Fusing Earth Observation, Volunteered Geographic Information and Artificial Intelligence for improved Land Management

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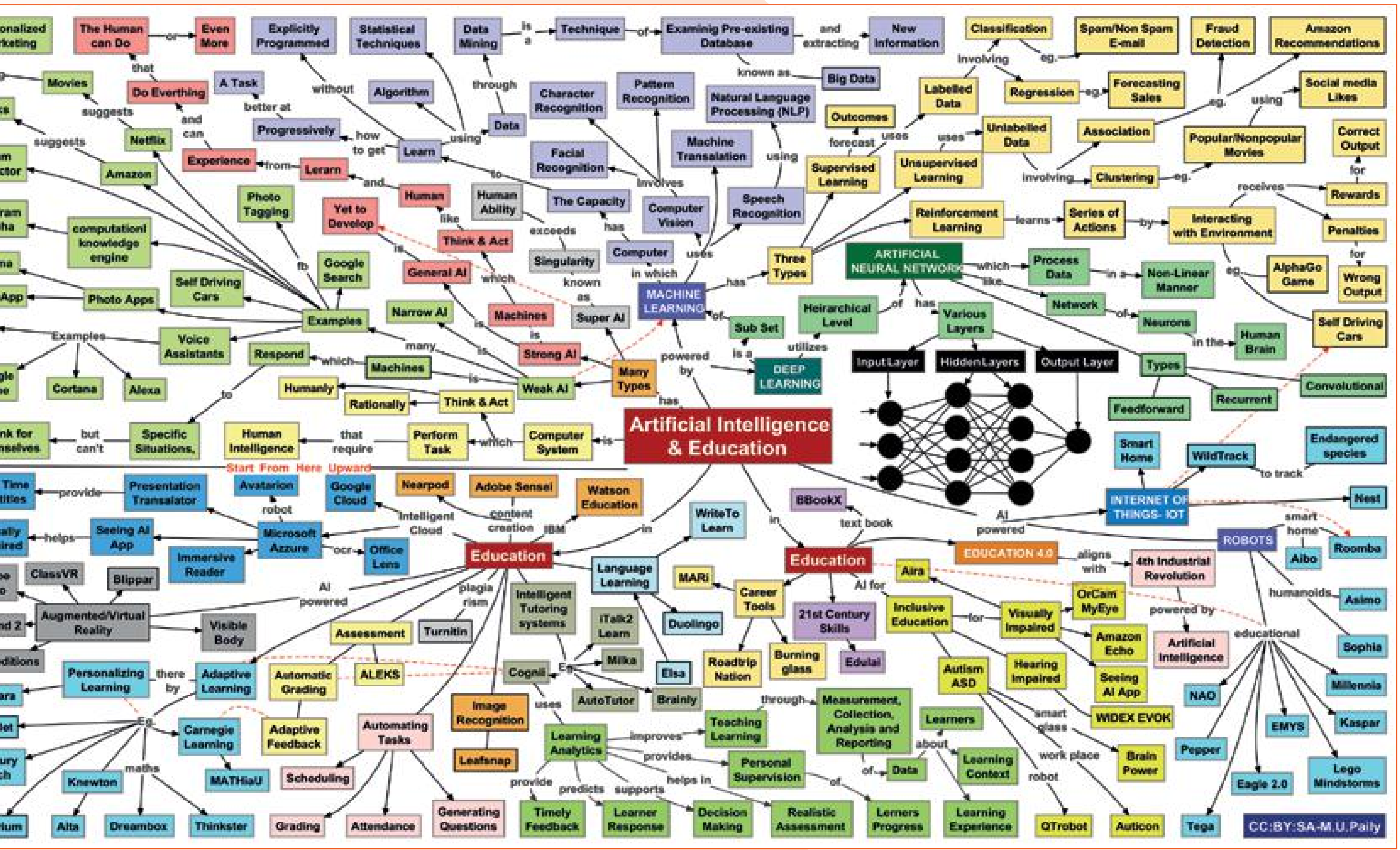
Fusing Earth Observation, Volunteered Geographic Information and Artificial Intelligence for improved Land Management

by Vyron Antoniou, Flavio Lupia



Earth Observation data deluge is calling for Artificial Intelligence methods to support geomatics in producing valuable information for land management. Open-source data, software and services and volunteered geographic information will be relevant contributors.

Existing and future developments in Earth Observation

The last few years we have witnessed a proliferation of Earth Observation (EO) systems with improved sensing capabilities and shorter revisiting periods. Perhaps one of the most successful paradigms of freely available EO data is those provided by the European Commission (EC) Copernicus program through the Sentinel constellation. However, broad EO data availability was unknown until recently. At the beginning, high resolution imagery was a sole privilege of governments or robust private companies, while later, broadly available imagery was of medium resolution and long revisiting times (e.g. through the Landsat program). Today though, initiatives like Sentinel provide free imagery of up to 10m resolution and of 5-day revisiting period. Taking advantage of these developments, many stakeholders turn to the publicly available data to cover their needs as high quality and timely imagery is easily accessible from individuals and researchers up to start-up companies. As a consequence, the private sector today needs to offer imagery well below the thresholds set by freely available data pushing the space-based EO in a virtuous cycle. A similar positive momentum exists for the global co-ordination of EO sensors. Examples can be found in initiatives such as the GEO (Group on Earth Observations), an international organization consisting of more than 200 governments and organizations. Its mission is to implement GEOSS (Global Earth Observation System of Systems) which is a set of interacting earth observation, information and processing systems aiming to provide access to information to a broad range of users and purposes. GEOSS links these systems, facilitates the sharing of environmental data and information, ensures that these data are accessible and assures their quality, provenance and interoperability. More than 150 data providers contribute to GEOSS and in total, there are around 200 million datasets available. A direct result of these developments is the creation of huge volumes of data, on top of the already produced ones. It is expected that more than 8500 smallsats (i.e., less than 500 Kg) will be launched in the next decade alone, at an average of more than 800 satellites per year, and the constellations will account for 83% of the satellites to be launched by 2028 (Euroconsult, 2019), many of which will be for EO purposes.

New Challenges – New Solutions

All these create new challenges when it comes to efficiently storing, managing, processing and analysing EO imagery. Moreover, there is increased need for automation and end-to-end methodologies for image analysis in order to take advantage of the wealth of data generated. An interesting way forward is paved by the progress in satellite imagery Data Cubes. Data Cubes are novel approaches for storing, organizing, viewing and analyzing large volumes of imagery and thus, enable more efficient management and analysis methods. They allow a homogenized way of storing time-repeating imagery for a defined area. This creates a virtual cube of data over a specific area where the z-axis corresponds to time. Data Cubes ensure high quality and consistency of the stored data while they provide the necessary infrastructure, tools and services. However, processing of large data volumes, in or outside Data Cubes, still remains a challenge. To this end, an interesting development comes from advances in Artificial Intelligence (AI), Machine Learning (ML) and Deep Learning (DL). Important breakthroughs that took place during the last few years have contributed to their proliferation. First, it is the improvements of the AI/ML/DL field itself. New algorithms, improved models and better processes allow AI/ML/DL to excel in long standing problems and challenges compared to existing solutions and show the potential of the field in the future. A second factor is the open approach that many stakeholders hold towards AI issues. Partially from concerns that have to do with the power and the control that AI models can have over important decisions and partially inspired by the principles set by open-source software and wiki-based projects, AI models, training datasets and other helpful material are freely accessible onli-

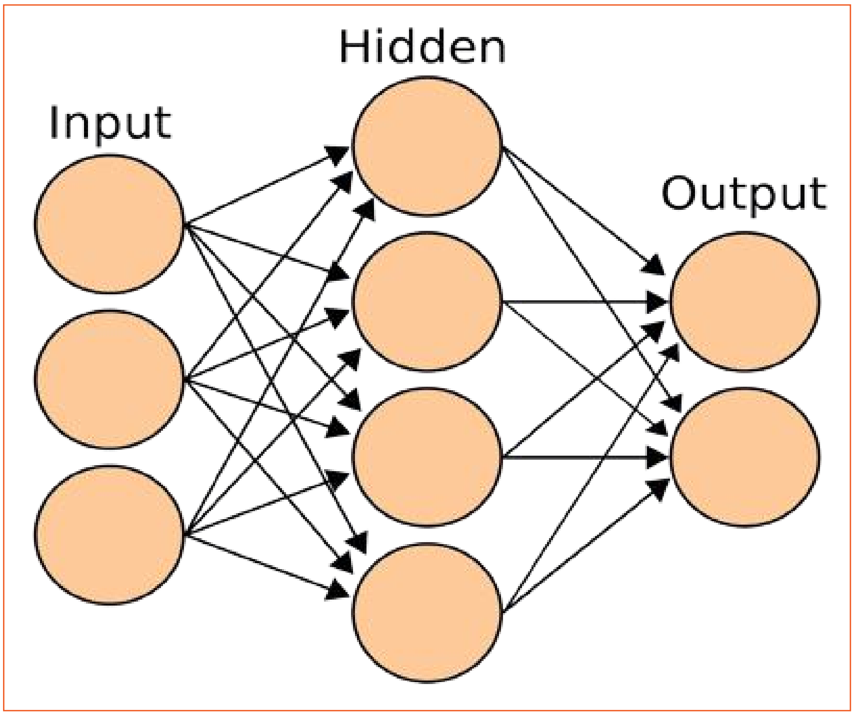


Fig. 1 - An example of artificial neural network with a hidden layer (Source: https://commons.wikimedia.org/wiki/File:Artificial_neural_network.svg)

ne which lower the entry bar of an individual to this field. Moreover, big companies offer for free the necessary computational power so that anyone can experiment and progress into the AI domain (see for example Google's Colab - https://colab.research.google.com/).

Machine Learning in Geomatics

In general, ML/DL is revolutionizing how massive data volumes are analysed. In the Geomatics domain, ML/DL allows the development of geospatial applications that, a few years ago, were beyond reach in terms of efficiency and processing capacity. Examples can be found in satellite image artefact reduction (Wegner et al., 2018); image denoising (Huang et al., 2019); pan-sharpening (Yang et al., 2017) or super resolution (Huang et al., 2015) to name a few. Of course, the ML/DL field is not without challenges. One of the most puzzling ones is the stability of the results. Gilmer et al. (2018) illuminates the problem and explains how easy it is for deep neural networks (DNN), which are highly accurate on benchmark datasets, to be confused and perform poorly when they have to work with real-life adversarial cases. For example, Hendrycks et al. (2019) show that with a set of adversarial images a DNN achieved an accuracy of approximately 2%, which was a drop of approximately 90% compared to its accuracy with the benchmark IMAGENET dataset. However, ML/DL is constantly gaining momentum and the user and developer pool is getting bigger and more active in all domains, including Geomatics. This trend is also seconded by multiple virtual places where engineers meet and compete to produce novel or more efficient AI models. For example, the Kaggle platform (https://www.kaggle.com/) hosts open competitions that challenge researchers and developers to present models that are capable of accurately evaluating benchmark datasets. Similar is the concept behind the DigitalGlobe challenge (https://spacenetchallenge.github.io/) which focus exclusively in remote sensing application, the Crowd AI mapping challenge (https://www.crowdai.org/challenges/mapping-challenge) which focuses on building detection for humanitarian response in areas with poor mapping coverage, and the Defense Science and Technology Laboratory (Dstl) challenge, which focus on natural or manmade features, such as waterways and buildings from multispectral satellite imagery.

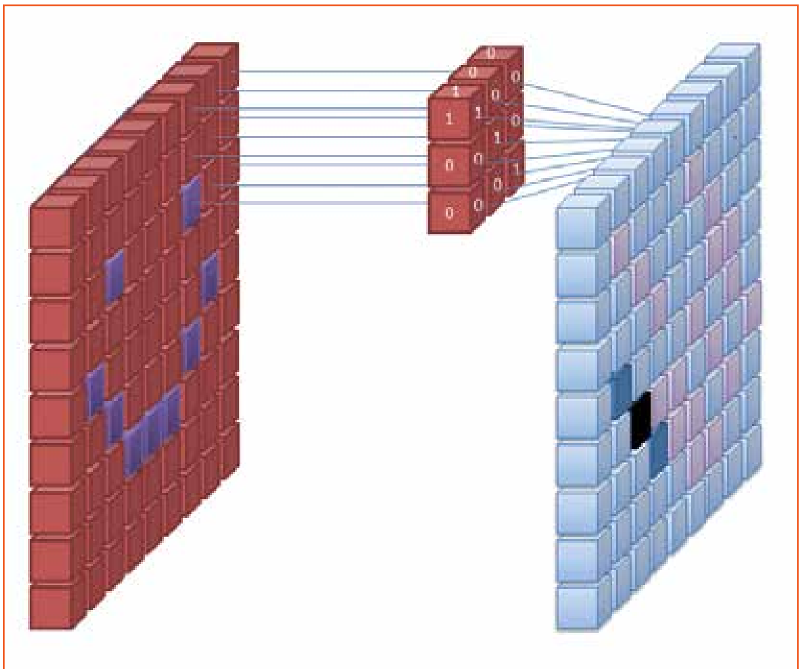


Fig. 2 - A filter in the first layer of a convolutional artificial neural network interpreting an image (Source: https://commons.wikimedia.org/wiki/File:Convolutional_Neural_Network_NeuralNetworkFilter.gif).

Volunteered Geographic Information in the service of Machine Learning

One important factor that affects the progress of ML/DL is the availability of training datasets. In Geomatics, the solution can be found in the growth of Volunteered Geographic Information (VGI). For more than a decade now, VGI is spearheading the creation of freely available data. OSM, the flagship of VGI, provides global coverage with free data where someone can find vectors that outline natural and man-made features including land use and land cover data. The geometry of the features, along with their imagery counterpart, can form rich sources of training datasets that can be used to train ML/DL models in order to perform complex processes such as automatic road network extraction, object detection or land classification (Antoniou and Potsiou 2020).

Agriculture and Earth Observation

It is widely recognized that EO and geospatial data of high quality, frequency and with wider accessibility can enable and fully support global, regional and country initiatives and regulations. New data-driven approaches and Big Data Analytics provide unique opportunities to track and monitor human actions toward sustainability as required by Agenda 2030 in a really consistent and comparable manner.
At EU level, environmental and agricultural sector will benefit for the deluge of data from EO (e.g. Copernicus Programme) and other sources (in-situ/proximal/ground sensors) helping to support the European Green Deal - the roadmap for addressing climate change issues making the EU economy sustainable and the new Common Agricultural Policy (CAP).
CAP is already exploiting Copernicus satellite data to generate several products: land use/land cover and crop type maps, land take, crop conditions, soil moisture, high nature value farmland, and landscape fragmentation. In addition, CAP subsidies to farmers will take advantage of the EO data to perform the full monitor of the farmers compliance and to dramatically reduce the sample field checks.
In this arena, managing petabytes of data from EO and other sources data to be synergistically integrated will be the challenge and new tools, such as AI, will be pivotal in extracting actionable geospatial information. To this end, EU is moving toward the development of cutting-edge, ethical and secure AI trough a coordinated effort and cooperation among Member States, as stated by the Coordinated Plan on Artificial Intelligence (European Commission, 2018).

Agriculture and Machine Learning

The growing use of ICT in agriculture and precision farming have opened up the Digital Agriculture era where a large amount of data coming from a variety of sensors will enable data-driven precise farming strategies. The final goal is always to handle a complex system of systems, where several components (soil, weather, crops and farm management) interact at different spatial and temporal scales, in search of sustainability of farm inputs and growth of product quality and economic performances.
ML/DL techniques have already been proven as a powerful tool to unravel the complexities of the agricultural ecosystem. Liakos et al. (2018), in their review found the following as the most promising applications: crop management (yield estimates, diseases and weeds detection, crop quality and identification), livestock management (animal welfare and production), water and soil management. ML/DL models dominate in the field of crop management where there is a consolidated use of imagery that can be used directly, often without the need of data fusion from different sources. ML applications are less common when data recorded from different sensors need to be integrated into big datasets thus, requiring a lot of effort to be managed (e.g. livestock management). Literature reports Artificial Neural Networks (ANNs) and Support Vector Machines (SVMs) as the most widespread models used in agriculture.
Despite the difficulties to compare the experimental conditions of the literature, Kamilaris & Prenafeta-Boldú (2018) in their review found that DL-based technics (mainly Convolutional Neural Networks - CNNs) have always better performances when compared with classical state-of-the-art approaches using EO and Unmanned Aerial Vehicle data in various agricultural areas (leaf classification, leaf and plant disease detection, plant recognition and fruit counting). Moreover, several papers reported advantages of DL in terms of reduced effort in feature engineering where manual identification of specific components is always challenging and time consuming. Other advantages are the good performance in generalization and the robustness in difficult conditions (such as illumination, complex background, different resolution, size and orientation of the images).

What lies ahead

In general, ML/DL approaches seem very promising for addressing the complexity of the agricultural domain by providing the ingredients to move towards a knowledge-based agriculture. In Geomatics, the need for large annotation datasets, as training inputs, can be supported by VGI which offer large volumes of free data. However, at the same time, several weaknesses need to be addressed such as the limitation to generalize beyond the boundaries of benchmark datasets, time-consuming preprocessing and safeguarding the consistency of the results in order to further accelerate the use of AI/ML/DL. Finally, we stress the need to orchestrate these promising solutions dealing with specific aspects of agriculture within a wider decision-making environment.

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KEYWORDS

Earth observation; VGI; machine learning; deep learning; digital agriculture, land management

ABSTRACT

The ever-growing availability of Earth Observation (EO) data is demonstrating a wide range of potential applications in the realm of land management. On the other hand, large volumes of data need to be handled and analysed to extract meaningful information and Geomatics coupled with new approaches such as Artificial Intelligence (AI) and Machine Learning (AI) will play a pivotal role in the years to come. Training datasets need to be developed to use these new models and Volunteered Geographic Information can be one of the promising sources for EO processing. Among the various applications, agriculture may benefit from the large dataset availability and AI processing. However, several issues remain unsolved and further steps should be taken in the near future by researchers and policy makers.

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