

MACHINE LEARNING AND DEEP LEARNING IN SOLAR PHYSICS

a. asensio ramos @aasensior github.com/aasensio



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Invited Talk

5. Opportunities and challenges

Machine learning to investigate magnetic field and other complex data sets

<u>Andres Asensio-Ramos¹</u>

¹ Instituto de Astrofísica de Canarias, IAC, La Laguna, Spain

In the last decade, machine learning has experienced an enormous advance, thanks to the possibility to train very deep and complex neural networks. In this contribution I show how we are leveraging deep learning to solve difficult problems in Solar Physics. I will focus on how differentiable programming (aka deep learning) is helping us to have access to velocity fields in the solar atmosphere, correct for the atmospheric degradation of spectropolarimetric data and carry out fast 3D inversions of the Stokes parameters.



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what is machine learning?

Using statistical techniques to give computers the ability to progressively improve performance on a specific task with data, without being explicitly programmed.

REGRESSION



CLASSIFICATION

Cartesian coordinates



Polar coordinates



CLASSICAL MACHINE LEARNING

- Principal component analysis (PCA)
- k-nearest neighbors (k-NN)
- Support vector machines (SVM)
- Artificial neural networks (ANN)
- Random forests (RF)
- Gaussian Process (GP)

CLASSICAL ML



CLASSICAL ML







WHY DEEP LEARNING?



Curse of dimensionality

Deep Learning Timeline



BASIC INGREDIENTS



Convolution

Activation

Loss

ENORMOUS LANDSCAPE







Output Dilation = 8

Hidden Layer Dilation – 4

Hidden Layer Dilation = 2

Hidden Layer Dilation = 1

Input

measuring velocities

DEEPVEL https://github.com/aasensio/deepvel



Asensio Ramos, Requerey & Vitas (2017)

SMALL SCALE VORTEX FLOWS



KINETIC ENERGY SPECTRUM



VORTEX DETECTION

DeepVortex



enhancing HMI images

ENHANCE: SINGLE IMAGE SUPERRESOLUTION

HMI





Hinode





ENHANCE https://github.com/cdiazbas/enhance



courtesy of S. Castellanos Durán

real-time multiframe deconvolution

MULTIFRAME BLIND DECONVOLUTION

Encoder-decoder



Recurrent



https://github.com/aasensio/learned_mfbd

POLARIMETRY



15

15

20

20

0 5 10 15 20 0 5 10 15 20 Distance [arcsec] Distance [arcsec]



GENERALIZATION TO UNSEEN DATA



100 images/s

3D inversion of Stokes profiles with height information

warning: WIP!!

3D INVERSION OF STOKES PROFILES



- Trained on Rempel's 3D MHD magnetoconvection snapshot (still too few)
- End-to-end deep neural network
- Severe augmenting during training
- Still without polarimetry

HINODE INVERSION - TEMPERATURE (WIP)

6900

6600

6400

6200 H

6000

5800

6500

6000

- 5500 🖂

- 5000

4500

5500

5250

5000

4750

4250

4000

3750

Ξ













5800

5400

5200

6000

5500

5000 2

4500

4000

4000

3500

 $\log \tau = -2.5$



log τ=-3.0

log T=-1.0

1.2 1.00.8 0.5 0.4 0.2

š

5750

5500

5250

5000

4750 🖂

4500 H

4250

4000

3750

 $\log \tau = -1.5$



log 7=0.0





 $\log \tau = -2.5$



log $\tau = -1.0$



 $\log \tau = -3.0$





- 5000

4750

4250 H

4000

3750

3500

- 5500

- 5400

-5200 🗵

- 5000

4500

5000

4500

- 4800 E

- 4400

4200

HINODE INVERSION - WILSON DEPRESSION (WIP)



1.15

1.10

1.05

0.95

0.90

0.85

0.80

250

200

120 [km] 120 [km]

100

50

ŝ

200

100

0

[km]

-100 🖥

-200

-300







log τ=-1.5







C

-100

-200 E

-300 =

400

-500

300

200

100

-100

-200

-BDD

n

tau [km]

log T=0.0

log τ=-2.0

 $\log \tau = -0.5$

100

50

0

-50

-100

100

-100 [Eg -200 [g

-300

400

400

300

200

100

-100

-200

n.

tau [km]

0

tau (km)



log τ=-2.5



 $\log \tau = -0.5$



 $\log \tau = -2.5$





log τ=-3.0 450 400 300 ^{ta} 250 200

 $\log \tau = -1.0$ 200







400

300

0

200 [w 200 [w 200 [m] 200 [m]

-100

-200

 $\log \tau = -3.0$

HINODE INVERSION - WILSON DEPRESSION (WIP)



CONCLUSIONS

- very fast image correction
- 3d inversion of Stokes profiles
- more potential applications
 - fast 2d inversion of IRIS spectra
 - inversions without response functions
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