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Deep Learning in Solar Astronomy

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Preface

Deep learning has been extensively developed in the last decade. It is regarded as the most promising approach for artificial intelligence (AI), triggering a revolution of entire field of computer science. The most successful examples include image classification, object detection, recognition, tracking, segmentation, natural language processing (NLP), and machine translation. Recently, we have witnessed the fast development of deep learning in astronomy, which is mostly concerned with big data processing, including filtering and archiving massive observation data, detecting/recognizing objects/events, forecasting astronomical events, imaging observational data, and image restoration.

Deep learning directly learns compact/compressed features from massive raw data, without need of prior knowledge, which is superior to handcrafted features in case prior knowledge is unavailable or unreliable. This is very common in astronomy, where most of the physical processes are unknown. It should be pointed that feature extraction from raw data is indispensable in machine learning; since raw data is tremendously high-dimensional, it is impossible to establish classification/regression model over such high-dimensional data. In addition, deep learning model is an end-to-end system without need of human intervention, which endows us with an affordable human labor consumption for manipulating massive data. Besides, deep learning could simultaneously mine implicit data knowledge from “on-site” data and exploit prior knowledge already verified through statistics, by using pre-trained model and adding constraints in loss function. Nowadays, modelling over massive data has been granted a fashionable name, data-driven. Deep learning has been repeatedly verified to be the most efficient technique for data-driven modelling. The classical deep learning models, such as AlexNet, VGG, ResNet and DenseNet, have already been well pre-trained on large-scale databases. For a specific application, a light-weight network and a few samples are sufficient for modelling. Recently, we have seen a popular usage of deep learning for exploiting both prior knowledge and data-driven, where a light-weight network was embedded into a backbone network to achieve higher efficiency than either of them separately used. Data-driven implies mining data knowledge underneath massive data. A single network cannot use the prior knowledge efficiently, while mining data

knowledge simultaneously. Thus, disentangling the two tasks can make independent optimization of them easier, by employing two sub-networks each of which is responsible for each task. For example, a lightweight subnetwork was embedded into a backbone network to realize super-resolution with both high-fidelity image content and elaborate gradients/edges.

Inspired by success of deep learning in computer vision, we investigated the applications of deep learning in solar big data processing: (1) object detection, e.g., sunspot, filament, active region, and coronal hole detection; (2) time series analysis, e.g., solar flare, solar radio flux, and CME forecasts; and (3) image generation, e.g., image deconvolution, deblur, desaturation, super-resolution, and magnetogram generation.

In this book, a comprehensive overview of the deep learning applications in solar astronomy, concerning concept and details of network design, experimental results, and competition with state of the art are reported and discussed for the first time. The content of this book comes from our previous publications and the latest progress on this topic. This book is expected to be a good reference for students and young researchers who are majoring in astronomy and computer science, especially the ones who are conducting interdisciplinary research.

The content of this book is arranged as follows. The first chapter gives a brief introduction of AI, deep learning, and big data of solar astronomy. The second chapter presents the classical deep learning models in the literature. Then, deep learning applications in solar astronomy are classified into four categories: classification, object detection, image generation, and forecasting, each of which is presented in a separate chapter, from the third chapter to the sixth chapter.

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Acronyms

AI	Artificial intelligence
SVM	Support vector machine
MAP	Maximum a posterior estimation
MLE	Maximum likelihood estimation
GCN	Graph convolutional network
FCN	Fully connected neural network
DBN	Deep belief network
RBM	Restricted Boltzmann machines
PCA	Principal component analysis
GRU	Gated recurrent unit
SGD	Stochastic gradient descent
BP	Back propagation
CNN	Convolutional neural network
GAN	Generative adversarial network
RNN	Recurrent neural network
LSTM	Long short-term memory
AE	Auto-encoder
R-CNN	Region-based convolutional neural network
YOLO	You only look once
RPN	region proposal network
CV	Computer vision
NLP	Natural language processing
HVS	Human vision perception system
DPM	Deformable part-based model
HOG	Histogram of oriented gradients
EUV	Extreme ultra-violent
AR	Active region
CME	Coronal mass ejection
PSNR	Peak signal to noise ratio
SSIM	Structural similarity index
SDO	Solar Dynamics Observatory

HMI	Helioseismic and Magnetic Imager
AIA	Atmospheric Imaging Assembly
SOHO	Solar and Heliospheric Observatory
MDI	Michelson Doppler Imager
EIT	Extreme ultraviolet Imaging Telescope
STEREO	Solar TERrestrial RELations Observatory
LASCO	Large Angle and Spectrometric COronagraph
SECCHI	Sun Earth Connection Coronal and Heliospheric Investigation
SKA	Square Kilometre Array
SBRS	Solar Broadband Radio Spectrometer
MUSER	MingantU SpEctral Radioheliograph
FAST	Five-hundred-meter Aperture Spherical radio Telescope
NASA	National Aeronautics and Space Administration
ESA	European Space Agency
NOAA	National Oceanic and Atmospheric Administration
SWPC	Space Weather Prediction Center of National Oceanic
JSOC	Joint Science Operations Center