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Report on the ESO Workshop

Artificial Intelligence in Astronomy

held at ESO Headquarters, Garching, Germany, 22–26 July 2019

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In July 2019, ESO hosted one of the first international workshops on artificial intelligence in astronomy, with the double aims of presenting the current landscape of methods and applications in astronomy and preparing the next generations of astronomers to embark on these fields. In addition to a wide range of review and contributed talks, as well as posters, the ~ 150 attendees could learn the techniques through several dedicated tutorials.

It is certainly an understatement that artificial intelligence (AI), i.e., intelligence demonstrated by machines, has taken the world by storm, with breakthroughs appearing in the news almost daily. Indeed, the incredible progress in computer power, the availability of large amounts of data and the ability to process them (even if they are unstructured), coupled to a theoretical understanding of techniques such as machine learning, and, more generally, data mining, have allowed AI to advance at a frantic rate, including in science. Astronomy is no exception. The sheer volume of astronomical data (which is increasing exponentially; see for example, Stoehr, 2019) necessitates a new paradigm. Data analysis must become, to a large extent, more automated and more efficient, in particular through AI. And this is indeed what is happening. A look at the NASA Astrophysical Data System shows that before 2005 only 21 refereed papers had "machine learning[a]" in their abstract. Since then the number has been multiplied by 41, with 663 papers published within the last five years, in an almost exponential way (there were twice as many published in 2018 than in 2017, for example).

As AI methods become more commonly used, a fundamental understanding of their limitations, assumptions, and performance is due. The rigour of the scientific process requires that such methods are applied with extreme care and to ensure that "the machine is being taught to take into account certain relevant known facts" (Griffin 2014). Moreover, the perspectives of information theory, neural science, and other areas on AI are expected to stimulate and guide the development of the next generation of intelligent methods used in astronomy and elsewhere. It was therefore thought to be an ideal time to host an international workshop on AI in astronomy. ESO organising such a workshop was important for several reasons, but perhaps less known is that ESO has had an interest in AI for a long time (for example, Adorf, 1991).

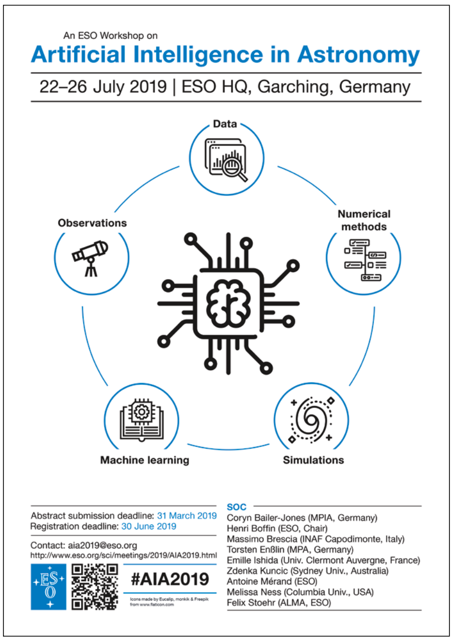

Figure 1. Conference poster.

Artificial intelligence covers a wide range of algorithms and methods. The first goal of the workshop was to provide a clear map by which to navigate this jungle and show which techniques are used for which kind of science. This was done in a few invited talks by prominent speakers to clearly set the scene. Laura Leal-Taixé provided an introduction to deep learning using computer vision and its application to autonomous driving as a clear example that will affect our lives more and more. She stressed the importance of increasing the diversity in the data, but also in the community which is building the algorithms, in order to avoid biases (that, in daily life, can be fatal). Emille Ishida showed the need for active learning in astronomy, as the basic assumption of supervised machine learning — that the training set is fully representative of the target sample — is often not fulfilled. It is thus essential that humans intervene in the process to enhance the efficiency of the learning. She stressed the need for optimised samples and algorithms for machine learning applications and that interdisciplinarity is the key, but also that serendipitous discoveries will only get more difficult with the next generation of large-scale surveys and it is therefore essential to plan for the unknown with adaptable algorithms. Alberto Krone-Martins presented the other way to achieve results in astronomy: with unsupervised learning, that is, essentially clustering and dimensionality reduction. These can be done through a variety of methods and it is important to know which one is best suited to a given problem. He presented several applications, such as how to find 101 new stellar clusters in the Milky Way or several lensed quasars thanks to Gaia or how to discover hundred of thousands of new galaxies by combining WISE and Gaia data. These results would have been hard, if not impossible, to obtain without the use of machine learning, but it is important to note that while unsupervised learning is powerful, it also requires some taming and a clear understanding of the limitations. That this is true was reviewed by Giuseppe Longo, who also explained that the use of these methods will lead to often unexpected results that make sense to humans only *a posteriori*. Dalya Baron showed in impressive fashion how one can mine for novel information in large and complex datasets using outlier detection and dimensionality reduction algorithms (Baron, 2019). Particularly impressive was how such techniques allowed astronomers to find a new correlation amongst active galactic nuclei.

Finding the right method is not an easy task and it is important to bring together experts from different fields.

Figure 2. Conference photo.

Mi Dai presented the Photometric LSST Astronomical Time series Classification Challenge (PLAsTiCC) and described how to involve the community at large and its thousands of machine learning experts via, for example, the Kaggle platform[2], to come up with the best algorithms to classify the very many transient sources that will be found by the Large Synoptic Survey Telescope. Similarly, Rafael de Souza presented the Cosmostatistics Initiative, an endeavour aimed at fostering interdisciplinary collaborations around astronomy and characterised by a residence programme.

It was also important to make sure that the ground covered by the workshop was as wide as possible. Accordingly, John Skilling spoke on how to do computation in big spaces, presenting the framework of inference, i.e. the Bayes therorem, and how the prior space is often much bigger than the small posterior space, leading to a lot of confusion. Only by reducing dimensionality can one hope to solve the problems. Jens Jasche showed how to perform large-scale Bayesian analyses of cosmological datasets, using computer programs and not analytic functions to perform a hierarchical Bayes analysis. This allows one, for example, to infer the mass density in a super-galactic plane or estimate galactic cluster masses. In the same vein, Torsten Enßlin presented both in a contributed talk and in a tutorial the fully Bayesian information field theory and the Numerical Information Field Theory (NIFTy) library[3].

Perhaps even further from what we usually see in astronomical conferences, Zdenka Kuncic presented a special, and quite inspiring, talk about emergent intelligence from neuromorphic complexity and synthetic synapses in nanowire networks. After presenting a brief history of AI, she showed that to reach the ultimate goal of general intelligence, one needs to move away from mainstream computing. She told us that companies are already developing sophisticated neuromorphic chips, which consume orders of magnitude less power than conventional processors and which try to emulate the brain. She also described how scientists and engineers are now creating biomimetic structures of nanowires that self-assemble into a complex, densely interconnected network, with a topology similar to a biological neural network and characterised by a collective memory.

This very impressive series of invited talks was complemented by numerous contributed talks and posters, covering the whole range of applications of AI methods in astronomy, from meteorite hunting to augmenting *N*-body simulations with deep learning models, through applications in adaptive optics. A poster competition was organised, and participants were asked to vote for the best posters. The three winners each received a mounted ESO image; they were: Philipp Baumeister (Using Mixture Density Networks to Infer the Interior Structure of Exoplanets); Timothy Gebhard (Learning Causal Pixel-Wise Noise Models to Search for Exoplanets in Direct Imaging Data); and Colin Jacobs (Using Deep Learning in the Cloud to find Strong Lenses).

As already indicated, there were also four three-hour tutorials and hands-on sessions that allowed the participants to delve directly into the techniques. These covered an introduction to machine learning using Python notebooks, machine learning and deep learning using disitributed frameworks and optimised libraries, and how to use NIFTy.

The workshop closed with a final discussion led by Torsten Enßlin which proved that AI is needed in astronomy and will be even more in the future, especially as we won't be able to store all the data and on-the-fly decisions will have to be made. It was also stressed that interdisciplinary teams are required, as well as a new kind of physicist who will have to be trained. The need to better understand the methods that are used was also stressed — as scientists, we shouldn't rely on "black boxes" and need to be very critical. This requires us to learn the language of the data scientists and the basic underpinning of the methods, such as Bayesian probability.

The workshop was a great success and participants praised the overall quality of the talks and tutorials, as well as of the abstract booklet[4]. Many were already hoping that a related workshop would take place next year! We therefore invite the community to organise such events as regularly as possible. The PDFs of all the talks and posters and the material of two of the three tutorials are available on the workshop webpage[1]. All in all, the talks, tutorials and posters covered a very wide range of topics in artificial intelligence and the workshop fulfilled its aim. The available material will surely be very useful for many years to come.

Demographics

The workshop had a very high level of participation, with about 130 registered participants coming from all parts of the world and approximately two dozen unregistered participants from ESO and neighbouring institutes, including several software engineers, highlighting the great interest generated by the topic.

The Scientific Organising Committee worked hard to ensure fair representation from the community. Among the 10 invited speakers, five were female. Three of the five sessions were also chaired by women. Among the abstracts submitted, a quarter were by women, and this was also the female/male ratio among the contributed speakers. We had a very high level of participation from young researchers, most likely due to a combination of a highly discounted registration fee for students and the fact that this field is relatively young. Thus, among the registered participants, we had 41% students, 22% postdoctoral researchers, and 37% tenure-track or tenured faculty. The talk selection was made blindly (the chair of the SOC removed names and identifying information about the authors, including their seniority and their affiliation), and was based solely on the merits of the abstract and its relation to the themes of the workshop. This resulted in 62% of the talks and 50% of the posters being given by students.

Acknowledgements

It is a great pleasure to thank the members of the Scientific Organising Committee (Coryn Bailer-Jones, Henri Boffin, Massimo Brescia, TorstenEnßlin, Emille Ishida, Zdenka Kuncic, Antoine Mérand, Melissa Ness, and Felix Stoehr) for setting up an amazing programme, the invited speakers for remarkable and clear reviews, and the organisers of the four tutorials (Patrick van der Smagt, Fabio Baruffa, Luigi Iapichino, Philipp Arras, Torsten Enßlin, Philipp Frank, Sebastian Hutschenreuter, and Reimar Leike) for their exceptional work. We especially thank Stella Chasiotis-Klingner for her efficient organisation of many practical aspects of the Workshop, as well as ESO catering and ESO logistics, for ensuring the best conditions during the meeting.

References

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Stoehr, F. 2019, ASPC, 387, 523

Notes

[a] Machine learning is one of the most commonly used subsets of AI.

Links

[1] Workshop website: https://www.eso.org/sci/meetings/2019/AIA2019.html
[2] The Kaggle platform website: kaggle.com
[3] Numerical Information Field Theory: http://ift.pages.mpcdf.de/nifty/
[4] 2019 AIA workshop programme: https://www.eso.org/sci/meetings/2019/AIA2019/Booklet_final.pdf

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Report on the IAU Conference

Astronomy Education — Bridging Research & Practice

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Astronomy education contributes to the spread of scientific literacy among successive generations, helping to attract students into science, technology, engineering and mathematics (STEM) subjects and potentially also into astronomy research. Although the field of research into astronomy education has grown significantly, the sustainable transfer from research institutes into the classroom is lacking. The goal of this conference was to bring together all stakeholders — teachers, educators and researchers — to communicate and discuss their various needs in order to effectively bridge the gap between astronomy education research and its practical application.

Astronomy is not only one of the oldest sciences, but also a perennially fascinating one to the broader public, who often ask educators questions such as, “where do we come from?”, or “are we alone?” For this reason, astronomy has always been a relatively easy area of science to convey to the public and it can serve as a gateway to other scientific concepts, especially in young people.

Astronomy therefore plays a special role within public science communication. The literature is full of suggestions and advice about how to best communicate astronomy to the public. Astronomy education or teaching astronomy is different from communication, however. Whereas communication and outreach are processes aimed at generating inspiration and awareness, education aims to develop knowledge, skills and competences, and core values and attitudes through a range of pedagogies and methodologies that account for the abilities and development level of the learner. Astronomy education is less prominent within the scientific community than