SpringerBriefs in Computer Science

SpringerBriefs present concise summaries of cutting-edge research and practical applications across a wide spectrum of fields. Featuring compact volumes of 50 to 125 pages, the series covers a range of content from professional to academic.

Typical topics might include:

- A timely report of state-of-the art analytical techniques
- A bridge between new research results, as published in journal articles, and a contextual literature review
- A snapshot of a hot or emerging topic
- An in-depth case study or clinical example
- A presentation of core concepts that students must understand in order to make independent contributions

Briefs allow authors to present their ideas and readers to absorb them with minimal time investment. Briefs will be published as part of Springer's eBook collection, with millions of users worldwide. In addition, Briefs will be available for individual print and electronic purchase. Briefs are characterized by fast, global electronic dissemination, standard publishing contracts, easy-to-use manuscript preparation and formatting guidelines, and expedited production schedules. We aim for publication 8–12 weeks after acceptance. Both solicited and unsolicited manuscripts are considered for publication in this series.

**Indexing: This series is indexed in Scopus, Ei-Compendex, and zbMATH **

Long Xu • Yihua Yan • Xin Huang

Deep Learning in Solar Astronomy

Springer

Long Xu
NSSC
Chinese Academy of Sciences
Beijing, China

Yihua Yan
NSSC
Chinese Academy of Sciences
Beijing, China

Xin Huang
NSSC
Chinese Academy of Sciences
Beijing, China

ISSN 2191-5768 ISSN 2191-5776 (electronic)
SpringerBriefs in Computer Science
ISBN 978-981-19-2745-4 ISBN 978-981-19-2746-1 (eBook)
https://doi.org/10.1007/978-981-19-2746-1

This Springer imprint is published by the registered company Springer Nature Singapore Pte Ltd.
The registered company address is: 152 Beach Road, #21-01/04 Gateway East, Singapore 189721, Singapore

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.

Beijing, China Long Xu
Beijing, China Yihua Yan
Beijing, China Xin Huang
March 2022

Acknowledgments

This work was supported by the National Natural Science Foundation of China (NSFC) under Grants 11790301, 11790305, 11873060 and U1831121, the National Key R&D Program of China under Grant 2021YFA1600504, the Beijing Municipal Natural Science Foundation under Grant 1202022.

Contents

About the Authors

Long Xu received his PhD degree from the Institute of Computing Technology, Chinese Academy of Sciences (CAS), in 2009. He was selected into the 100-Talents Plan of CAS in 2014. From 2014 to 2022, he was with the National Astronomical Observatories, CAS. He is currently with both National Space Science Center, CAS and Peng Cheng Laboratory. His research interests include image/video processing, solar radio astronomy, wavelet, machine learning, and computer vision. He has published more than 100 academic papers, and also a book, titled Visual Quality Assessment by Machine Learning, with Springer in 2015.

Yihua Yan received his PhD degree from the Dalian University of Technology in 1990. He was a foreign research fellow with the NAOJ (Japan) from 1995 to 1996 and an Alexander von Humboldt Fellow with the Astronomical Institute, Wurzburg University, Germany, from 1996 to 1997. He was the President of IAU Division E: Sun and Heliosphere from 2015 to 2018. He was the director of the CAS Key Laboratory of Solar Activity (2008–2019) and the director of Solar Physics Division (2013–2021) at NAOC. He is currently a professor and chief scientist at the National Space Science Center, Chinese Academy of Sciences.

Xin Huang received his PhD degree from Harbin Institute of Technology in 2010. He was an associate professor at Solar Activity Prediction Center, NAOC, in 2013. Now, he is with the Space Environment Prediction Center, National Space Science Center, Chinese Academy of Sciences. His research interests include data mining, image processing, and short-term solar activity forecasting. He has published more than 20 academic papers, including one of the top 1% most cited papers in IOP Publishing's astrophysics journals, published over the period of 2018-2020.

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