AGU PUBLICATIONS

Space Weather

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Key Point:
- Machine learning, information theory, deep learning techniques, and methods have the potential to help solve important open questions in Space Weather

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Space Weather in the Machine Learning Era: A Multidisciplinary Approach

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Abstract The workshop entitled *Space Weather: A Multidisciplinary Approach* took place at the Lorentz Center, University of Leiden, Netherlands, on 25–29 September 2017. The aim of this workshop was to bring together members of the Space Weather, Mathematics, Statistics, and Computer Science communities to address the use of advanced techniques such as Machine Learning, Information Theory, and Deep Learning, to better understand the Sun-Earth system and to improve space weather forecasting. Although individual efforts have been made toward this goal, the community consensus is that establishing interdisciplinary collaborations is the most promising strategy for fully utilizing the potential of these advanced techniques in solving Space Weather-related problems.

The understanding of the complex, nonlinear nature of the solar-terrestrial system, and the related ability to forecast the effects of this connection at Earth, or Space Weather (SW), requires more advanced tools than those traditionally learned and used by space physicists. While the solar-terrestrial research community may not yet fully realize the potential of the tools designed to mathematically explore complex nonlinear systems, researchers from the fields of mathematics, information science, computer science, machine learning, and data mining are experienced with such sophisticated methods and are eager to apply them to challenging new problems.

With this backdrop, the workshop entitled *Space Weather: A Multidisciplinary Approach* was convened at the Lorentz Center in Leiden, Netherlands on 25–29 September 2017 (see workshop poster in Figure 1). Scientists from 13 countries with expertise ranging from space physics to statistics, computer science, information science, machine learning, data mining, and operational forecasting met to foster symbiosis, cross-fertilization, and convergent thinking. Although many of these topics are largely overlapping, they typically have different goals and use different mathematical tools. For instance, information science deals with understanding causality between observable or latent quantities by using entropy-based measures, data mining is concerned with untangling nontrivial patterns and correlations in large data sets, and machine learning builds predictive models (often using information theory and data mining).

The purposefully multidisciplinary team was tasked to develop strategies to more effectively address the stochastic nature of SW in future forecasting and to produce SW user-tailored products. The workshop team also engaged with decision-makers from the European Space Agency and the Netherlands government.

The workshop featured a mixture of invited talks, contributed talks, and posters that served to describe the current open problems/challenges in SW, introduce machine learning (ML) techniques, and present some of the efforts researchers are currently taking to bring these two subjects together.

Three main subjects stood out during these discussions: the exploitation of information theory, system science, and nonequilibrium statistical mechanics approaches to studying solar-terrestrial interactions; the use of pattern recognition, deep learning, and feature selection techniques, in absence of more physics-based models for forecasting certain SW conditions (e.g., occurrence and characteristics of solar flares, Coronal Mass Ejections, energetic particles; solar wind conditions at L1); and data mining techniques and ML methods in general for solving SW problems.

Self-organizing working groups formed during the week following an “unconference” format, focusing on specific, well-defined problems, which can be generally divided into the following:

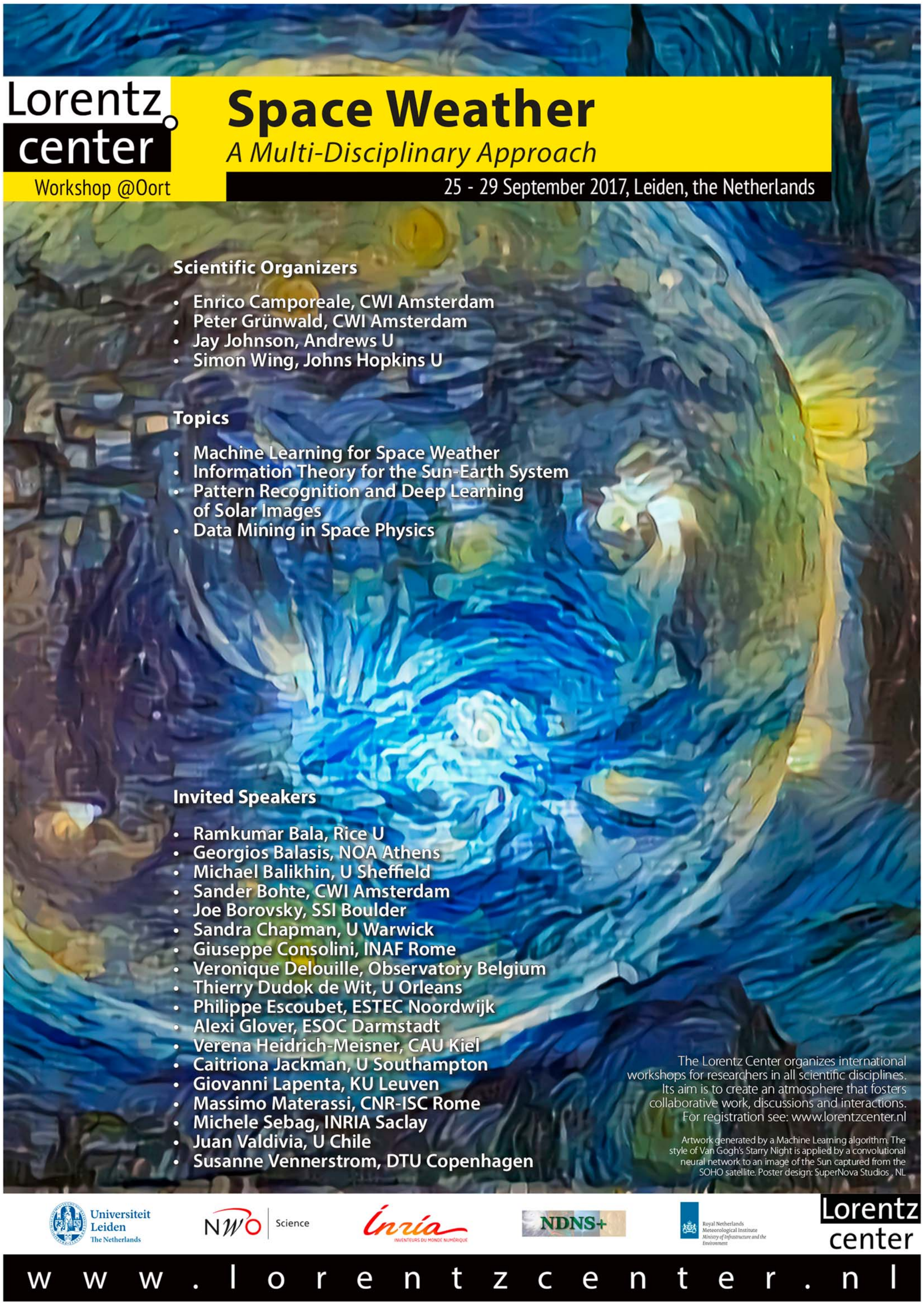

Figure 1. Aside from its applications in modeling and forecasting, Machine Learning can be used for fun. The workshop poster was generated by an Artificial Neural Network that applies the style of Van Gogh's "Starry Night" to an image of the Sun captured from the SOHO satellite.

1. Implementation and use of algorithms for automatically identifying events/features to be used in place of traditional, time-consuming, nonreproducible manual selection. These kinds of identification algorithms can, for example, help in correctly identifying magnetic reconnection in planetary magnetospheres,

coronal holes, coronal mass ejections, and features in solar active region imagery, which are useful for forecasting. In this case, techniques such as convolutional neural networks (CNN) have shown a great potential in helping with these tasks. CNNs are typically used in traditional image recognition thanks to their ability to extract features with an increasingly higher degree of abstraction. The core idea is based on the iterative application of small filters (convolutions, in mathematical terms) over many neural network layers (which makes the architecture "deep").

2. Knowledge discovery: methods to study causality and relationships within highly dimensional data and to cluster similar events, with the aim of deepening our physical understanding. Information theory and unsupervised classification algorithms fall in this category.
3. Space Weather forecasting: machine learning techniques capable of dealing with large class imbalances and/or significant data gaps to forecast important SW events from solar images, solar wind, and geospace in situ data.

One important outcome of the discussions between solar physicists and machine learning experts was the idea to craft and pose a Space Weather Grand Challenge to machine learning practitioners in the trending mold of Kaggle (kaggle.com). This will be a challenge open to the general public (typically with a modest monetary prize), with a well-defined objective (such as flares or geomagnetic index prediction), that would encourage to exploit the large amount of data freely available (in forms of solar images and in situ measurements). An initial design for such a challenge was crafted by the participants during the meeting and a coordinating committee to develop and deliver a final product was formed.

The format of the workshop encouraged small group discussions led to many exciting collaborations where space scientists contributed data and mathematical/information/computer scientists contributed tools/algorithm. These collaborations are expected to continue.

It was clear to attendees from all disciplines that Space Weather is a field ripe for Machine Learning. A general consensus was reached that progress will require multidisciplinary cooperation and the close integration of domain knowledge and technical expertise. One barrier to adoption of Machine Learning is the skills/jargon gap between the communities. Targeted workshops such as ours allow for the building of collaborations, and the identification of exciting paths forward. Increased funding and recognition of the immense promise in this interdisciplinary field by policy makers would allow us to realize its full potential.

Workshop materials will be available at http://bit.ly/2xblUEW.

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