows the parameter space we wish to optimise for our new model i.e. changes the bias



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How is it used?

- There are two main places where transfer learning can be directly utilised by the user:

    A. in the initialisation of the new network — the weights of the different layers in the new network can be influenced by the weights from the previous network

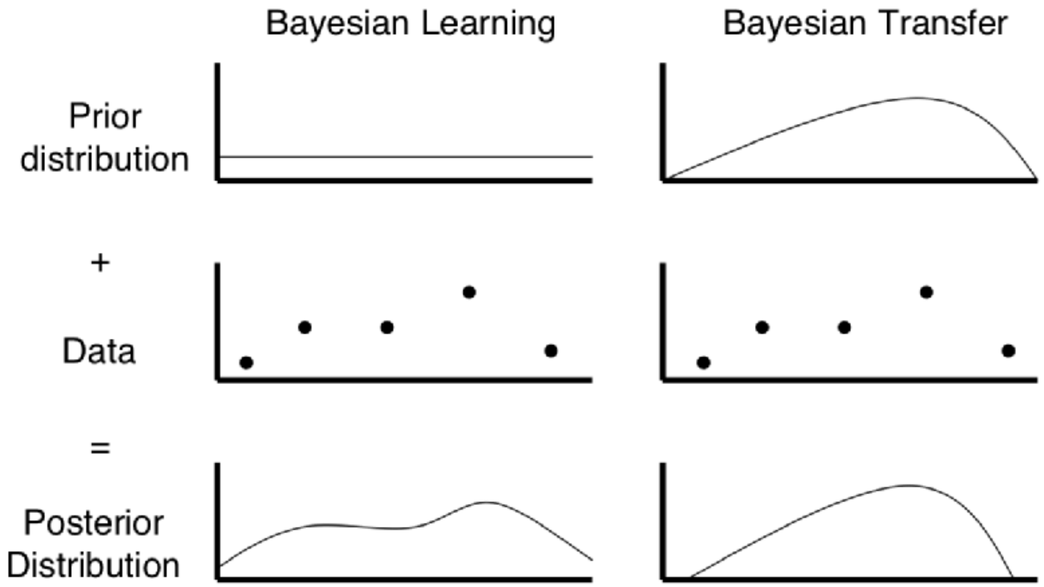
    B. in the loss function — the choice of loss function can be influenced by the prior information (or the loss function can take information directly from the previous network)

BEWARE: Negative Transfer

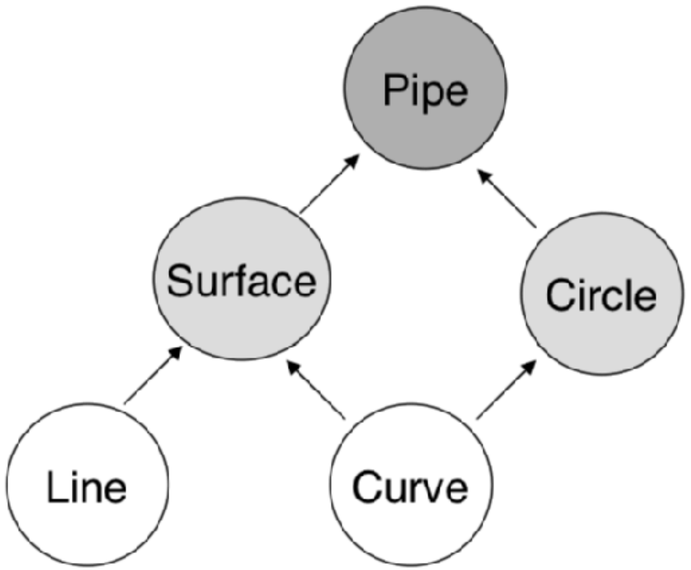
- Sometimes when employing a transfer of knowledge, the new network can experience the opposite of the desired effect
- This is known as negative transfer
- This can be a result of the previous network's model is not sufficiently related to the new network's model
- For example, training a neural network on solar optical data and then applying it for the classification of solar X-ray data.

Two examples of transfer

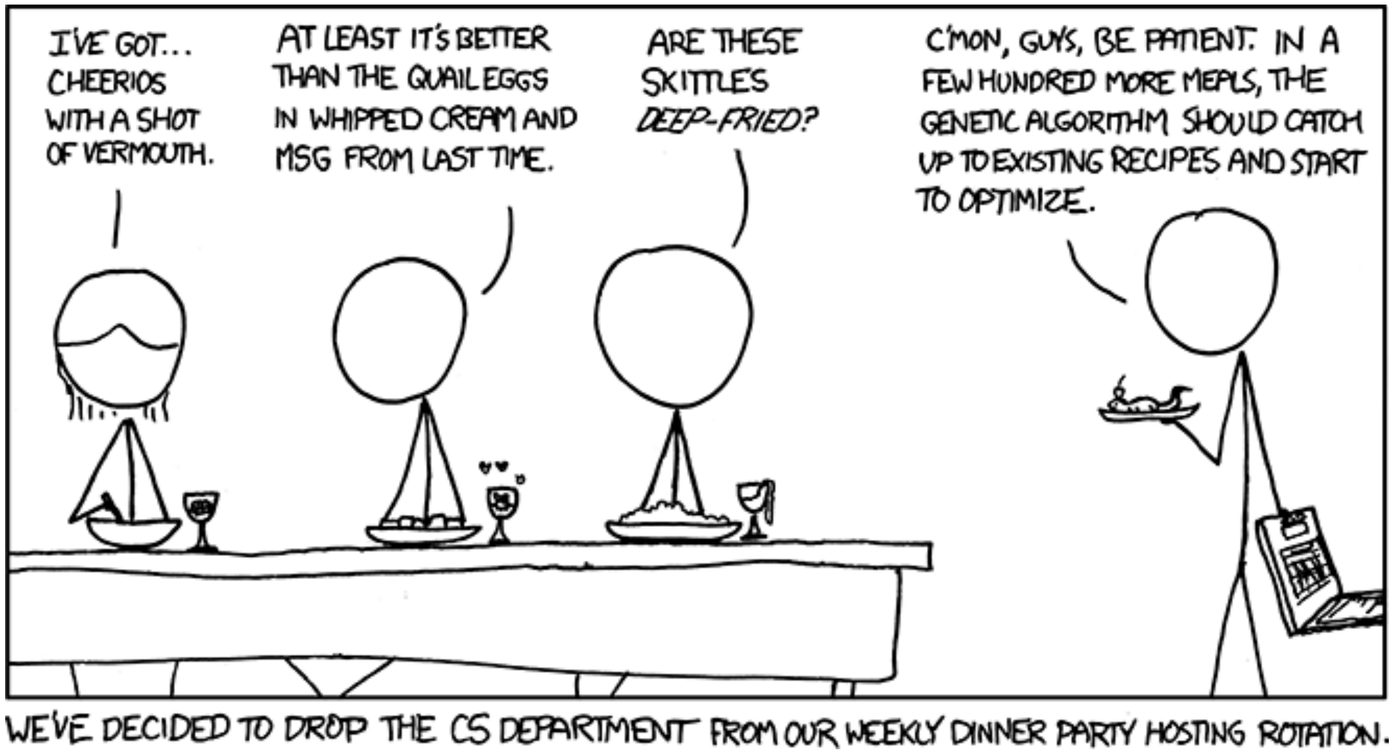
Bayesian Transfer



Hierarchical Transfer



An example that needs transfer

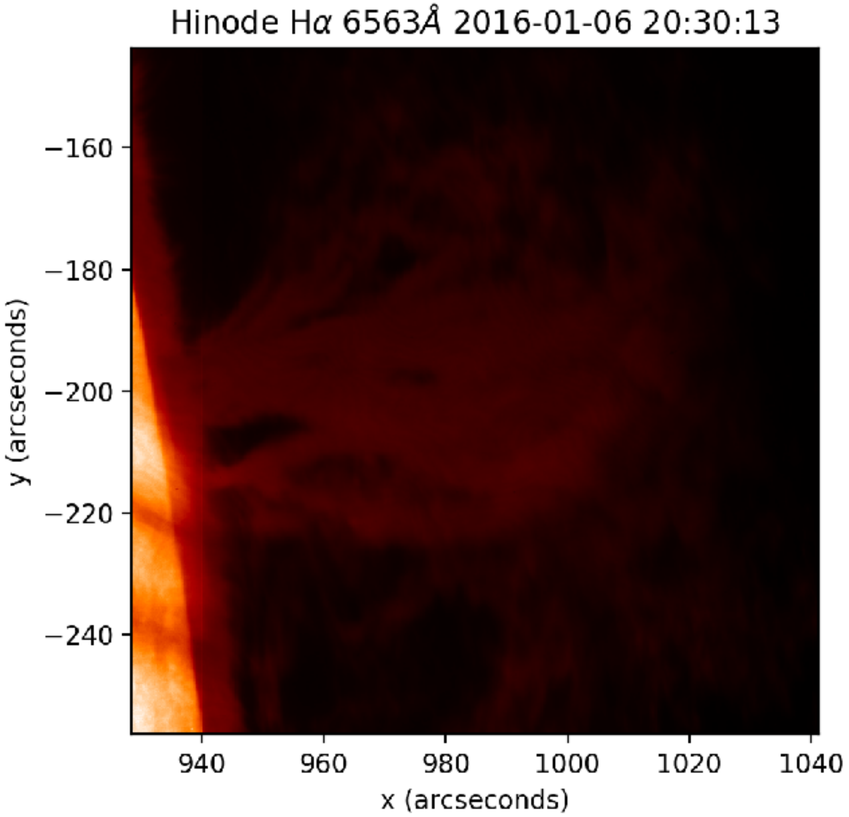


Source: https://xkcd.com/720/

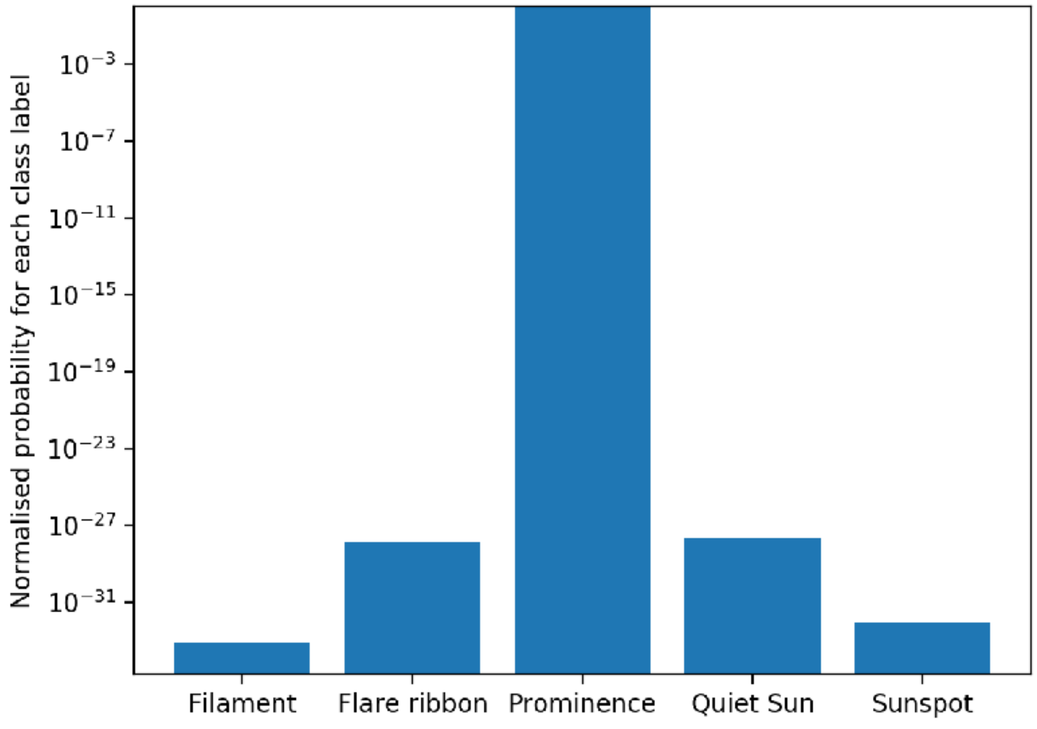
Why is it needed in solar physics?

- Can lead to better performance in a shorter time for new deep learning models
- Encourages collaboration
- Can allow people to train models without needing supercomputer resources
- Helps demystify how one's deep learning model "thinks"
- Now on to some current uses of transfer learning in solar physics….

Teaching a computer what the Sun looks like

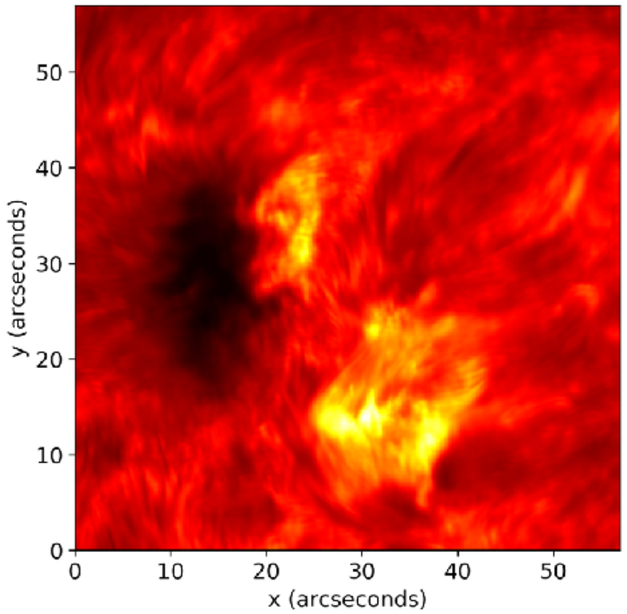


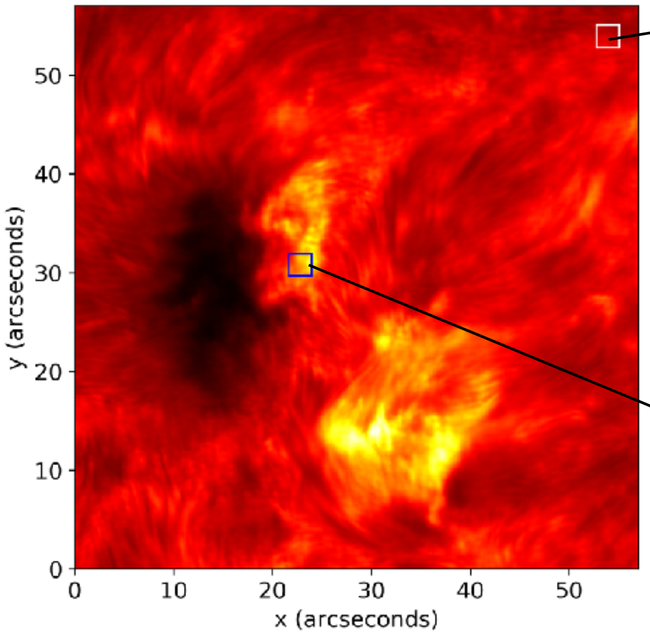
Deep CNN

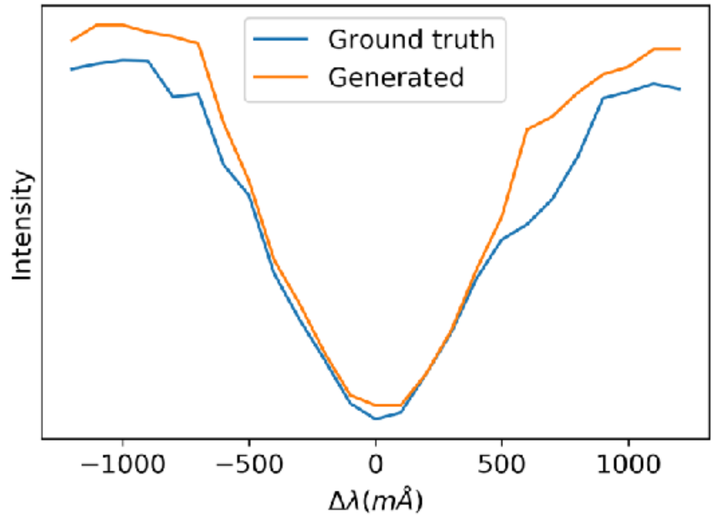


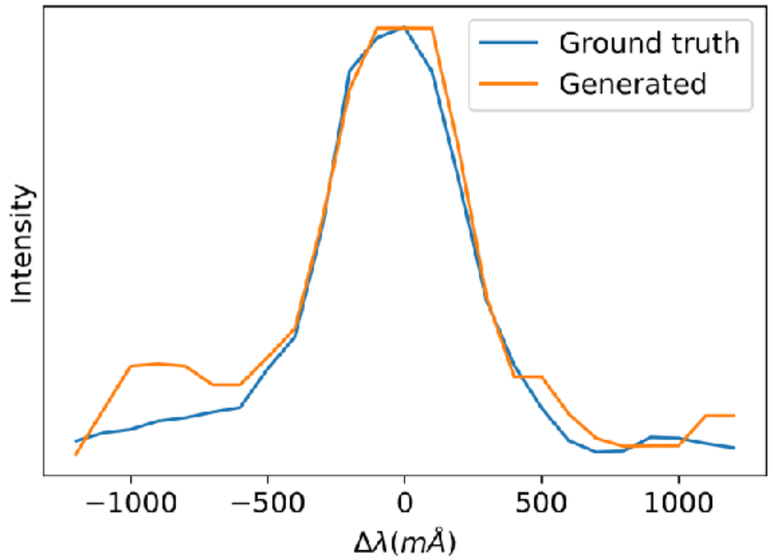
Source: Armstrong & Fletcher (*in prep*)

Correcting for seeing in flares









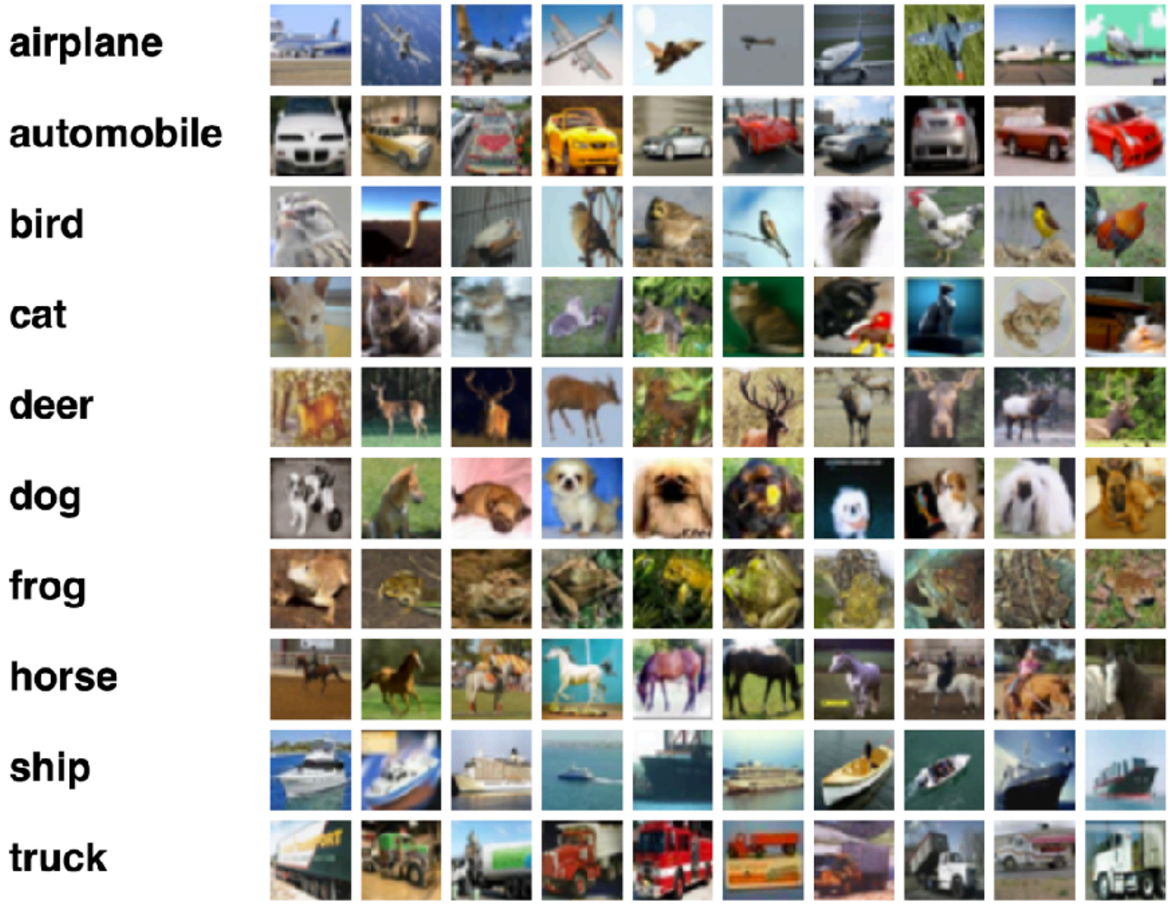
Perceptual loss

$$\mathscr{L}_X = \frac{1}{W_{i,j}H_{i,j}} \sum_{x=1}^{W_{i,j}} \sum_{y=1}^{H_{i,j}} \left(\phi_{i,j}\left(I_S\right)_{x,y} - \phi_{i,j}\left(G\left(I_B\right)\right)_{x,y} \right)^2$$

- The feature maps of the pre-trained CNN for some deep layer are applied as functions to the target and input images.
- This is how information is transferred between the two networks.
- This should lead to better convergence.

ImageNet

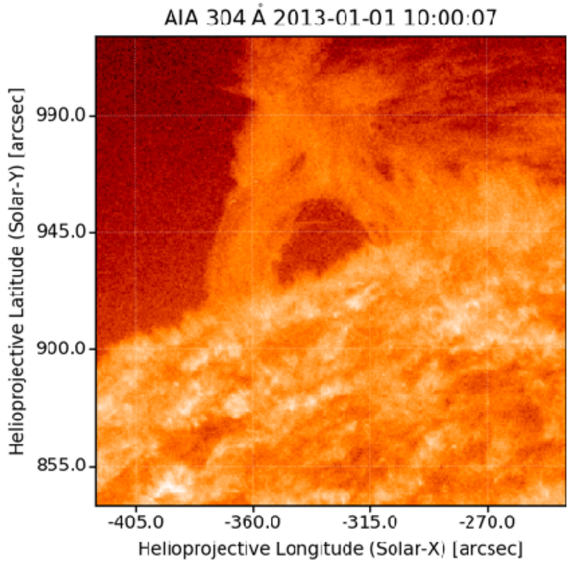
- This is the largest collection of images in the world
- There are millions of images sorted into thousands of classes
- A deep CNN pre-trained on this dataset is almost always used for transfer learning when applied to real-life problems



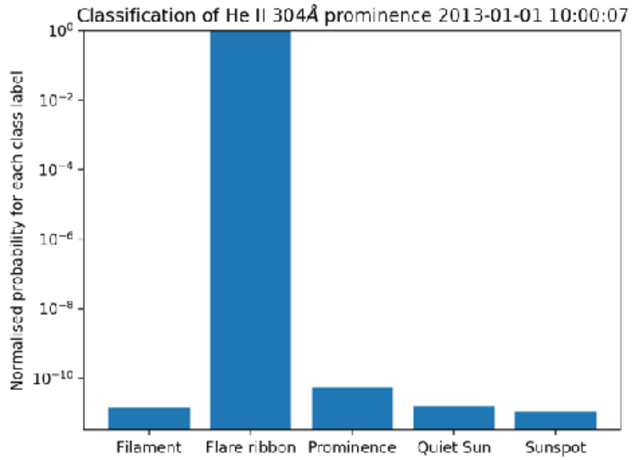
Source: https://bit.ly/2yACH87

Solar ImageNet

- Our previous CNN cannot be used for transfer learning for different wavebands
- This would result in a new deep CNN needing trained every time we are looking at a different part of the EM spectrum
- An idea is to create a solar “ImageNet” such that one deep CNN learns what solar features look like across the EM spectrum.



Deep CNN



What is the feasibility of this?

- This would require the manual download, augmentation and classification of millions of solar images — which is likely 100s of hours of work (possibly a citizen science endeavour)

- To train such a large network would need supercomputing resources and possibly weeks of training

- This would only be worth doing if other people want to apply deep learning to their research

- However, this could mean a great increase in the accuracy and decrease in training time of future solar DNNs….

Closing thoughts

- Transfer learning is something that has great potential in solar physics (though we must be wary of *negative* transfer)
- A solar ImageNet could potentially be a good idea
- However, we wouldn’t know until after it had already been done.
- (If anyone wants to spare a lot of time then they can do the solar ImageNet themselves!)