Booklet

Artificial Intelligence in Astronomy

22 – 26 July 2019 | ESO HQ, Garching, Germany

WELCOME TO AIA2019

—

Presenting the current landscape of machine learning methods and applications in astronomy, and preparing the next generations of astronomers to embark on these fields.

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SOC & LOC

SOC:
Coryn Bailer-Jones (MPIA, Germany)
Henri Boffin (ESO; Chair)
Massimo Brescia (INAF Capodimonte, Italy)
Torsten Enßlin (MPA, Germany)
Emille Ishida (Univ. Clermont Auvergne, France)
Zdenka Kuncic (Sydney Univ., Australia)
Antoine Mérand (ESO)
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MONDAY

07

PROGRAMME

09:00 – 09:20	—	*Welcome*
09:20 – 10:00	—	**What is Deep Learning and what can it do for you ?** Laura Leal-Taixé
10:00 – 10:20	—	Meteorite Hunting using Deep Learning Aisha Alowais
10:20 – 10:40	—	Image in science out: a proof of concept with deep learning on molecular cloud simulations Mario Pasquato
10:40 – 11:20	—	*Coffee Break*
11:20 – 12:00	—	**Human in the loop - Active Learning in Astronomy** Emille Ishida
12:00 – 12:20	—	Deep learning for the selection of YSO candidates from IR surveys David Cornu
12:20 – 12:40	—	Unraveling interior evolution of terrestrial planets using Machine Learning Siddhant Agarwal
12:40 – 14:00	—	*Lunch*
14:00 – 14:20	—	Recognition of total eclipses in binaries with computer vision Olivera Latkovic
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14:40 – 15:00	—	SuperNNova : Bayesian Neural Network light-curve classification Anais Möller
15:00 – 18:00	—	**Tutorial :** Introduction to Machine Learning with Intel® Software tools
18:00 – 19:00	—	*Beer & Brez'n : Poster Viewing*

INVITED TALK

What is Deep Learning and what can it do for you ?

Laura Leal-Taixé
Technische Universität München

In this talk, I will cover the basics of Deep Convolutional Neural Networks and their applications in image classification, object segmentation and video processing. I will also present some of the current work in my group and how we use Deep Learning to tackle various Computer Vision tasks.

Meteorite Hunting using Deep Learning

Aisha Alowais
University of Sharjah

Expeditions for meteorite hunting could be long and time consuming if metal and thermal detectors were used to find them. Moreover, the UAE desert makes a perfect environment for hunting them due to the clear contrast between the sand and the meteorite itself. With the advent of new AI techniques like Deep Learning (DL), meteorite detection can be greatly enhanced. Our meteorite detection system employs a drone carrying a Single Board Computer (SBC), an optical camera, and a GPS shield. The SBC involves analyzing each video frame and running it through our DL model via Transfer Learning performed on Convolutional Neural Networks (CNN). Data augmentation was performed on the meteorites and meteor-wrongs (false detections) datasets, and later on used for training. The system is tested on a number of samples and it was able to recognize meteorites with a positive accuracy result of ~90%. Future developments include the addition of an infra-red camera to capture thermal images.

Image in science out: a proof of concept with deep learning on molecular cloud simulations

Mario Pasquato
Padua Observatory (INAF)

I present an application of deep convolutional neural networks to the measurement of the turbulence index of molecular clouds based on projected density maps. Our group built a deep CNN to perform regression on images generated by hydrodynamical simulations of turbulent gas motion. I discuss the results of prediction on an unseen holdout dataset, and discuss the difficulties that we need to overcome for application to real observational data. The framework used is Keras (on top of Tensorflow).

INVITED TALK

Human in the loop – active Learning in Astronomy

Emille Ishida
CNRS/LPC-Clermont

The full exploitation of the next generation of large scale photometric supernova surveys depends heavily on our ability to provide a reliable early-epoch classification based solely on photometric data. In preparation for this scenario, there has been many attempts to apply different machine learning algorithms to the supernova photometric classification problem. Although different methods present different degree of success, text-book machine learning methods fail to address the crucial issue of lack of representativeness between spectroscopic (training) and photometric (target) samples. In this talk I will show how Active Learning (or optimal experiment design) can be used as a tool for optimizing the construction of spectroscopic samples for classification purposes. I will present results on how the design of spectroscopic samples from the beginning of the survey can achieve optimal classification results with a much lower number of spectra than the current adopted strategy.

Deep learning for the selection of YSO candidates from IR surveys

David Cornu
Institute UTINAM / Univ. Franche-Comté

The robust identification of YSOs is an important step for characterizing star-forming regions. They are typically observed in the IR domain where they can be extracted from various other types of sources. Such classification is commonly performed using straight cuts in CMDs diagrams obtained in this domain. However, Machine Learning algorithms may outperform these methods with adaptive and non-linear separations in any number of dimensions.

Unraveling interior evolution of terrestrial planets using Machine Learning

Siddhant Agarwal
Deutsches Zentrum für Luft- und Raumfahrt

Understanding the thermal evolution of terrestrial planets requires computationally-intensive convection models. These models are constrained by spacecraft- and telescope-based observations such as magnetic fields, surface topography, and composition. Yet, the problem of inferring the interior evolution from surface observables is severely under-determined: a large number of parameters and initial conditions are poorly known and need to be systematically varied. We use Mixture Density Networks (Bishop 1995) to invert the observables for several Mars-like thermal evolution simulations to constrain viscosity parameters and the initial temperature of the mantle. We quantify the extent to which different combinations of parameters constrain each parameter. Inference of initial temperature, for example, requires radial contraction with at least one other parameter such as elastic lithospheric thickness.

Recognition of total eclipses in binaries with computer vision

Olivera Latkovic
Astronomical Observatory of Belgrade

A total eclipse in the light curve of an eclipsing binary is a phenomenon easily recognizable by humans, but not trivial to establish from data. In attempting to automate the modeling of binaries, we also had trouble predicting total eclipses from model parameters. A totality will occur at a high enough orbital inclination, but relative sizes of the stars and their temperature distributions influence what is high enough, making it hard to derive robust analytical conditions. We are testing machine learning methods, and the most promising so far is image recognition. Trained with hundreds of simulated images of light curves with partial and total eclipses, computer vision achieved very good results in our first tests. While not the most efficient, this method has the advantage of needing no preprocessing of the observations. Plus, it might provide insights for tackling more complex tasks with computer vision, like light curve classification of variable stars from massive survey data.

Data Mining in Hubble's archive to find extrasolar systems

Elodie Choquet
Laboratoire d'Astrophysique de Marseille

The direct detection and characterization of extrasolar systems is a long-standing technical challenge. It requires complex instruments with exquisite control of the wavefront and optimized coronagraphs, as well as dedicated observing strategies and aggressive image processing to reveal exoplanets and circumstellar dust at high contrast to their host star. Hubble was equipped early-on with an near-IR coronagraphic instrument, NICMOS (1997 - 2008), which enabled the discovery of 5 bright debris disks during its operations. Yet, because of the telescope thermal variations and of limitations to implement efficient observing strategies, it did not succeed in reaching the contrast limits required for exoplanet detections. I will present how we used the NICMOS archives (data mining?) to improve these detection limits and discover a zoo of faint debris disks in their midst.

SuperNNova Bayesian Neural Network light-curve classification

Anais Möller
CNRS / LPC Clermont

In the era of time-domain surveys, automated light-curve classification has become an area of intensive research. SuperNNova is an open source photometric classification framework that leverages the power of Recurrent Neural Networks. Using supernova simulations, we obtain classification accuracies >84% for events with a handful photometric observations and >96% for complete light-curves. Our algorithm is able to accurately classify multiple classes of supernovae within seconds. SuperNNova can be trained in a principled, Bayesian way and yield calibrated predictions with sensible uncertainty estimates. Using supernova cosmology as an example, I will discuss the impact of often neglected pitfalls of machine learning algorithms and present tests to evaluate classifier robustness. These include assessing prediction calibration and model uncertainties. This is particularly important where training samples are incomplete and predictions may be requested for out-of-distribution events.

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TUESDAY

07

PROGRAMME

09:00 – 09:40	—	**Unsupervised Learning** Alberto Krone-Martins
09:40 – 12:40	—	**Tutorial :** Machine Learning: an introduction in Python notebooks
12:40 – 14:00	—	*Lunch*
14:00 – 14:20	—	Classifying Exoplanet Candidates with CNNs: Applications to the NGTS Aleksandar Chaushev
14:20 – 14:40	—	Automated Classification of eROSITA's Transient and Variable Sources Adam Malyali
14:40 – 15:00	—	Machine learning techniques to classify transients using LSST: a proof of concept using MeerLICHT Johannes Petrus Marais
15:00 – 18:00	—	**Tutorial :** Deep Learning at Scale using Distributed Frameworks
18:00 – 19:00	—	*Beer & Brez'n : Poster Viewing*

INVITED TALK

Unsupervised Learning

Alberto Krone-Martins
Universidade de Lisboa

Astronomical surveys in the 21st Century are producing an enormous wealth of data, resulting in significant opportunities for studying the known and exploring the unknown frontiers of the Universe. But how to do this? How to look for objects and phenomena when these objects and their properties are ill-defined or not defined yet? One possible answer is the adoption of unsupervised learning.

In this talk I will first review the fundamentals of how to learn in the absence of labeled data, and how this relates to data clustering, dimensionality reduction, data compression and density estimation. Then I will show some astronomical applications of unsupervised learning and I will comment on how we can profit from such methods, either by adopting them as an extension of our thought process during interactive data exploration, or by wrapping them inside larger methods and software systems built for instance to discover new objects; stellar clusters, galaxies and multiply-imaged and gravitationally lensed quasars searches will be used as examples.
Finally, I will comment on some heuristics developed to enable these approaches to tackle large datasets, as online and continuous learning directly from data streams.

Classifying Exoplanet Candidates with CNNs: Applications to the NGTS

Aleksandar Chaushev
Technical University of Berlin

The Next Generation Transit Survey (NGTS) is a ground based experiment aiming to detect Neptune and Super-Earth sized planets around bright host stars. A key part of the detection pipeline is the manual vetting of candidates which, with 190,000+ potential detections, is a slow and time-consuming process. We show that a convolutional neural network (CNN) is effective at removing 90% of false positives while recovering 92% of known planets in the data. A comparison between our extensive database of candidate flags and the CNN shows good agreement, with candidates at a later stage in the vetting process receiving higher probabilities. We also show that the training dataset composition can be altered to reduce the number of labelled lightcurves required, a key bottleneck, while improving the overall classification accuracy. Future work will focus on improving the precision and adding information to help identify blended targets, improvements which are readily applicable.

Automated Classification of eROSITA's Transient and Variable Sources

Adam Malyali
Max Planck Institute for Extraterrestial Physics

eROSITA on-board the SRG satellite will perform the next large X-ray all-sky survey. With its 30-fold increased sensitivity relative to its predecessor ROSAT and its multi-visit, multi-cadence survey strategy, eROSITA will provide a new and deeper look into X-ray time domain astrophysics. To better handle the vast number of sources eROSITA is expected to detect, and assist with planning multi-wavelength follow-up, we are developing a pipeline (that operates in near-real time during the all-sky survey) for automated classification of the transient and variable source populations. We present an overview of this pipeline, and discuss the challenges of developing machine learning algorithms for classification of eROSITA's variable sources, where the only training datasets available are non-representative and biased.

Machine learning techniques to classify transients using LSST: a proof of concept using MeerLICHT

Johannes Petrus Marais
University of the Free State

The Large Synoptic Survey Telescope (LSST) currently under construction in Chile is expected to produce 10 million transient alerts every night during the 10 year survey mission. Hidden in this massive amount of data, new and novel transient classes are waiting to be discovered. Machine learning approaches will provide the most robust detection of these new classes. To prepare for the arrival of the LSST, we will be investigating different machine learning classifiers to evaluate their performance in detecting and classifying variable stars in the Magellanic Clouds, using data obtained from the MeerLICHT telescope located at the South African Astronomincal Observatory, South Africa. We present the outlined aims and objectives, as well as the preliminary results from this project.

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WEDNESDAY

07

PROGRAMME

09:00 – 09:40	—	**Artificial intelligence in Astronomy – successes and open problems** Giuseppe Longo
09:40 – 10:20	—	**The Photometric LSST Astronomical Time-Series Classification Challenge (PLAsTiCC)** Mi Dai
10:20 – 10:40	—	Bioinspired Computation in Astrophysics Ivan Zelinka
10:40 – 11:20	—	*Coffee Break*
11:20 – 11:40	—	Modern Neural Networks: A Pathway to Better Adaptive Optics Alison Wong
11:40 – 12:00	—	Machine learning based atmosphere prediction for extreme adaptive optics Markus Bonse
12:00 – 12:20	—	MaxiMask: A new tool to identify contaminants in astronomical images using convolutional neural networks Maxime Paillassa
12:20 – 12:40	—	Background prediction on astronomical images with deep learning Laura Cabayol García
12:40 – 14:00	—	*Lunch*
14:00 – 14:40	—	**Mining for novel information in large and complex datasets** Dalya Baron
14:40 – 15:00	—	Stellar Formation Rates for photometric samples of galaxies using machine learning methods Michele Delli Veneri
15:00 – 15:40	—	*Coffee Break*
15:40 – 16:20	—	*Poster Viewing*
	—	*Free Afternoon*

INVITED TALK

Artificial intelligence in Astronomy successes and open problems

Giuseppe Longo
University of Napoli Federico II

Artificial intelligence covers a quite ill defined spectrum of specialistic domains encompassing among the others also Machine Learning and its most recent subfield: Deep learning. In the last few years the number of groups working in the field as well as the amount of publications based on these new methodology has exploded.
In spite of such growth, however, many aspects and methods still remain almost unexplored by the astronomical community (e.g. transfer learning, imputation, etc.)
The talk will present a review of some ongoing efforts in the application of Machine Learning methods to astronomical problems listing some of the most relevant recent contributions and the main problems which still remain to be solved.

INVITED TALK

The Photometric LSST Astronomical Time-Series Classification Challenge (PLAsTiCC)

Mi Dai
Rutgers, The State University of New Jersey

The Photometric LSST Astronomical Time-Series Classification Challenge (PLAsTiCC) was a data challenge to classify astronomical transients and variables that will be observed by the Large Synoptic Survey Telescope (LSST). Photometric classification of the varying objects in the sky is important for many science cases. It becomes even crucial with the huge amount of data that LSST is going to observe and the limited resources for getting spectroscopic types. With PLAsTiCC, we aimed to generate realistic simulations that represents the challenges we face, and engage the data science community to develop novel methods for solving the problem. The public challenge was hosted on Kaggle – a public data science platform from September 28, 2018 to December 17, 2018. We'll describe the data generation and validation, what we learnt from hosting a public challenge, and interesting results that came out of the challenge.

Bioinspired Computation in Astrophysics

Ivan Zelinka
VŠB-TUO

This talk discusses the use of so-called bioinspired algorithms in astrophysics data processing and mathematical model synthesis. Three classes of the bioinspired algorithms belonging to soft computing area discussed here together with its applications on the Solar activity prediction and classification model synthesis on astrophysical data obtained from the robotic telescope.

Modern Neural Networks: A Pathway to Better Adaptive Optics

Alison Wong
University of Sydney

Ground based telescopes rely heavily on adaptive optics (AO) to overcome atmospheric seeing. AO has already seen huge success, but the advent of modern machine learning offers scope for further improvement. Early attempts to apply neural networks (NNs) to AO systems were met with limited success. However, advances in computer performance, the rise of deep learning, improvement in NN performance and the emergence of more complex networks, such as recurrent NNs (RNNs) and convolutional NNs (CNNs), demand that we revisit this task. I will present our current research into the application of NNs in wavefront prediction. NNs and RNNs extend current predictive control as they can model non-linearities and long term temporal behaviours. NNs are also well suited to combining information from multiple sources, thereby providing the means for sensor fusion in wavefront prediction. We also find NNs and CNNs can predict the point spread function in real time from wavefront data.

Machine learning based atmosphere prediction for extreme adaptive optics

Markus Bonse
TU Darmstadt

The most significant term in the extreme adaptive optics error budget is the temporal bandwidth error which represents the ultimate limit to the sensitivity of ground-based imaging of exoplanets. With the commonly used integrator control law, the system is always slightly lagging behind the measured evolution of the turbulence leading to imperfect corrections. Algorithms have been proposed to predict the atmosphere based on a recent block of wavefront measurements in order to pre-compensate the wavefront before the measurement. While on simulations these algorithms have shown great potential to reduce the temporal error, their application on sky still remains challenging. We illustrate how Convolutional LSTM Networks can be adapted to the problem and motivate three fundamental constrains based on the frozen flow hypothesis to improve prediction robustness. Experiments on real data from SPHERE demonstrate a ~30% better performance over previously proposed predictors in terms of rms.

MaxiMask: A new tool to identify contaminants in astronomical images using CNN

Maxime Paillassa
Laboratoire d'Astrophysique de Bordeaux

In this work, we propose to use convolutional neural networks to detect contaminants in astronomical images. Once trained, our networks are able to detect various contaminants, encompassing a broad range of ambient conditions (seeing), PSF sampling, detectors, optics and stellar density. MaxiMask performs semantic segmentation and can output a probability map for each contaminant, assigning to each pixel the probability to belong to the given contaminant class. Tracking errors are detected using a second convolutional neural network. Training and testing data are gathered from real data originating from various ground-based imagers and from image simulations. We show that MaxiMask achieves good performance on test data and that its behavior can be further optimized for other instrumental contexts with a simple set of priors.

Background prediction on astronomical images with deep learning

Laura Cabayol García
IFAE

The PAU Survey (PAUS) is an imaging survey using a 40 narrow-band filter camera, named PAUCam. Images obtained with the PAUCam suffer from scattered light: an optical effect where light appears where it is not intended to be. Scattered light is not a random effect, it can be predicted and corrected for. Nevertheless, currently, around 8% of the PAUS flux measurements are flagged as scattered light affected and removed.
Moreover, failures to flag scattered light result in photometry and photo-z outliers. With the aim of understanding and predicting scattered light, we have built BKGnet, a deep neural network for background prediction. BKGnet is trained with 120x120 pixel stamps and their corresponding positions on the CCD. To benchmark the BKGnet performance, we have developed a skyflat correcting method to remove the effect of scattered light on images. On PAUCam images on the COSMOS field, we get a 28% improvement on average with BKGnet compared with the skyflat correction method.

Stellar Formation Rates for photometric samples of galaxies using machine learning methods

Michele Delli Veneri
INAF - Osservatorio Astronomico di Capodimonte

Stellar Formation Rates or SFRs are crucial to constrain theories of galaxy formation and evolution. SFRs are usually estimated via spectroscopic observations requiring large amounts of telescope time. We explore an alternative approach based on the photometric estimation of global SFRs for large samples of galaxies, by using methods such as automatic parameter space optimisation, and supervised Machine Learning models. We demonstrate that, with such approach, accurate multi-band photometry allows to estimate reliable SFRs. We also investigate how the use of photometric rather than spectroscopic redshifts, affects the accuracy of derived global SFRs.

INVITED TALK

Mining for novel information in large and complex datasets

Dalya Baron
Tel Aviv University

Astronomy is experiencing a rapid growth in data size and complexity. As surveys become larger and deeper, we face unprecedented data volumes which challenge the classical methods with which we extract information. This challenge is not only due to the data volume, but also due to its complexity, where the combination of different surveys often provides a multi-temporal and multi-wavelength view of astronomical objects. How can we extract novel information and detect new physical phenomena in these large complex datasets? Dimensionality reduction and outlier detection algorithms, which are unsupervised machine learning algorithms, can be used to extract the most relevant information and detect new phenomena in large and complex datasets. In this talk I will give an overview of such state-of-the-art tools and their application to astronomical datasets. I will finish by discussing some of the open questions and current challenges that we face in the field.

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THURSDAY

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PROGRAMME

09:00 – 09:40	—	**Computation in big spaces** John Skilling
09:40 – 10:00	—	Quasar and galaxy classification in Gaia DR 2 Coryn Bailer-Jones
10:00 – 10:20	—	Searching for what no one is looking for Sebastian Ratzenböck
10:20 – 10:40	—	New catalogue of Pre-Main Sequence objects using AI Miguel Vioque
10:40 – 11:20	—	*Coffee Break*
11:20 – 11:40	—	Mapping the Milky Way Galaxy with Deep Learning Henry Leung
11:40 – 12:00	—	Comparing Performance of Machine Learning Algorithms for Galaxy Classification Fuat Korhan Yelkenci
12:00 – 12:20	—	Machine Learning as a Service - Application of Google Cloud Platform to Machine Learning problems Marco Landoni
12:20 – 12:40	—	Information field theory Torsten Enßlin
12:40 – 14:00	—	*Lunch*
14:00 – 15:00	—	**Emergent Intelligence from Neural Network Hardware** Zdenka Kuncic
15:00 – 18:00	—	**Tutorial :** Numerical Information Field Theory - turning data into images the Bayesian way
19:00	—	*Social Dinner*

INVITED TALK

Computation in big spaces

John Skilling
Maximum Entropy Data Consultants, Kenmare, Ireland

Modern problems involve big data and big spaces, and attract a variety of computational techniques. There is a need for a normative framework that can bring these efforts into a coherent framework. Nested sampling provides such a framework. By shifting viewpoint from Riemannian integration (try to look at every place) to Lebesgue (try to look at every value), multidimensional problems become coded in one-dimensional terms. That offers theoretical simplicity as well as practical generality and power.

Quasar and galaxy classification in Gaia Data Release 2

Coryn Bailer-Jones
Max Planck Institute for Astronomy

We construct a classifier based on Gaussian Mixture Models to probabilistically classify objects in Gaia data release 2 (GDR2) using only photometric and astrometric data in that release. The model is trained empirically to classify objects into three classes – star, galaxy, quasar – using eight features (magnitude, latitude, parallax, proper motion, two colours, photometric variability amplitude, uwe) for G=13-20.7. Even when allowing for the fact that quasars and galaxies are expected to be much rarer than stars (the class imbalance problem), we expect to classify quasars with a completeness of 0.77 and purity of 0.73. Performance on galaxies is poorer – completeness of 0.47 and purity of 0.56 – but surprisingly good considering the limited features used. Not accounting for the low expected frequency of extragalactic objects (the class prior) would give both erroneously optimistic performance predictions and unreliable classification results. Applying our model to 1.22 billion objects in GDR2, we identify 3.6 million quasars and 0.7 million galaxies (classified with a probability greater than 0.5). Galaxies are rarer because GDR2 is biased towards point sources. We provide class probabilities, so it is easy to adjust our results to correspond to a different class prior and to construct samples with a desired completeness or purity (within limits). The quasar sample is rather robust to perturbations of the model training. The galaxy sample is more sensitive, and also shows particular stellar contaminants, although some of these can be removed post-hoc with cuts on the data.

Searching for what no one is looking for

Sebastian Ratzenböck
University of Vienna

Gaia's second data release constitutes a massive set of photometric data covering magnitudes of G=21 to G≈3 together with unprecedented positional measurements. This catalog of roughly 1.69 billion sources provides the opportunity to use statistical learning techniques in order to uncover what no one is looking for: potentially new classes of objects, new Galactic structure, and new physics. However, due to the sheer size of the data, a wide variety of common clustering techniques cannot be deployed on a single machine. Additionally, scalable algorithms such as k-Means face difficulties capturing the non-linearities present in the data. Here we present a selection of different approaches tackling these issues of scalability and non-linearity. These include sophisticated feature engineering and deploying autoencoder networks in order to construct feature spaces more suitable for scalable clustering algorithms.

New catalogue of Pre-Main Sequence objects using AI

Miguel Vioque
University of Leeds

Gaia Data Release 2 has greatly increased the number of sources with an astrometric solution available. In combination with other catalogues, it constitutes a splendidly big data breeding ground for applying Machine Learning techniques and algorithms. We present our results discovering Pre-Main Sequence objects within Gaia DR2, AllWISE and the IPHAS and VPHAS+ catalogues, spanning all the mass range visible in the optical by using a combination of different Machine Learning algorithms.

Mapping the Milky Way Galaxy with Deep Learning

Henry Leung
University of Toronto

Gaia has revolutionized Galactic astronomy, but mysteries still have not been solved due to the lack of precise distance to stars from the center to the edge of MW. Large spectroscopic surveys like APOGEE-2 are providing big spectroscopic data sets covering a large volume of the MW and future projects like SDSS-V Galactic Genesis program will produce a spectroscopic stellar map densely sampled across the entire sky. Spectra contain information about the stars including their abundances and luminosity and modern deep learning technique excels at determining the complex relations between input (spectra) and output (abundance, luminosity..) We have shown that neural network trained on the Gaia DR2 '96 APOGEE DR14 overlap can produce high precision spectro-photometric distances beyond where Gaia delivers precise parallaxes. I will discuss this application of deep learning to stellar distance measurement and present applications to studying the structure of the inner MW using these distances.

Comparing Performance of Machine Learning Algorithms for Galaxy Classification

Fuat Korhan Yelkenci
Istanbul University

With new, wide and big data of galaxies, now working on galaxy classification has been moved to a different level. Machine learning algorithms are also used to classify galaxies precisely. We compare the performance of several machine learning algorithms for galaxy morphologies obtained with parametric methods.

Machine Learning as a Service Application of Google Cloud Platform to Machine Learning problems

Marco Landoni
INAF - National Institute of Astrophysics

The availability of data to astronomers is increasing exponentially every day and a strong synergy between machine learning (ML) algorithms, Big Data and proper computational environment is mandatory. In this context, Cloud Platforms could make a difference allowing to exploit the proper tools of the Data Science while offering the right computational environment for Machine Learning inferences in a BigData fashion just with few clicks. I will review how the Google Cloud Platform could enable astronomers to take the advantages of machine learning (in BigData regime) in an «as-a-service» fashion (MLaaS). I will illustrate the offered tools starting from the data preparation and Data Cleaning (Cloud Dataprep) and off-the shelf machine learning algorithms both for classification and regression problems. The focus of this contribution will be oriented in order to let the people aware of what kind MlaaS services are available and how to exploit them for real astronomer's

Information field theory - machine learning with a knowledge driven network design

Torsten Enßlin
Max-Planck-Institut für Astrophysik

Information field theory (IFT), the information theory for fields, is a mathematical framework to derive optimal Bayesian algorithms for imaging and signal reconstruction, which take domain knowledge explicitly into account. IFT methods have been applied across the full electromagnetic spectrum in astrophysics and cosmology. The resulting algorithms can be understood as neural networks with a design that directly implements physical knowledge. Thereby, the need to train an IFT method before it is operable is alleviated.

SPECIAL TALK

Emergent intelligence from neuromorphic complexity and synthetic synapses in nanowire networks

Zdenka Kuncic
University of Sydney

Neuromorphic computing is an emerging area that aims to integrate neuro-inspired hardware and software – i.e. implementing artificial neural networks onto neuromorphic computing architecture. Such hardware is realized through advances in nanotechnology, resulting in new nano-electronic device components that can meet the increasingly demanding requirements of AI software for computational density and energy efficiency. The human brain, however, is more than just a computer – it possesses general intelligence. This property alone is the "holy grail" of AI research. A completely different approach to the quest for general intelligence is to consider hardware itself; the brain, after all, is a physical device, so in principle we should be able to build a similar device that produces similar intelligence. In this talk, I will present an overview of current efforts towards demonstrating the physical nature of intelligence. In particular, I will present and discuss a physical system comprised of nanowires that self-assemble (like a biological system) into a complex network with junctions that behave like synapses in response to electrical stimulation. Moreover, the density of these synthetic synapses is orders of magnitude higher than can be achieved with conventional electronic circuitry. The neuromorphic structure and function of such nanowire networks are inextricably linked, with the system complexity giving rise to emergent neural-like dynamics such as collective memory, recurrence and criticality, all of which are hallmarks of intelligence arising from biological neural networks.

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FRIDAY

07

PROGRAMME

09:00 – 09:40	—	**Cosmostatistics Initiative: how to catalyse interdisciplinarity** Rafael S. de Souza
09:40 – 10:20	—	**Large Scale Bayesian Data Interpretation in Cosmology** Jens Jasche
10:20 – 10:40	—	
10:40 – 11:20	—	*Coffee Break*
11:20 – 11:40	—	Extracting Meaningful Features from Early-Science Radio Data Matthew Alger
11:40 – 12:00	—	Deriving Constraints on Quasar Lifetime and Obscuration Using Likelihood-Free Inference Tobias Schmidt
12:00 – 12:20	—	Detecting and characterizing interstellar structures with Machine Learning methods Dominic Bernreuther
12:20 – 12:40	—	*Group Photo*
12:40 – 14:00	—	*Lunch*
14:00 – 14:20	—	Painting with baryons: augmenting N-body simulations with gas using deep generative models Tilman Troester
14:20 – 14:40	—	Testing a cosmological galaxy simulation with unsupervised clustering Sebastian Turner
14:40 – 15:10	—	*Final Discussion*
	—	*End of Workshop*

INVITED TALK

Cosmostatistics Initiative: how to catalyse interdisciplinarity

Rafael S. de Souza
University of North Carolina

Although the division of scientific disciplines enables each field to specialise on its own pace, all sciences belong to a greater scheme, making any division ultimately artificial. The purpose of science is to understand a world which is inherently complex and, as such, intangible by any particular discipline alone.

We are now facing a situation where interdisciplinarity is required to fully exploit contemporary data structures. During this talk, I will describe my experience in building an interdisciplinary community – the Cosmostatistics Initiative (COIN).

COIN was founded in 2014 with the goal of overcoming the cultural barriers preventing the daily collaboration between researchers from different fields. Since its conception, COIN has grown to more than 60 researchers from six continents, from fields as diverse as astrophysics, statistics, computer science, epidemiology, biostatistics, and medical sciences.

The discussion will be followed by examples of how customized statistical models enables scientific advances. This includes the discovery of 41 stellar open clusters (OC) in the solar neighbourhood (COIN-Gaia OCs), and the development of a recommendation system for supernovae spectroscopic follow-up.

INVITED TALK

Large Scale Bayesian Data Interpretation in Cosmology

Jens Jasche
Stockholm University

The recently established phenomenological standard model of cosmology successfully passes the bulk of cosmological tests but falls short in providing physical insights into the origin of cosmic structure, the accelerating cosmic expansion and dark matter. In order to gain more fundamental cosmological insights the community currently invests into major next-generation galaxy surveys. However, progress in the field critically depends on our ability to connect theory with observation and to infer relevant cosmological information from next-generation data. State-of-the-art data analysis methods focus on extracting information only from a limited number of statistical summaries but ignore significant information entailed in the complex filamentary distribution of cosmic matter.

To go beyond classical approaches, in this talk I will present a novel Bayesian physical forward modelling approach aiming at extracting the full physical plausible information content from cosmological large scale structure data. This approach infers 3D initial conditions from which observed structures originate, maps non-linear density and velocity fields, and provides dynamic structure formation histories including a detailed treatment of uncertainties. A hierarchical Bayes approach paired with an efficient implementation of a Hamiltonian Monte Carlo sampler permits to account for various observational systematic effects while exploring a multi-million-dimensional parameter space.

The method will be illustrated through various data applications providing an unprecedented view of the dynamical evolution of structures surrounding us. Inferred mass density fields are in agreement with and provide complementary information to gold-standard gravitational weak lensing and X-ray observations. Further, the method promises to significantly improve cosmological parameter constraints by exploiting the geometric information entailed in observed galaxy distributions. These results demonstrate that a full characterization of the spatial state and its dynamical evolution of our Universe is becoming feasible.

Extracting Meaningful Features from Early-Science Radio Data

Matthew Alger
The Australian National University

Early-science data from the Australian Square Kilometre Array Pathfinder (ASKAP) are coming fast. Wide-area radio projects such as the Evolutionary Map of the Universe (EMU) and the Polarisation Sky Survey of the Universe's Magnetism (POSSUM) already have terabytes of ASKAP observations for use in early-science and survey planning. We have applied unsupervised machine learning methods to learn a meaningful representation of these early-science observations and demonstrated that this representation generalises across different sets of observations. We use this representation to address physical problems such as polarised source characterisation and physical model-fitting. Our approach provides a way to use early-science data even without full understanding of the unique instrumentation effects brought to the table by ASKAP.

Deriving Constraints on Quasar Lifetime and Obscuration Using Likelihood-Free Inference

Tobias Schmidt
INAF Trieste

We often encounter problems for which in a forward-model approach accurate mock data can be generated from numerical simulations, but a Bayesian comparison of data and model is challenging e.g. due to non-Gaussianity and strong correlations of the observable. The usual multivariate Gaussian likelihood is therefore inapplicable, requiring 'likelihood-free inference'. I will present a case in which the likelihood is determined free of assumptions directly from mock samples. However, due to the 'curse of dimensionality', such an approach becomes computational infeasible if the combined dimensionality of model and observable is larger than a few. I therefore employ a data compression algorithm that reduces the dimensionality of the observable (about 20000 in our case) to the dimensionality of the model (here just 1). This then allows to cover the 1+1-dimensional space with samples and to derive 20% constraints on the lifetime of quasars from Lyman-alpha Forest Tomograph.

Detecting and characterizing interstellar structures with Machine Learning methods

Dominic Bernreuther
FAU

The interstellar medium (ISM) is filled with structures of various sizes and shapes, which are observable over a wide range of the electromagnetic spectrum. We are developing a tool to detect and characterise stellar bubbles, superbubbles, shells, and filaments in the ISM based on Machine Learning algorithms. Currently, we are using the open source software ImageJ to perform a pixel-based segmentation on optical emission-line images. We use archival Halpha images from surveys in the Milky Way and the Local group galaxies. We will use the tool to characterise interstellar structures in the Magellanic Clouds and to study their origin by comparing these structures with the distribution of different phases of the ISM as well as stellar populations.

Painting with baryons: augmenting N-body simulations with gas using deep generative models

Tilman Troester
University of Edinburgh

Running hydrodynamical simulations to produce mock data of large-scale structure and baryonic probes, such as the tSZ effect, at cosmological scales is computationally challenging. We propose to leverage the expressive power of deep generative models to find an effective description of the large-scale gas distribution and temperature. We train two deep generative models, a variational auto-encoder and a generative adversarial network, on pairs of matter density and pressure slices from the BAHAMAS hydrodynamical simulation. We then apply the trained models on 100 lines-of-sight from SLICS, a suite of N-body simulations optimised for weak lensing covariance estimation, to generate maps of the tSZ effect. We consider a specific observable, the cross-correlation between weak lensing and the tSZ effect and its variance, where we find excellent agreement between the predictions from BAHAMAS and SLICS, thus enabling the use of SLICS for tSZ covariance estimation.

Synergies between low- and intermediate-redshift galaxy population classifications revealed with unsupervised machine learning

Sebastian Turner
Liverpool John Moores University

Machine learning approaches will be crucial for the analysis of galaxy populations in the impending era of big data in astronomy. M. Siudek et al. (2018) tested a clustering algorithm on a sample of ~50000 galaxies from VIPERS, which samples an SDSS-like volume at z~1, when the Universe was half its current age and the global star formation rate was much higher than at present. The study used 13 input features: spectroscopic redshift, and 12 absolute magnitudes in bands from UV to IR, ensuring that information across the full wavelength coverage of VIPERS was used. The 11 clusters that were found revealed a detailed substructure to the galaxy population and demonstrated the utility of the chosen input features - broad band photometric magnitudes - in discerning subpopulations of galaxies and facilitating comparisons with other samples.

We now compare these results to those from a ongoing parallel study of a z~0 SDSS sample of ~500000 galaxies. This is with a view to understanding the cosmic evolution of the galaxy population, in terms of subpopulations given by clusters, since z~1. The same algorithm and input features are used, and yield 12 clusters. Advantages of the algorithm, which combines dimensionality reduction with model-based clustering, will be discussed in the context of broader ideas about feature selection clustering approaches. I will discuss and interpret similarities and differences between the two sets of results.

TUTORIALS

TUTORIAL 1

Machine Learning: an introduction in Python notebooks

—

In this short course you'll learn what Machine Learning is about, and it will give you a quick refresher on the mathematics you need. You will learn what a neural network is, how you program it, how you use it. Participants are expected to know how to start a Python notebook, and bring their laptop to run the notebooks on their machines.

Patrick van der Smagt

Patrick van der Smagt is director of the open-source Volkswagen Group Machine Learning Research Lab in Munich, focussing on probabilistic deep learning for time series modelling, optimal control, reinforcement learning, robotics, and quantum machine learning. He previously directed a lab as professor for machine learning and biomimetic robotics at the Technical University of Munich while leading the machine learning group at the research institute fortiss, and before founded and headed the Assistive Robotics and Bionics Lab at the DLR Oberpfaffenhofen. Quite a bit earlier, he did his PhD and MSc at Amsterdam's universities. Besides publishing numerous papers and patents on machine learning, robotics, and motor control, he has won a number of awards, including the 2013 Helmholtz-Association Erwin Schrödinger Award, the 2014 King-Sun Fu Memorial Award, the 2013 Harvard Medical School/MGH Martin Research Prize, and best-paper awards at machine learning and robotics conferences and journals. He is founding chairman of a non-for-profit organisation for Assistive Robotics for tetraplegics and co-founder of various tech companies.

Luigi Iapichino

Luigi Iapichino holds a position of scientific computing expert at LRZ and is a former member of the Intel Parallel Computing Center. His main tasks are code modernization for many-core and multi-core systems, and HPC high-level support in the PRACE framework. He got in 2005 a PhD in physics from the Technical University of Munich, working at the Max Planck Institute for Astrophysics. Before moving to LRZ in 2014, he worked at the Universities of Würzburg and Heidelberg, involved in research projects related to computational astrophysics. He is the team lead of the LRZ Application Lab for Astro and Plasma Physics (AstroLab).

TUTORIAL 2

Introduction to Machine Learning with Intel® Software tools

—

The use of data analytics techniques, such as Machine Learning and Deep Learning, has become the key for gaining insight into the incredible amount of data generated by scientific investigations (simulations and observations). Therefore it is crucial for the scientific community to incorporate these new tools in their workflows, in order to make full use of modern and upcoming data sets. In this tutorial we will provide an overview on the most known machine learning algorithms for supervised and unsupervised learning. With small example codes we show how to implement such algorithms using the Intel® Distribution for Python*, and which performance benefit can be obtained with minimal effort from the developer perspective. Moreover, we present the portfolio of tools and services of LRZ for AI academic users, focusing on the systems available for the different user groups and on the software environment and tools to enable efficient computing.

TUTORIAL 3

Deep Learning at Scale using Distributed Frameworks

—

The demand of using Deep Learning techniques in many scientific domains is rapidly emerging and the requirements for large compute and memory resources is increasing. One of the consequences is the need of the high-performance computing capability for processing and inferring the valuable information inherent in the data. The Leibniz Supercomputing Centre (LRZ) has recently installed its new high-end system, SuperMUC-NG. Based on Intel® technology, it targets among others also workloads at the crossroads of AI and HPC. In this tutorial we will learn various optimization methods to improve the runtime performance of Deep Learning algorithms on Intel® architecture. We cover how to accelerate the training of deep neural networks with Tensorflow, thanks to the highly optimized Intel® Math Kernel Library (Intel® MKL). We also demonstrate techniques on how to leverage deep neural network training on multiple nodes on a HPC cluster. Finally, an overview of the high-level support initiatives for AI users at LRZ will be provided.

Fabio Baruffa

Fabio Baruffa is a senior software technical consulting engineer at Intel. He provides customer support in the high performance computing (HPC) area and artificial intelligence software solutions at large scale.
Prior at Intel, he has been working as HPC application specialist and developer in the largest supercomputing centers in Europe, mainly the Leibniz Supercomputing Center and the Max-Plank Computing and Data Facility in Munich, as well as Cineca in Italy. He has been involved in software development, analysis of scientific code and optimization for HPC systems. He holds a PhD in Physics from University of Regensburg for his research in the area of spintronics devices and quantum computing.

Torsten Enßlin

Torsten Enßlin is a scientist at the Max-Planck-Institut für Astrophysik (MPA), Garching (near Munich), and lecturer at the Ludwig Maximilians University, Munich in Germany. He is interested in Information Theory, especially Information Field Theory (IFT), Cosmology and High Energy Astrophysics. His group develops the NIFTy software for scientific imaging.

TUTORIAL 4

Numerical Information Field Theory – turning data into images the Bayesian way

—

The reconstruction of images and signals from noisy and incomplete data is an ill-posed problem usually, which requires the usage of prior information on the signal to be recovered. Numerical information field theory (NIFTy) is an open source Python library that facilitates the reconstruction of signals by converting a generative statistical model of the signal into a signal inference machine. In this tutorial, the basic usage of NIFTy will be taught.
See http://ift.pages.mpcdf.de/nifty for more details.

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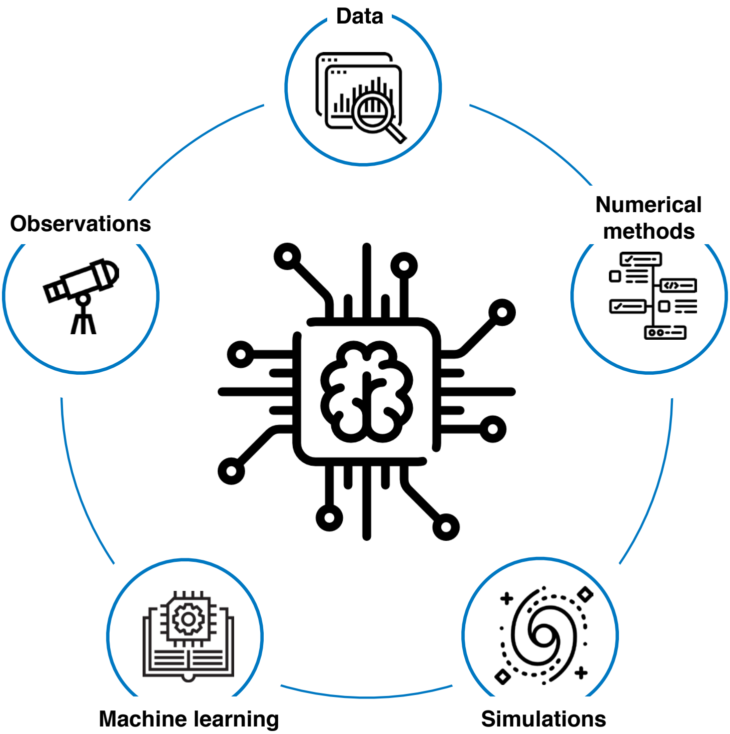

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POS

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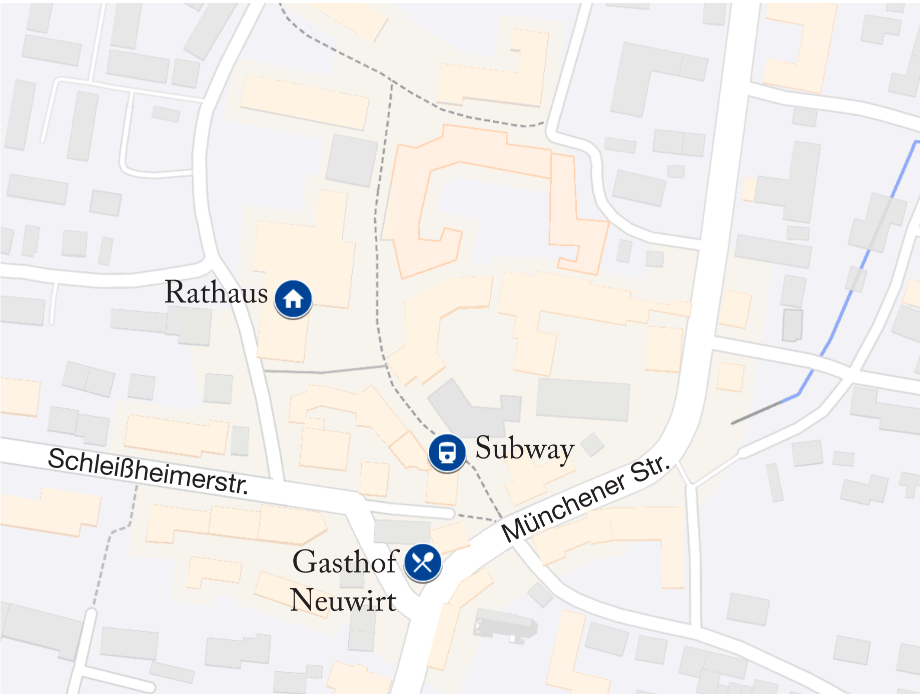

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Notes

“Machine intelligence is the last invention that humanity will ever need to make.”

— Nick Bostrom