Activity Report 2019

Team OBELIX

Environment Observation through Complex Imagery

D5 – Digital Signals and Images, Robotics

1 Team composition

Head of the team

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2 Overall objectives

2.1 Overview

Observation is one of the key issues in the understanding of environmental systems. A large amount of possibilities, ranging from local probes or networks to hyperspectral remote sensing images, is at the moment available to sense and extract environmental parameters. Among them, aerial or satellite imaging sensors allows for observation at a very large scale. But Earth Observation raises also fundamental challenges. Its impacts are numerous and related to a wide range of application fields, often related to environmental issues: agricultural monitoring and planning for a better exploitation of crops and fields; urban remote sensing for built-up area assessment, urban-natural interaction understanding, pollution monitoring, etc.; analysis of coastal ecosystems through geomorphology studies; land cover mapping and monitoring for identifying the impact of our society on Earth; crisis management and global security aiming to deliver rapid and critical information to rescue operations, e.g., damage assessment, flood delineation, etc. These last applications require fast and even real-time tools for remote sensing.

Unsurprisingly, the number and the complexity of applications based on earth observation are continuously growing. Indeed, our society benefits from the availability of a wide range of earth observation satellites, and several new sensors are launched every year. Within Europe, the Sentinel Copernicus program aims to freely deliver 4 TB daily within the next few years. The dynamics of the remote sensing field leads today to abundant resources of geospatial image data. This advantage has now turned into a serious issue when one has to explore the available data to find some information of interest, and geospatial big data becomes one of the major challenges to be addressed within computer and information sciences. Indeed, how not to be lost in the massive amount of available geospatial data, not far from reaching the Zettabyte scale (ZB)?

Beyond the exceptional data volume to be handled in remote sensing, image intrinsic complexity also brings hard scientific and technological challenges. With the continuous improvement of earth observation satellite sensors, geospatial data are now: multi- or even hyperspectral delivering rich information about observed objects or lands from across the electromagnetic spectrum, beyond the visible light our visual system is used to deal with; daily observations of the same part of Earth which can be revisited by a satellite with ever higher frequencies; at a high or even very-high resolution, allowing to observe from space (from a distance of more than 500km) what occurs on the ground on only 30 centimeter square. This also raises the problem of multiple observations of the same object or part, at various resolutions, and thus with various viewpoints expecting to deliver a globally better understanding of our environment. Moreover, the generalization of very high spatial resolution sensors has a direct influence on the data volume tackled by methods and systems in the field, with an increase of an order of magnitude of 10,000 (one Landsat pixel was representing 30m2 while one WorldView-3 pixel will represent 31cm2). Finally, the complexity also comes from the significant noise, imprecision, and incompleteness that characterized observations provided by remote sensing.

Key Issues. The overall objective of the team is the processing of complex images for environmental purposes. In such a context, available data form a massive amount of multidimensional (multi- or hyperspectral) noisy observations with high spatio-temporal variability and coming from multiple sources. While understanding these data stays very challenging, environmental systems always come with some additional knowledge or models that are worth being exploited to achieve environment observation. Finally, whatever the task involved (e.g., analysis, filtering, classification, clustering, mining, modeling, etc.), specific attention has to be paid to the way results are provided to the end-users, helping them to benefit from their added value.

2.2 Scientific foundations

2.2.1 Processing complex environmental data

Environment observation requires one to perform various data processing tasks: analysis to describe the data with relevant features; filtering and mining to highlight significant data; clustering and classification to map data with predefined or unknown classes of interest; and modeling to understand the underlying phenomena. In this context, processing complex data brings various challenges that will be addressed by the team, both from theoretical and computational points of view. Highly dimensional images, massive datasets, noisy observations, fine temporal and spatial scales, together motivate the design of new dedicated methods that can handle this complexity. The underlying techniques refer to scale-space models (e.g., using hierarchical tree-based image representations) for feature extraction and manifold learning for the theoretical part, and to massive computing using GPUs networks and data intensive systems (based on Hadoop for instance) for the operational level.

Observing data at multiple scales Multiscale modeling of an image enables the access, analysis, processing, understanding and interaction with the image at various levels of details, but also enables one to provide some independence to raw geospatial data, thus introducing a way to deal with the intrinsic complexity of heterogeneous geospatial image repositories. This will allow real-time global land cover monitoring, and foster geospatial description and learning methods to anticipate future challenges faced by our data-intensive society.

Geospatial objects of interest, such as buildings or military targets, manifest themselves most often at various scales within and across the acquired images. Moreover, the clarity of interactions among landscape components (with the purpose of compound object recognition for instance) can also vary greatly with respect to the observation scale. Consequently, image representation schemes capable of accommodating multiple scales are invaluable in the context of geospatial data analysis. Besides, the wide acclaim of the object-based image analysis paradigm has further emphasized the need for multiscale image representation methods [Bla10]. This paradigm relies on a prior segmentation step that aims to gather pixels into regions for further analysis. The team

[Bla10] T. Blaschke, "Object based image analysis for remote sensing", *ISPRS Journal of Photogrammetry and Remote Sensing 65*, 1, 2010, p. 2–10.

has introduced various efficient segmentations algorithms, with a focus on supervised techniques that rely on user knowledge or input.

In particular, given a satellite image at a single resolution, various methods have been designed for constructing its multiscale representation. Wavelets and Gaussian pyramids for example, are popular multiresolution tools in this regard, employed especially with the purpose of image fusion (pan sharpening) and change detection. Unfortunately, they fail to preserve the contours of the image components, and consequently do not lend themselves well for multiscale object-based image analysis. Hierarchical representations form a relevant alternative introduced by the mathematical morphology community. Among the available tree models belonging to this category, partition hierarchies consist of producing segmentation maps of their input at various coarseness levels, with the latter being directly related to the scale under consideration. Inclusion hierarchies rely on the iterative nesting of image components, e.g., from isolated extrema to larger objects. Both models enable efficient representation and direct subsequent extraction of meaningful image regions at arbitrary scales. Hence, multiple tree models relying on these powerful representations have been introduced [SW09], e.g., binary partition trees, or min/max trees. Moreover, certain tree variations can accommodate flexible segmentation strategies according to arbitrary criteria, while additionally preserving the contours of image components [PLCS12]. We explore in the team how to build such hierarchical models from large and multivariate datasets. In order to face the inherent complexity of remote sensing data, we also consider to exploit some prior knowledge when constructing the image model, e.g., in high dimensional spaces.

The description of image content (or feature extraction) is a stage of crucial importance for various geospatial applications, such as content-based retrieval, classification and mapping. Consequently, a plethora of content descriptors have been elaborated in this regard, either at pixel, region or global level, capturing spectral, textural, shape-based, geometric and even localized image properties. Even though content-description approaches have come a long way in the past couple of decades, the challenges, practical requirements and complexity of the data under consideration have increased just as much, if not more. Indeed, content description has to be robust against global and local illumination, rotation, scale variations and geometric deformations. Moreover, with the advances in terms of spatial and spectral resolutions, content descriptors are expected to adapt to their variations, so as to exploit the additional information; for instance by means of descriptors capable of capturing fine spectral image characteristics, or even particular spatial arrangements of predefined objects. Furthermore, the availability of time series has enabled a whole new level of temporal queries that require suitable temporal features. The team aims to elaborate such original and robust features, e.g., with a focus on morphological attributes taking into account some prior knowledge.

Facing the curse of dimensionality Environmental data usually come with high dimensionality, either in the number of samples or in the number of dimensions per

[SW09] P. Salembier, M. Wilkinson, "Connected operators", *IEEE Signal Processing Magazine 6*, 6, 2009, p. 136–157.

[PLCS12] B. Perret, S. Lefèvre, C. Collet, E. Slezak, "Hyperconnections and hierarchical representations for grayscale and multiband image processing", *IEEE Transactions on Image Processing 21*, 1, January 2012, p. 14–27.

sample. A good example is found in Hyperspectral Imaging, where a pixel is a vector of reflectances sampled over different wavelengths, and an image is therefore a data cube usually containing several hundreds of reflectances per pixel. This dimensionality comes with several problems that arise either from a statistical viewpoint (curse of dimensionality) or from computational issues. A good solution is found in dimensionality reduction techniques, which hopefully provide concise representation of the initial information. This reduced information set could be obtained through the embedding of the original data in a lower dimensional but meaningful space. This embedding usually stems from a variety of different energy functions to be optimized, generally associated to the quality of reconstruction of the samples from the embedding space to the original input space. The matrix factorization problem provides a well-grounded framework to a wide class of dimensionality reduction techniques. By decomposing a given data matrix into a product of two matrices (representing respectively the embedding space and the surrogate representation on the data in this space), one can find the expression of several well known transformations by setting constraints on the embedded space or the decomposition. Hence, the Principal Component Analysis is obtained when an orthogonality constraints is set on the vectors of the embedding space. Setting a positivity constraint on both matrices lead to the well known nonnegative matrix factorization. Adding sparsity constraints on the embedding vectors leads to sparse PCA techniques, while imposing it on the reduced coordinates lead to the sparse coding.

We have started in the team to work extensively on the convex formulation of these problems, since it buries strong relations with the underlying physics of the phenomena: the observed data are then assumed to a be mixture of existing, identified, components. As examples, in the case of hyperspectral data, at a given location, and because of the spatial resolution of the captor and scattering effects, the value contained in one pixel is assumed to be a combination of several spectra that describe the reflectance of a "pure" material (e.g., soil, water, asphalt, etc.). Those materials are said to be endmembers. The problem of unmixing [BDPD+12] those data amounts to find which of those endmembers are present in the pixel spectrum, and in which proportion (abundance). This constitutes a difficult ill-posed inverse problem for which no closed-form solutions are available, but where matrix factorization techniques provide appealing solutions (e.g. sparsity constraints or convexity constraints). We also plan to use those kind of technique for the analysis and unmixing of time series representing land covers.

Also, the dimensionality problems can be solved to some extent by subsampling the original dataset, and providing this way a subset of the data which contains most of the relevant information. As a matter of fact, this subsampling problem buries a lot of resemblances with the matrix factorization problem, since they both try to identify low ranks approximations of the original data matrix. In the literature, this sub-sampling problem is also referred to as precise definition or, as coarse graining. Several criteria can be defined to evaluate the quality of this approximation: Minimization of the eigenvector distortion, label propagation, spectrum perturbation, maximization of the data coverage and diversity, etc. Sometimes, these methods make the assumption that the dataset

[BDPD+12] J. M. Bioucas-Dias, A. Plaza, N. Dobigeon, M. Parente, Q. Du, P. Gader, J. Chanussot, "Hyperspectral unmixing overview: Geometrical, statistical, and sparse regression-based approaches", *Selected Topics in Applied Earth Obs. & Remote Sensing, IEEE J. 5*, 2, 2012, p. 354–379.

lives onto a smooth manifold, the structure of which should be preserved through the sub-sampling process. Among others, it is possible to characterize the manifold thanks to the Laplace-Beltrami operator, which is a generalization of the Laplace operator to Riemannian manifolds. In [CL06], the Laplace-Beltrami operator is shown to be fairly well approximated by the Gaussian kernel, exhibiting a strong link between the manifold study and kernel methods in machine learning (with RBF kernels) from which the team has designed a new manifold learning algorithm [CBJ11]. Furthermore, the team is studying the manifold in the input space, or its image in the feature space induced by a kernel, and is further exploring the problem of low rank approximations with dedicated and scalable kernel methods.

Adapting distributions and correcting data shifts Domain adaptation problems occur naturally in many applications of machine learning to real-world datasets [QCSSL09]. In remote sensing image analysis this problem arises frequently, since the acquisition conditions of the images (cloud cover, acquisition angle, seasonal variations) are most often different. As a consequence, even if the images contain the same type of objects, the observed data distribution undergoes a d-dimensional and often nonlinear spectral distortion, i.e. a distortion that is local, class-specific and that impacts differently each region of the electromagnetic spectrum.

One way to solve this problem is to perform an adaptation between the two d-dimensional image domains, in order to achieve a relative compensation of the shift by matching the data clouds to each other. Provided that the data are expressed as graphs and embed a topological structure, this problem can be seen as a graph matching problem and has been tackled as such in hyperspectral remote sensing.

Dealing with time series and dynamic patterns With the growing temporal resolution of remote sensors come new challenges including knowledge extraction from these large temporal datasets. New methods should then be designed so as to better understand dynamics of the observed phenomenons. One possible application is the monitoring of agricultural plots from series of remote sensing images. Here, data are available and their temporal resolution is such that a fine-grained analysis of farming behaviors can be performed.

Time-sensitive metrics (such as Dynamic Time Warping, DTW) have shown great impact on many time series retrieval tasks. We intend to investigate the use of such metrics at the core of machine learning and/or indexing algorithms. This implies to tackle two main (and related) issues.

First, many of these algorithms rely on the assumption that similarity between objects can be measured using distances, or metrics that are distances in some (possibly

[CL06] R. Coifman, S. Lafon, "Diffusion maps", *Applied and Comput. Harmonic Anal. 21*, 1, 2006, p. 5–30.

[CBJ11] N. Courty, T. Burger, L. Johann, "PerTurbo: a new classification algorithm based on the spectrum perturbations of the Laplace-Beltrami operator", *in: ECML/PKDD*, *1*, p. 359–374, 2011.

[QCSSL09] J. Quiñonero-Candela, M. Sugiyama, A. Schwaighofer, N. D. Lawrence, *Dataset shift in machine learning*, *Neural information processing series*, MIT Press, Cambridge, MA, 2009.

unknown) spaces (this is the case of kernel functions), which is not the case for standard time-sensitive metrics. This has several implications on the use of time-sensitive metrics for machine learning. Some algorithms (*e.g.* k-means) make intensive use of barycenter computations: when using DTW-like metrics, new methods to approximate these as best should be introduced [PKG11]. Other algorithms, in the context of indexing, rely on triangular inequality to prune out the search space at query time. When such inequality does not hold, new pruning methods should be designed so as to perform efficient queries.

Second, most machine learning algorithms make intensive use of distance computations, which can be affordable if the considered distance is fast to compute but becomes a strong limitation when using DTW-like metrics. In order to deal with this issue, fast yet approximate computation of such distances could be used at the core of machine learning algorithms so as to trade accuracy for efficiency.

2.2.2 Incorporating prior knowledge and models

To deal with the intrinsic complexity of images, environment observation can most often benefit from supplementary information (additional measurements, expert knowledge, physical models). Incorporating such information when processing environmental data is thus highly expected. We will address this issue in four different ways: i) data assimilation when dealing with physical models; ii) data fusion and dimensionality reduction when dealing with additional measurements, iii) active learning for interactions with expert knowledge and iv) supervision in the early steps of computer vision (e.g., feature extraction, image segmentation and representation, etc.). The two first points are discussed below whereas the third one is presented in the next section. Let us recall that the last point has been addressed in the previous section.

Coupling data and models In general many physical models exist to describe an environmental system. However, such models are rarely compatible with data analysis tools (e.g., models are non-linear and thus do not fit the classic assumptions in computer vision) and it is therefore of prime importance to design alternative strategies able to accurately mix the recent physical models with variables derived from images. Mixing data and models is commonly known as the data assimilation problem that has largely been studied in the geosciences community. However some specific difficulties due to the intrinsic nature of images (high dimension, 2D/3D projections, indirect observations, etc.) require the design of adapted methodologies.

From a thematic point of view, we will focus on two main applications: the recovery of small-scale velocity fields and the estimation of bio-physical parameters. Although these two aspects seem to be disconnected, they are of prime importance for us since: (i) they require the use of complementary data (low spatial resolution satellite with high temporal rate for wind fields and conversely, high and very high spatial resolution for biophysical parameters with low temporal rate); (ii) associated models are of different nature; we will thus explore a large panel of solutions; and (iii) as longer-term goal, we

[PKG11] F. Petitjean, A. Ketterlin, P. Gançarski, "A global averaging method for dynamic time warping, with applications to clustering", *Pattern Recognition 44*, 3, 2011, p. 678–693.

plan to use complex models of climate/land cover interactions that require the knowledge of both biophysical variables and local winds (as pollutant dispersion or landscape evolution models).

From a methodological point of view, variational data assimilation and stochastic filtering techniques will be explored. Indeed, promising results have been obtained very recently through approaches relying on optimal control theory and data assimilation. The techniques proposed melt an imperfect modeling (based on Partial Differential Equations) of the physical process and an observation operator, leading to adequate optimal tools for consistent combination of model and observations. In this context the variational approach (3D-4D var) is a popular methodology. For turbulent 2D flows, curve and front tracking or data reconstruction from images, this enabled the recovering of the whole scale range of the flow. However as already mentioned, it has been observed that errors still remain on the fine scale structures. Yet, they are of prime importance in many applications related to climate and land-cover interactions as urban pollution understanding.To deal with fine scales, we will rely on our first works that consist in performing a multi-scale estimation by exploiting the framework of data assimilation where the usual temporal variable is now an artificial time between scales and the models are based on downscaling laws issued from fluid mechanics. We will rely on various observation operators: image-based ones and direct observations (issued from local sensors at lower altitudes) in order to estimate, in a single scheme, the velocities at various layers of the atmosphere by keeping the physical interactions between these layers. To that end, a large variety of physical models of scale interactions will be explored. These models are mainly developed in the Turbulence Laboratory of Tsinghua University (Beijing, China) with which we have many links and projects. The design of adapted image-based observation operators (link between the image luminance and the fine scale velocities) and the adaptation of existing physical models to this specific problem will be the key axes of researches.

When dealing with land cover studies, main parameters to be extract from remotely sensed data are: kind of land cover (built areas, water, roads or vegetation), surface roughness, temperature, moisture and the LAI (Leaf Area Index, related to the vegetation). In practice all parameters of interest can already be estimated from images. Let us however mention that in specific environments (urban, highly intensive agricultural landscapes), the estimation of the temperature is delicate since many interactions between land cover and temperature occur. We will thus build upon some previous work from OSUR [FDQ12] to design precise temperature estimation tools in urban environments. The idea is to adapt the existing models of temperature (at regional scales) to the scale of a city by extracting correlations/statistical relations between land cover and temperature. These relations will be computed from sparse representations and manifold learning techniques discussed in previous section. The specific case of bio-physical parameter and in particular LAI estimation will also be managed through stochastic filtering techniques. The underlying physical process of annual growth of leaves is indeed known and this information is at the moment not taken into account in existing and operational estimation tools. It may therefore be of high interest to take this knowledge

[FDQ12] X. Foissard, V. Dubreuil, H. Quenol, "Spatialization of urban heat island by multi regression in Rennes, France", *in: 8th International Conference on Urban Climate, 2*, Dublin, Ireland, 2012.

into consideration. It has indeed two advantages: i) reduction of the noise and interpolation of missing data associated to the low temporal observations and ii) extraction of some hidden parameters related to the calibration of the dynamic models. We have been involved in this direction for the recovery of bio-physical parameters from medium resolution images in collaboration with the CPLANT team of CASIA (Institute of Automation of Chinese Academy of Sciences) which develops since more than 30 year a well known plant growth model (named GreenLab). Within the OBELIX team, we plan extend our first works and move from medium resolution to very high resolution data. As the GreenLab model requires many calibration parameters and is highly non linear, we will rely both on reduction techniques (to learn some parameters on known data sets) and particle-smoothing approaches which are more adapted to the manipulation of complex models than the variational data assimilation (in particular they do not require adjoint models which are tricky to design with GreenLab).

Combining various sources of information Since complementary observations are available for analyzing land cover parameters or winds (a wide range of remote sensing data, a set of on site measurements, hemispherical photographs, surveys), a specific care should be done regarding the combination of these data: even if mixing various sources can generally improve the quality of the estimation, an improper handling of this wealth of information is sometimes likely to introduce more noise and uncertainty in the measurement than expected precision. Combining this information is a crucial step since extracting values with a minimum of noise is the key point for analyzing and understanding the land covers. An accurate management and homogenization of this mass of information is then essential in order to extract usable time series. In particular, reducing the uncertainty is the fundamental issue when observations have variable degrees of confidence. Here we will explore the theory of evidence that is particularly suited to decision making by management of uncertainty [Sha76]. We recently explored this aspect to combine observations in order to detect edges in satellite images, to detect changes in remote sensing data from past and present or to evaluate the influence of climatic parameters on the land. Recently, several theoretical extensions have been proposed in order to properly handle sources of data potentially paradoxical, subjective or symbolic [DS06] or to apprehend correlated sources [Den99]. We will explore such solutions that are perfectly suited to the variety of data we have to deal with.

2.2.3 Putting the user in the loop

Since most of the results of the methodological developments of the team will be aimed towards nonspecialists of computer science (computer vision and image processing, machine learning and data mining), a particular focus will be given to their understanding by the end-user. The objectives are both to facilitate their interactions with the tools, and provide easy ways to understand the results of the different algorithms. We refer to

[Sha76] G. Shafer, *Mathematical Theory of Evidence*, Princeton University Press, 1976.

[DS06] J. Dezert, F. Smarandache, “Introduction to the Fusion of Quantitative and Qualitative Beliefs”, *Information and Security 20*, 2006, p. 9–49.

[Den99] T. Denoeux, “Reasoning with imprecise belief structures”, *Int. J. Approx. Reasoning 20*, 1, 1999, p. 79–111.

the first category as "active processing", where the user is supposed to interact with the algorithm to achieve a better result, and to the second one as "visual analytics", since the visualization of the algorithm results is meant to provide a thorough understanding of the observed phenomenon.

Active processing Analysis and understanding of EO images is usually performed in a supervised mode, where the expert is able to provide a representative learning dataset. The latter usually contains a sufficient information about the underlying distributions, which is usually not true, mostly because the labelling activity is time consuming (and also prone to errors), and also because only few criteria can be designed to assess the completeness of descriptions. As a matter of fact, increasing the learning set size can be efficiently done if the learning algorithm is endowed with auto-analysis properties, and is capable of determining which is the best information to add to the system (which samples should be labelled to gain accuracy in the class models, or in the boundaries between the classes). It then ask the user to label this data (or a subset of the data). Yet, this problem of active learning has been well studied in the previous decades, and has also been completed by recent advances in the context of semi-supervised learning, which assumes that also the unlabelled samples can be used for learning class models or driving feature extraction. We propose nethertheless to work on this type of active learning strategies, either by designing new strategies to determine the missing pieces of the learning (such as the one developed in the Perturbo framework or by integrating prior knowledges from physical models or simulation methods in the active strategy. Here, the learning set is enhanced by samples that are not collected from real data, but automatically produced by a simulation model. This kind of bootstrapping by synthetic data has recently been shown to work successfully in the context of crowd video analysis, and we foresee to extend these concepts to environmental data.

Following the objectives of the team to develop supervised feature extraction and supervised image representation and segmentation, we also consider involving the expert in the earlier steps of computer vision through the active paradigm. Indeed, the team will build upon its expertise on efficient algorithms for image representation and segmentation to propose interactive segmentation and analysis schemes that will let the user to explore its datasets in real-time. Image representations and segmentations will be produced in real-time by tacking into account user feedback, leading to a specific view of the data that fits user needs.

Visual Analytics The multimodal observation of the environment through a variety of sensors, as well as simulation models running at fine scales, contribute to produce a large amount of information, which complexity cannot be handled directly by the user. For this information to be processed directly by a human operator, new paradigms of representations are to be explored. Those paradigms usually involve the visual system, which demonstrates in our day to day life capacities which computer scientists fail to reproduce with computers. Turning an information in a some visual clues or easy-to-apprehend chart is in itself a challenging task. Environmental data, that are in essence spatialized and temporal, can however be easily mapped on animated geocentric earth representations. It remains nonetheless that complex data will lead complex representations, that require one to pre-analyze the data before its visualization, either for computational issues, or either to extract the meaningful information inside.

The team intends to first specialize some methodologies to achieve this goal (e.g., explain some unobserved data by a combination of known data, as can be done with matrix factorization techniques), before considering visualization methods. This last point belongs to the category of visual analytics and can be considered as a crucial step to help decision makers exploit rapidly scientific advances. those aspects constitute some middle-term objectives for the development of the team. To ensure dissemination among the scientific communities, the team aims to follow open-source initiatives and to deliver a series of tools dedicated to the end-user appropriation of results.

3 Scientific achievements

3.1 Hierarchical image analysis

Participants: Sébastien Lefèvre, François Merciol, Laetitia Chapel, Thomas Corpetti, Minh Tan Pham, Caglayan Tuna, Florent Guiotte, Behzad Mirmahboub.

Hierarchical representations provide a powerful way to model, analyze and process images beyond the simple grayscale ones. Application of hierarchies on 3D point clouds (PhD of Florent Guiotte) was performed through rasterization strategies that aim at moving from the unstructured point cloud to a grid structure usual in the field of digital image processing. It allows us to apply then standard tree-based algorithms. Such rasterization can be applied in 2D [22, 23] or 3D [7, 21], with reprojection of the results in 2D if needed in the latter case [24].

As far as Satellite image time series (PhD of Caglayan Tuna) are concerned, we have explored various strategies: projecting the time series into a single, representative image on which the tree and subsequent processing can be applied, e.g. for urban growth monitoring [34]; computing a tree per date before comparing these different trees, e.g. for flood detection [32]; or creating a single spatio-temporal tree for the whole sequence. These 3 strategies were compared in the context of classification with attribute profiles in [33].

Finally, large-scale mapping initiated in 2017 was completed with a journal paper [11].

3.2 Deep Learning for Remote Sensing

Participants: Sébastien Lefèvre, Luc Courtrai, Minh Tan Pham, Javiera Castillo Navarro, Ahmed Samy Nassar, Jean-Christophe Burnel.

The Ph.D. of Nicolas Audebert on semantic segmentation completed in 2018 with ONERA led to two additional journal papers: a review of deep networks for hyperspectral image analysis together with an open-source library and some critical discussion of the current flaws faced when evaluating deep networks [2], and a consolidation of the work on distance transform regression to improve the spatial accuracy of the semantic segmentation task [1]. It has laid foundations for a new PhD on semi-supervised segmentation started by Javiera Castillo-Navarro, still with colleagues from ONERA. First works consist in a study of the amount of data that is really needed when training a deep network [14] and subsequently the proposal of some semi-supervised architecture [15].

Object detection was receiving more attention, through different projects and PhD/postdoc studies. Small object detection, e.g. vehicle observed from Space, was considered, leading to the design of a novel architecture that was compared with existing models in [39].

The Ph.D. of Ahmed Samy Nassar on object detection from multiple views (cosupervised with Jan Dirk Wegner from ETH Zurich) led to first published results, with the coupling of geometric and visual information in a Siamese network to learn the matching between multiple views [26], or even to perform the object detection itself (published in ICCV 2019 [27]). Street-view images were previously used by Ahmed Sammy Nassar during his M.Sc. for accessibility sign mapping and this original application was presented at JURSE 2019 [28].

In the postdoc of Clément Dechesne and within the project SESAME, the object detection task was appended with two other tasks, namely classification and object length estimation, in a multi-task network. A successful application on SAR imagery for the purpose of ship characterization was reported in [16, 4].

3.3 Change detection and time series analysis

Participants: Thomas Corpetti, Romain Tavenard, Laetitia Chapel, Chloé Friguet, François Painblanc, Marc Rußwurm, Zheng Zhang.

Time series analysis From a thematic point of view, the analysis of crops and the way they are managed is a very hot point. Therefore, High Spatial Resolution (HSR) remote sensing time series are of prime importance to monitor those systems. However, because of the complexity of the resulting time series, the identification of various practices using conventional tools is no easy task. On this topic, we have investigated the question of early classification, that is the problem of performing time series classification before entire time series are observed [40] and applied the proposed method to the task of agricultural monitoring [31]. Another track of research in the context of time series analysis is the development of time series classifiers [20, 19]. Lastly, we have explored the use of time series for a sustainable management of grasslands [5, 8] and rainfalls [12].

Time series generation To be able to generate data from scratch is a powerful tool in many situations like semi-supervised learning. The models designed for generation are often neural networks because they can have a great expressiveness, in other words, those models are capable of modelling a wide variety of phenomena. A model recently introduced in the scientific literature proposes a new model of neural networks using Ordinary Differential Equations (ODE). We studied this model with the internship of François Painblanc, whose aim was to understand how the model works, to implement it and test the sensitivity of its performances depending on its parameterization and the data structure and how it could be included in existing works of the MATS project.

3.4 Active learning to assist annotation of aerial images in environmental surveys

Participants: Romain Dambreville, Chloé Friguet, Mathieu Laroze, Sébastien Lefèvre.

Remote sensing technologies greatly ease environmental assessment using aerial images. Such data are most often analyzed by a manual operator, leading to costly and non scalable solutions. In the fields of both machine learning and image processing, many algorithms have been developed to fasten and automate this complex task. Their main common assumption is the need to have prior ground truth available. However, for field experts or engineers, manually labeling the objects requires a time-consuming and tedious process. Restating the labeling issue as a binary classification one, we propose a method to assist the costly annotation task by introducing an active learning process, considering a query-by-group strategy. Assuming that a comprehensive context may be required to assist the annotator with the labeling task of a single instance, the labels of all the instances of an image are indeed queried. A score based on instances distribution is defined to rank the images for annotation and an appropriate retraining step is derived to simultaneously reduce the interaction cost and improve the classifier performances at each iteration. Then, we focus on the initialisation of the active learning algorithm, a crucial step that is not always explored in the literature. We propose a fully non supervised approach tuned for small object detection and imbalanced case. Our method use both convolutional auto-encoder (C-AE) properties and characteristics of an imbalanced data framework to propose object localisation at two different scales in a non supervised manner. C-AE embed feature representation and localisation information of object representation so that it can grasp object of interest while reconstructing background. Using convolutional auto-encoder allow a good and unsupervised set up for multi-instance learning paradigm and for extracting object position in feature maps. The main results regarding the use of a convolutional auto-encoder and the proposed strategy to initialise an active learning algorithm have been presented in a conference [25] and a symposium (https://osur.univ-rennes1.fr/news/maclean-machine-learning-for-earth-observation.html).

***Keywords**: Active learning, object detection, aerial images, data annotation, human-in-the-loop*

3.5 Optimal Transport for machine learning and remote sensing

Participants: Jean-Christophe Burnel, Laetitia Chapel, Nicolas Courty, Kilian Fatras, Romain Tavenard, Titouan Vayer.

Following our works on optimal transport for domain adaptation initiated in 2014, we developed an activity centered around the theme of optimal transport for machine learning. This research axis is mainly supported through ANR OATMIL led by Nicolas Courty.

Target shift and Domain adaptation: JCPOT. In this work, we tackle the problem of reducing discrepancies between multiple domains, i.e. multi-source domain adaptation, and consider it under the target shift assumption: in all domains we aim to solve a classification problem with the same output classes, but with different labels proportions. This problem , generally ignored in the vast majority of domain adaptation papers, is nevertheless critical in real-world applications, and we theoretically show its impact on the success of the adaptation. Our proposed method is based on optimal transport, a theory that has been successfully used to tackle adaptation problems in machine learning. The introduced approach , Joint Class Proportion and Optimal Transport (JCPOT), performs multi-source adaptation and target shift correction simultaneously by learning the class probabilities of the unlabeled target sample and the coupling allowing to align two (or more) probability distributions. Experiments on both synthetic and real-world data (satellite image pixel classification) task show the superiority of the proposed method over the state-of-the-art. Published at AISTATS 2019 [29]

Optimal Transport for structured data and Gromov-Wasserstein This line of work explores how the optimal transport distance can be used in the case where the distributions are defined in different metric spaces, making the initial formulation of the optimal transport problem uneffective. Those results were mostly obtained in the context of Titouan Vayer's PhD.

- **Fused Gromov-Wasserstein**. This work considers the problem of computing distances between structured objects such as undirected graphs, seen as probability distributions in a specific metric space. We consider a new transportation distance (i.e. that minimizes a total cost of transporting probability masses) that unveils the geometric nature of the structured objects space. Unlike Wasserstein or Gromov-Wasserstein metrics that focus solely and respectively on features (by considering a metric in the feature space) or structure (by seeing structure as a metric space), our new distance exploits jointly both information, and is consequently called Fused Gromov-Wasserstein (FGW). After discussing its properties and computational aspects, we show results on a graph classification task, where our method outperforms both graph kernels and deep graph convolutional networks. Exploiting further on the metric properties of FGW, interesting geometric objects such as Fréchet means or barycenters of graphs are illustrated and discussed in a clustering context. This work was published at ICML 2019 [35, 41].

- **Sliced Gromov-Wasserstein**. Recently used in various machine learning contexts, the Gromov-Wasserstein distance (GW) allows for comparing distributions whose supports do not necessarily lie in the same metric space. However, this Optimal Transport (OT) distance re-quires solving a complex non convex quadratic program which is most of the time very costly both in time and memory. Contrary to GW, the Wasserstein distance(W) enjoys several properties (e.g.duality) that permit large scale optimization.Among those, the solution of W on the real line, that only requires sorting discrete samples in 1D, allows defining the Sliced Wasserstein (SW) distance. This work proposes a new divergence based on GW akin to SW. We first derive a closed form for GW when dealing with 1D distributions, based on a new result for the related quadratic assignment problem. We then define a novel OT discrepancy that can deal with large scale distributions via a slicing approach and we show how it relates to the GW distance while being

O(nlog(n))to compute. We illustrate the behavior of this so called Sliced Gromov-Wasserstein (SGW) discrepancy in experiments where we demonstrate its ability to tackle similar problems as GW while being several order of magnitudes faster to compute. Published at NeurIPS 2019 [36].

Generating natural adversarial samples for remote sensing Adversarial examples are a hot topic due to their abilities to fool a classifier's prediction. There are two strategies to create such examples, one uses the attacked classifier's gradients, while the other only requires access to the classifier's prediction. This is particularly appealing when the classifier is not full known (black box model). In this paper, we present a new method which is able to generate natural adversarial examples from the true data following the second paradigm. Based on Generative Adversarial Networks (GANs), it reweights the true data empirical distribution to encourage the classifier to generate ad-versarial examples. We provide a proof of concept of our method by generating adversarial hyperspectral signatures on a remote sensing dataset. Published at C&ESAR 2019 [13]

3.6 Coupling data and models

Participants: Thomas Corpetti.

Time-consistent estimation of biophysical variables. The monitoring of biophysical variables in intense agriculture areas is a key issue in order to evaluate relationships between agriculture practices and environment quality.

To this end the recovery of biophysical variables from satellite time series in intense agriculture areas from medium resolution remote sensing data (MODIS or SENTINEL) is a key issue. However in practice, a frame-by-frame estimation is unsatisfactory since the quality of each single data is subjected to undesirable effects due to atmosphere disturbance, lighting conditions, shooting angle, etc. These effects lead to a lack of temporal consistency of resulting time series. The reconstruction of such time series is delicate using conventional interpolation methods since underlying physical processes are not taken into account. We have tackle this issue by exploiting the prior information of a plant growth model, namely GreenLab, using stochastic data assimilation techniques [3].

3.7 Coupling UAV and satellite data

Participants: Thomas Corpetti.

Unmanned Aerial Vehicles (UAV) and satellite constellations are both essential Earth observation systems for monitoring land surface dynamics. UAVs are frequently used for their capability to acquire spontaneous or opportunistic images (even under cloud coverage or during specific behavioral or phenological events); conversely, satellites are interesting for the supply of times series data on wider areas than those covered by UAVs. However, satellite spatial and temporal resolutions are often insufficient or become too expensive to provide appropriate data in heterogeneous landscapes and dynamic ecosystems, or at key periods. The combination of UAV and satellite data, defined here as 'synergy', makes it possible to overcome these problems by refining or combining information at different spatial or temporal resolutions. We have worked on this issue for the monitoring of vegetated areas [**?**, 9].

4 Software development

4.1 Software development

In compliance with ACM requirements, most of our research code is being made available through `http://gitlab.inria.fr/obelix` and `htt://github.io/myrepository` for reproducibility purposes.

In addition, the team contributed to the following pieces of software.

4.1.1 tslearn

Participants: Romain Tavenard.

`tslearn` is a general-purpose Python machine learning library for time series that offers tools for pre-processing and feature extraction as well as dedicated models for clustering, classification and regression. It follows `scikit-learn`'s Application Programming Interface for transformers and estimators, allowing the use of standard pipelines and model selection tools on top of `tslearn` objects. It is distributed under the BSD-2-Clause license, and its source code is available at `https://github.com/tslearn-team/tslearn`.

4.1.2 POT

Participants: Nicolas Courty, Laetitia Chapel, Romain Tavenard.

`POT` is an open source Python library that provides several solvers for optimization problems related to Optimal Transport for signal, image processing and machine learning. It has more than 110k downloads and 640 stars on github.

Website and documentation: `https://PythonOT.github.io/`

Source Code (MIT): `https://github.com/PythonOT/POT`

4.1.3 Triskele

Participants: François Merciol, Jérôme Moré, Charles DeltelGlenn Pedron.

`TRISKELE` stands for Tree Representations of Images for Scalable Knowledge Extraction and Learning for Earth observation. Triskele is an open source C++ library that provides several algorithms for building hierarchical representation of remote sensing images. (CeCILL-B licence)

Source Code (IRISA): `https://gitlab.inria.fr/obelix/triskele/`

4.1.4 Broceliande

Participants: François Merciol, Jérôme Moré, Charles Deltel.

`Broceliande` is a software for classification of remote sensing images. It uses TRISKELE and Random Forests. (CeCILL-B licence).

Source Code (IRISA): `https://gitlab.inria.fr/obelix/broceliande/`

4.1.5 Korrigan

Participants: François Merciol, Jérôme Moré, Behzad Mirmahboub.

`Korrigan` is a software to search patches in remote sensing databases based on Pattern Spectra. (CeCILL-B licence)

Source Code (IRISA): `https://gitlab.inria.fr/obelix/korrigan/`

5 Contracts and collaborations

5.1 International Initiatives

5.1.1 PHC Cai YuanPei – French Ministry of Foreign Affairs

Participants: Thomas Corpetti.

- Project type: PHC
- Dates: 2017–2019
- PI institution: CNRS
- Other partners: Chinese Academy of Sciences, Aerospace Institute Research Center
- Principal investigator: Thomas Corpetti

In a context of climate change, the monitoring of local climate evolution becomes crucial, especially for two main reasons:

- ensure quality of life of humans;
- ensure a sustainable agriculture.

As for the first point, prospective scenario expect that in 2050, 70% of the world population will live in cities (Unesco report, 2015). Ensuring a reliable quality of life in urban environments is then of prime importance. It is today admitted that vegetation can be an answer (it absorbs CO2, reduces heat, . . .). However, today we only have a sparse information of the vegetation inside cities (issued from public) but the amount of green areas issued from individuals is unknown. As for the second point, because of both the modifications in agricultural practices (intensive, increase in fertilization, . . .) and the climate change (increasing temperature inside parcels), the evolution of resources and potential of agriculture is a problem that has to be monitored. In both situations (urban and agriculture), it is then of prime interest to monitor, understand and model the interactions between vegetation and local climate at fine scales. Such links are today not well understood at the fine scales we are interested in. This is the goal of this project. Applications concern the cities of Rennes (France), Beijing (China) and a local agricultural parcel near to Yinchuan (China, Ningxia province).

5.1.2 MULTISCALE - PCRI 2019-2022

Participants: Laetitia Chapel, Sébastien Lefèvre, Thomas Corpetti, Minh-Tan Pham, François Merciol.

- Project type: ANR PRCI Tubitak

- Dates: 2019–2020
- PI institution: UBS
- Other partners: Costel Rennes 2, Gebze technical Univ., Istanbul technical univ.
- Principal investigator: Laetitia Chapel
- web: https://people.irisa.fr/Laetitia.Chapel/multiscale/

MULTISCALE is a research project that aims at providing a complete and integrated framework for multiscale image analysis and learning with hierarchical representations of complex remote sensing images. While hierarchical representations of RS images has led to an effective and efficient scheme to deal with panchromatic or at most multiband data, their application to complex data is still to be explored. In addition, despite their ability to encode structural and multiscale information, their so far exploitation have not reached beyond a mere superposition of monoscale analysis. In this context, the MULTISCALE project defines new methods for the construction of hierarchical image representations from multivariate, multi-source, multi-resolution and multi-temporal data, and provides some dedicated image analysis and machine learning tools to perform multiscale analysis. The new methodology will be implemented in various toolboxes used by the community to favor the dissemination of the results. Success of the project will be assessed by benchmarking the proposed framework on two remote sensing applications. Substantial breakthroughs over classical methods are expected, both in terms of efficiency and effectiveness.

5.1.3 OBIATS (Phase 2) - PHC Pamoja

Participants: Sébastien Lefèvre, Minh-Tan Pham, Jean-Christophe Burnel.

- Project type: PHC Pamoja
- Dates: 2019–2020
- PI institution: UBS
- Other partners: TU Kenya (Kenya)
- Principal investigator: Sébastien Lefèvre

The research aims to utilize the latest development of satellite based remote sensing for acquisition of timely information acquisition of spatio-temporal monitoring on tree species cover crowns within Kenya National Parks. Major application areas are as follows: 1) Development of object based image analysis algorithm for segmentation and pattern recognition of tree species crowns (specifically acacia xanthophloea spp) on remote sensing data sets. 2) Monitoring and characterization of condition and growth of tree species crown, using pixel and over-pixel based spectro- temporal analysis of Remote Sensing data. 3) Integration of step 1 & 2 to develop an integrated Remote

Sensing and Geographical Information System methodology for monitoring, mapping and analysis of tree species crown cover within Kenya National Parks. Such an initiative will be an important contribution towards natural resource management. 4) Application of raster fusion techniques on data sets of different resolutions, in order to achieve finer information details of high accuracy for surface features. More precisely, we focus on combining satellite image times series brought by the EU Copernicus Program, namely Sentinel-1 (SAR) and Sentinel-2 (optical), with single-date VHR (either aerial or satellite) imagery.

5.2 National Initiatives

5.2.1 OATMIL - ANR PRC 2017-2021

Participants: Nicolas Courty (project leader), Laetitia Chapel, Romain Tavenard.

- Project type: ANR OATMIL
- Dates: 2017–2021
- PI institution: UBS
- Other partners: INRIA-Panama (Rennes), LITIS (Rouen), Lagrange (Nice)
- Principal investigator: Nicolas Courty
- web: http://people.irisa.fr/Nicolas.Courty/OATMIL/

OATMIL is a research project that challenges some current thinkings in several topics of Machine Learning (ML). It introduces some paradigm shifts for problems related to machine learning with probability distributions. These shifts and the resulting innovative methodologies are achieved by bridging the gap between machine learning and the theory of optimal transport and the geometrical tools it offers and by rethinking the above ML problems from the optimal transport perspective. The new methodologies will be implemented as a toolbox that will be made available for the research community and potential industrial partners. The contributions of the project will be in 1) the design of new methods and algorithms for fundamental ML problems (e.g. domain adaptation) with optimal transport and 2) the definition of new algorithms for computing optimal transport and its variants on large scale collections of data.

5.2.2 SESAME - ASTRID 2017-2019

Participants: Romain Tavenard (WP leader), Laetitia Chapel, Chloé Friguet, Sébastien Lefèvre, François Merciol.

- Project type: ANR ASTRID
- Dates: 2017–2020

- PI institution: IMT Atlantique (Brest)
- Other partners: IRISA-Myriad (Rennes), CLS (Brest)
- Principal investigator: Prof. Ronan Fablet, IMT Atlantique, Signal & Comm. dept, Lab-sticc TOMS research team
- web: http://recherche.imt-atlantique.fr/sesame

The surveillance of the maritime traffic is a major issue for defense contexts (e.g., surveillance of specific zones, borders,...) as well as security and monitoring contexts (e.g., monitoring of the maritime traffic, of fisheries activities). Spaceborn technologies, especially satellite ship tracking from AIS messages (Automatic Identification System) and high-resolution imaging of sea surface, open new avenues to address such monitoring and surveillance objectives. SESAME initiative aims at developing new big-data-oriented approaches to deliver novel solutions for the management, analysis and visualization of multi-source satellite data streams. It involves four main scientific and technical tasks: Hardware and software platforms for the management, processing and visualization of multi-source satellite data streams for maritime traffic surveillance (Task 1), Analysis, modeling and detection of marine vessel behaviours from AIS data streams (Task 2), AIS-Sentinel data synergies for maritime traffic surveillance (Task 3), Visualization and mining of large-scale augmented marine vessel tracking databases (Task 4). A fifth task embeds the implementation of the proposed solutions for dual case-studies representative of the scientific and technical objectives targeted by the project.

5.2.3 DeepDetect - ASTRID 2018-2020

Participants: Luc Courtrai, Chloé Friguet, Sébastien Lefèvre (WP leader), Minh-Tan Pham (Postdoc until August 2019, Ass.Prof. from September 2019).

- Project type: ANR ASTRID
- Dates: 2018–2021
- PI institution: ENSTA Bretagne (Brest)
- Other partners: AMURE (Brest), MBDA (Paris)
- Principal investigator: Prof. Alexandre Baussard, ENSTA Bretagne (now with Univ. de Technologie de Troyes)

This project focuses on the detection and recognition of multiple small objects from remote sensing images with a variety of unknown backgrounds. The goal is to develop a deep learning architecture based on convolutional neural networks for detection and recognition purpose, and then to define relevant criteria for efficient evaluation process. The proposed framework is expected to tackle two applications: the detection and mapping of marine mammal populations from satellite images, and the detection and recognition of small vehicles in infrared images.

5.2.4 MATS - ANR/JCJC 2019-2023

Participants: Romain Tavenard (leader), Laetitia Chapel, Thomas Corpetti, Nicolas Courty, Chloé Friguet, Titouan Vayer (PhD).

- Project type: ANR JCJC
- Dates: 2019–2023
- PI institution: Univ Rennes 2
- Principal investigator: Romain Tavenard
- web: http://rtavenar.github.io/research/projects/mats.html

A huge trend in recent earth observation missions is to target high temporal and spatial resolutions (e.g. SENTINEL-2 mission by ESA). Data resulting from these missions can then be used for fine-grained studies in many applications. In this project we will focus on three key environmental issues: agricultural practices and their impact, forest preservation and air quality monitoring. Based on identified key requirements for these application settings, MATS project will feature a complete rethinking of the literature in machine learning for time series, with a focus on large-scale methods that could operate even when little supervised information is available. In more details, MATS will introduce new paradigms in large-scale time series classification, spatio-temporal modeling and weakly supervised approaches for time series. Proposed methods will cover a wide range of machine learning problems including domain adaptation, clustering, metric learning and (semi-)supervised classification, for which dedicated methodology is lacking when time series data is at stake. Methods developed in the project will be made available to the scientific community as well as to practitioners through an open-source toolbox in order to help dissemination to a wide range of application areas. Moreover, the application settings considered in the project will be used to showcase benefits offered by methodologies developed in MATS in terms of time series analysis.

5.2.5 6P - ANR/PRCE 2019-2023

Participants: Sébastien Lefèvre (WP leader), Thomas Corpetti.

- Project type: ANR PRCE
- Dates: 2019–2023
- PI institution: G&E (Bordeaux)
- Other partners: EPOC (Bordeaux), ISPA (Bordeaux), BRGM (Orléans), Avion Jaune (Montpellier)
- Principal investigator: Florian Delerue, G&E Lab., ENSEGID, Bordeaux

Mine tailings are witnesses of exploitation of ore bodies which took place several decades ago. These tailings are an important part of the 100 000 heavy-metal polluted sites which require urgent rehabilitation in Europe. These tailings represent a sizeable source of contaminated material spreadable in the environment. Despite their toxicity for non-adapted species, rare heritage plant communities, metallicolous grasslands, established on them gradually over many years. Six-P project aims to assess the role of plant-plant interactions in these specific plant communities, both as a key system to understand variation in plant-plant interactions along stress gradients and as a possible restoration tool. In mountainous areas, tailings form particularly harsh environments for plant growth (metal toxicity, climatic constraints). In such conditions, positive plant-plant interactions are expected according to a dominant ecological theory: The Stress Gradient Hypothesis (SGH). However, this hypothesis has been poorly investigated along (metal) pollution gradients. In addition, and regardless of pollution gradients, there is a need to better define its conditions of application. SixP aims to contribute to this active field of research by focusing on four directions: i) to characterize the variation of plant-plant interactions along gradients of metal phyto-availability, while explaining the specific role of metallicolous species in these interactions; ii) to better identify the effects of multiple stress factors on these interactions; iii) to specify the plant functional strategies at stake; and iv) to assess the effect of plant-plant interactions at the community scale. The project will be implemented in several mine tailings in the Pyrénées at different altitudes (in the montane zone, and at the subalpine-alpine zone). At each site, several areas will be specified from peripheral low-contaminated areas towards tailings centers corresponding to a gradient of metal phyto-availability. The first three research directions will then be addressed by experimentations manipulating species in interaction. As for the last direction, the combination of very high resolution airborne data (lidar, multispectral images) covering the studied areas with in situ observations in a deep learning framework will be used to map species distribution and their geomorphological position. Spatial patterns of the different interacting species (aggregation vs repulsion) will exhibit the effects of plant-plant interactions on the long-term. Six-P relies on a multidisciplinary consortium with expertise in ecology, metals biogeochemistry, airborne data acquisition, computer vision, machine learning and management of post-mining sites. In addition to the valuable and general knowledge acquired on plant-plant interactions, benefits are expected in the phyto-management domain, by proposing the use of several species associations as viable alternative to the already available techniques. Management of rare metallicolous grasslands of heritage value could also be improved thanks' to project results. Finally, Six-P will increase the interest of computer vision and artificial intelligence groups on ecological issues. The deep neural network models designed in SixP could also be applied to other problems in ecology, since transferability of deep networks is improving regularly.

5.2.6 Game of Trawls - FEAMP 2019-2021

Participants: Luc Courtrai, Sébastien Lefèvre, Jean-Christophe Burnel (Engineer).

- Project type: FEAMP 2014-2020 : 39 5 (Fonds europeen pour les affaires maritimes et de la peche).

- Dates: 2019–2021
- PI institution: Ifremer (Lorient)
- Other partners: Marport France SAS, Comité des Peches Maritimes du Morbihan
- Principal investigator: Julien Simon, Ifremer
- web: https://wwz.ifremer.fr/peche_eng/Le-role-de-l-Ifremer/Recherche/Projets/Description-projets/GAME-OF-TRAWLS

The main goal of the project is to allow future fishing boats to detect in real-time, with a network of sensors, the different species of fish before catching them to sort them in the trawl and thus limit discards. We will focus on underwater detection and recognition of fish species. Our data are diverse: underwater images, history of captures in a logbook, multi beam sounders, GPS, depth sensors, temperatures, . . . We therefore propose to design neural networks specialized in the detection and tracking of objects, taking advantage of multimodal data input while also taking care of efficiency for real-time processing of these data

5.2.7 SEMMACAPE - ADEME 2019-2022

Participants: Sébastien Lefèvre (project leader), Minh-Tan Pham, Deise Santana Maia (Postdoc), Behzad Mirmahboub (Postdoc).

- Project type: ADEME (Appel projet "Energies durables")
- Dates: 2019–2022
- PI institution: UBS
- Other partners: France Energies Marines (FEM, Brest), Office Francais de la Biodiversité (OFB, Brest), WIPSEA (Rennes)
- Principal investigator: Sébastien Lefèvre
- web: http://semmacape.irisa.fr/

The analysis of the development impacts of a Marine renewable energies project generally requires aerial observations of marine megafauna (marine mammals and birds) to better characterize the species that frequent these sites. The Semmacape project aims to demonstrate the relevance of software solutions for processing and analyzing aerial photographs to ensure the automated census of marine megafauna. The importance of such monitoring has been reinforced by the need for impact studies, which are required for any wind power project subject to environmental authorization. Computer vision has undergone a recent upheaval with "deep learning" in the form of deep convolutional networks. The application of these networks to aerial images for the automated observation of marine megafauna is promising, but adaptations of existing algorithms are to be expected. In particular, these animals evolve in a context (sea) characterized by a highly variable visual content, which is detrimental to the performance of these deep networks. The Semmacape project aims to respond to these scientific obstacles in order to provide a technological leap forward in the field of aerial census of marine megafauna and its application to the environmental monitoring of offshore wind farms. The main gain will lie in the completeness of the observations, while minimising the risk of identification errors and allowing a reduction in analysis time.

5.2.8 Comptage véhicules par apprentissage profond à partir d'images Pléiades (THR) - CNES R&T 2018-2019

Participants: Sébastien Lefèvre, Minh-Tan Pham, Romain Dambreville.

- Project type: CNES R&T
- Dates: 2018-2019
- PI institution: QuantCube (Paris)
- Principal investigator: Thanh-Long Nguyen (QuantCube)

Detection of new infrastructures (commercial, logistics, industrial or residential) from satellite images constitutes a proven method to investigate and follow economic and urban growth. The level of activities or exploitation of these sites may be hardly determined by building inspection, but could be inferred from vehicle presence from nearby streets and parking lots. The objective of this project is to exploit deep learning-based models for vehicle counting from optical satellite images coming from the Pleiades sensor at 50-cm spatial resolution (provided by the CNES). Both segmentation and detection architectures were investigated. These networks were adapted, trained and validated on a data set including 87k vehicles, annotated using an interactive semi-automatic tool developed by the partner Quantcube.

5.2.9 Représentation hiérarchique d'une image satellite pour l'optimisation des chaines de traitement - CNES R&T 2018-2020

Participants: François Merciol (project leader), Sébastien Lefèvre, Jérôme More, Behzad Mirmahboub.

- Project type: CNES R&T
- Dates: 2018-2019
- PI institution: UBS
- Principal investigator: François Merciol

The purpose of this study is to develop an efficient, large-scale software suite for content-based remote sensing image retrieval. The project relies on OBELIX expertise on hierarchical image representations and their use for image retrieval, and this project explores how such methods can be implemented in a scalable scenario. The study includes the design of novel tree models, efficient algorithms to build them and to search over trees structures to retrieve similar image parts. The software component is important with a dockerized solution to be provided to CNES.

5.2.10 Semantic analysis of a scene - DGA MMT 2019-2020

Participants: Sébastien Lefèvre, Bharath Bhushan Damodaran.

- Project type: DGA MMT
- Dates: 2019-2020
- PI institution: Magellium (Toulouse)
- Other partners: Thales LAS
- Principal investigator: Thomas Ristorcelli & Grégory Loeb (Magellium)

This project aims to perform semantic segmentation in operational databases using transfer learning methods and deep neural networks. The goal is to assess recent transfer learning solutions for semantic segmentation in a scenario where the training is achieved on a public, annotated dataset, while the inference targets some over operational databases where specific level of robustness are sought. Beyond evaluation of existing solutions, we develop novel methods for domain adapation, e.g. with the adaptation of DeepJDOT to the task of semantic segmentation.

5.2.11 Floodscape - CNES TOSCA 2018-2020

Participants: Sébastien Lefèvre, Gwendal Cachin-Bernard.

- Project type: CNES TOSCA
- Dates: 2018-2020
- PI institution: CEFE (Montpellier)
- Other partners: TETIS (Montpellier), Avion Jaune (Montpellier)
- Principal investigator: Doyle McKey (CNRS)

This projects aims to use optical and radar imagery, radar altimetry, and in situ observations to characterize a class of floodplains that are critical for biodiversity preservation but that raise significant challenges to spatial remote sensing. More specifically, we aim to explore the potential of deep learning for characterizing tropical savanna floodplains. We have first conducted a preliminary study to assess the performance of existing deep networks (Yolo v3) on a small dataset through the work of Arnaud Seysen. We have then proceed to a systematic analysis for a better understanding of the effect of training parameters (dataset size, network configuration, etc.) on the overall accuracy. Additional architectures for object detection and instance segmentation were explored. We also aim to address higher-level tasks such as spatial characterization of the landscape.

5.2.12 PARCELLE - CNES TOSCA 2018-2020

Participants: Thomas Corpetti, Sébastien Lefèvre, François Merciol, Charlotte Pelletier.

- Project type: CNES TOSCA
- Dates: 2018-2020
- PI institution: CESBIO (Toulouse)
- Other partners: DYNAFOR, TETIS, LaSTIG, LETG, ESPACE-DEV, LIVE, Agro ParisTech
- Principal investigator: Mathieu Fauvel (CESBIO / INRAe)

The PARCELLE project aims to foster shared developments on the iota2 processing chain that serves as the technical solution to provide national-level land cover map from 2016 to 2018. Within this project, we are more specifically dealing with the integration of multiscale, spatial descriptors to improve the iota2 classification performances. We consider both wavelet-based descriptors and attribute profiles (and their recent variants). The latter will be achieved by coupling our software libraries (e.g. TRISKELE) with the CNES Orfeo ToolBox (OTB).

5.3 Bilateral industry grants

- Wipsea, Rennes, through a scientific collaboration with Romain Dambreville (research engineer) and a CIFRE Ph.D. (Mathieu Laroze)
- Atermes, Montigny-le-Bretonneux, through a CIFRE Ph.D. (Heng Zhang)
- CLS, Plouzané, through a Ph.D. (Caglayan Tuna) co-funded with CNES
- Tellus, Bruz, through a Ph.D. (Florent Guiotte) co-funded with Région Bretagne
- SIRS, Lille, through a scientific collaboration on large-scale mapping with hierarchical image representations

5.4 Collaborations

National collaborations

- Agrocampus Ouest and IRMAR, Rennes, through a scientific collaboration with Mathieu EMILY (MCF-HDR Statistics)
- Rennes 1 University / IRISA (team LINKMEDIA) through a Ph.D. co-supervision with Ewa KIJAK (MCF Computer Science)
- AgroParisTech and MIA, Paris, through a scientific collaboration with Pierre GLOAGUEN (MCF Statistics)
- Univ. Bretagne Sud and LBCM, Lorient, through a scientific collaboration with Pierre Sauleau (MCF Marine biochemistry)
- DTIS team from ONERA, through a collaboration (PhD cosupervision of Javiera Castillo Navarro [15, 14]) with Bertrand Le Saux (CR ONERA) and Alexandre Boulch (CR ONERA), that follows a first collaboration (PhD cosupervision of Nicolas Audebert defended in 2018 [1, 2])
- DYNAFOR, through a scientific collaboration initiated with David Sheeren (MCF ENSAT) during the ASTERIX project (ended in 2017) [10]
- LITIS (Rouen), Observatoire de la Côte d'Azur (Nice), UJM (Saint-Etienne), in the context of the OATMIL ANR (e.g. [29])

International collaborations

- Wageningen University and Research, Laboratory of GeoInformation Science and Remote Sensing (The Netherlands), through a 6 months-visit for M. Laroze (Ph. D.) in this lab in 2018-19; scientific collaboration with Devis Tuia (Pr. Geospatial Computer Vision)
- Monash University (Australia), Faculty of Information Technology, through two Ph.D. co-supervisions with François Petitjean (senior research fellow in computer science) and Geoffrey I. Webb (Professor in computer science)
- ETH Zurich through the Ph.D. co-supervision/co-hosting of Ahmed Samy Nassar ([26, 28, 27]) with Jan Dirk Wegner (Ass. Prof.)
- Gebze Technical University, Kocaeli, Turkey: Erchan Aptoula (Associate Professor) is collaborating with the team on several topics, mainly related to image retrieval/classification with morphological hierarchies
- University of East Anglia, United Kingdom, through a scientific collaboration with Anthony Bagnall on time series classification
- Université des Iles Baléares (UIB), Espagne, with Bartomeu Coll (full Professor). We are co-supervising the PhD of Jamila Mifdal on image fusion (defended 2019)

- Université de Tsinghua (Chine), Aerospace Institute Research center of Chinese Academy of Sciences (Chine), visit of 6 months (professors) ans 12 months (students)

6 Dissemination

6.1 Promoting scientific activities

6.1.1 Scientific Events Organisation

General Chair, Scientific Chair

- Thomas Corpetti, Sébastien Lefèvre: JURSE'19 (Vannes): IEEE/ISPRS Joint Urban Remote Sensing Event
- Thomas Corpetti, Minh-Tan Pham, Sébastien Lefèvre: MACLEAN'19 (Würzburg): ECML-PKDD Workshop on Machine Learning for Earth Observation
- Romain Tavenard: AALTD'19 (Würzburg): ECML-PKDD time series workshop
- Chloé Friguet : Statlearn'19 (Grenoble) : challenging problems in statistical learning
- Nicolas Courty: 'Journée Optimal Transport et Machine Learning', GDR ISIS, Paris, Juillet 2019

Member of the Organizing Committees

- Chloé Friguet, Minh-Tan Pham : JURSE'19 (Vannes): Joint Urban Remote Sensing Event

6.1.2 Scientific Events Selection

Member of Conference Program Committees

- Sébastien Lefèvre: VISAPP 2019 (Prague), BiDS 2019 (Munich), LPS 2019 (Milan), ECML-PKDD 2019 (Würzburg) **(area chair)**, EarthVision 2019 (Long Beach), EARSeL 2019 (Salzburg), CBMI 2019 (Dublin); EGC 2019 (Metz), CFPT 2019 (Rouen), SFPT-GH 2019 (Toulouse), ORASIS (Saint-Dié-des-Vosges)
- Nicolas Courty: ICML, ICLR, CVPR Earthvision workshop, , ECML-PKDD 2019 (area chair), Orasis, Gretsi, CAP

Reviewer

- Charlotte Pelletier: European Conference on Machine Learning and Principles and Practice of Knowledge Discovery in Databases (ECML/PKDD), Pacific-Asia Conference on Knowledge Discovery and Data Mining (PAKDD)
- Sébastien Lefèvre: IGARSS (student contest), ICIP
- Thomas Corpetti: IGARSS (student contest), ICIP, ISPRS

- Laetitia Chapel: IGARSS, ICML, NeurIPS, AISTATS
- Romain Tavenard: KDD

6.1.3 Journal

Member of the Editorial Boards

- Chloé Friguet : Associate Editor of *Statistique et Société* (Société Francaise de Statistique)
- Minh-Tan Pham : Guest Editor of Remote Sensing, MDPI; Machine Learning, Springer
- Sébastien Lefèvre: Associate Editor of Transactions on Geosciences and Remote Sensing, IEEE; Editorial Board Member of Remote Sensing, MDPI, and ISPRS International Journal of Geo-Information, MDPI; Guest Editor of a special issue on "Image Retrieval in Remote Sensing" in Remote Sensing, MDPI
- Thomas Corpetti : Associate Editor of *Remote Sensing*.

Reviewer - Reviewing Activities

- Chloé Friguet : IEEE Transactions on Geoscience and Remote Sensing; Statistique et société
- Romain Tavenard : Journal of Machine Learning Research, Springer Data Mining and Knowledge Discovery, Signal Processing
- Charlotte Pelletier: Machine Learning, Springer; Data Mining and Knowledge Discovery, Springer; Knowledge and Information Systems, Springer; IEEE Transactions on Geoscience and Remote Sensing; IEEE Geoscience and Remote Sensing Letters; Remote Sensing of Environment, Elsevier; Remote Sensing MDPI; ISPRS Journal of Photogrammetry and Remote Sensing, Elsevier
- Minh-Tan Pham : IEEE Transactions on Image Processing; ISPRS Journal of Photogrammetry and Remote Sensing; IEEE Transactions of Geoscience and Remote Sensing; IEEE Geoscience and Remote Sensing Letters; IEEE Journals of Selected Topics for Applied Earth Observations and Remote Sensing; IEEE Geoscience and Remote Sensing Magazine ; MDPI Remote Sensing; MDPI Sensors; MDPI Journal of Imaging
- Sébastien Lefèvre: BMC Ecology, European Journal of Remote Sensing, Multimedia Tools and Applications (MTAP), Signal Processing: Image Communication
- Laetitia Chapel: Data Mining and Knowledge Discovery, Springer
- Nicolas Courty: ISPRS Journal of Photogrammetry and Remote Sensing, IEEE Transactions of Geoscience and Remote Sensing, Information & Inference

- François Merciol: Remote Sensing MDPI, IJGI MDPI, Forests MDPI, Applied Scences MDPI, Journal of Visualized Experiments
- Thomas Corpetti : Remote Sensing, IEEE TIP, IEEE JSTARS, IEEE TGRS, Image and Video Computing, Remote Sensing of Environment

6.1.4 Invited Talks

- Romain Tavenard : Weakly supervised learning for time series – Time Series Days event, Rennes, France
- Charlotte Pelletier : Journée Jeunes Chercheur·e·s MACLEAN, GdR MaDICS – Paris, France
- Ahmed Samy Nassar: Workshop on Deep Learning for Remote Sensing – Nordic Remote Sensing Conference (NoRSC'19), Aarhus, Denmark
- Sébastien Lefèvre, Ahmed Samy Nassar: Multidisciplinary Workshop on 'Revisioning transport and health" – Cambridge, UK
- Nicolas Courty: Séminaire de Mathématiques Appliquées, Université de Nantes
- Nicolas Courty: Séminaire de Mathématiques Appliquées, Université d'Angers
- Nicolas Courty: Séminaire de Statistiques et Machine Learning, ENSAI (Rennes)
- Nicolas Courty: Séminaire de l'école centrale de Nantes
- Nicolas Courty: invited talk, Valeo.AI (Paris)
- Nicolas Courty: Keynote Speaker at WOS9 (Rennes)
- Nicolas Courty: Keynote Speaker at NCCV2019 (Wagenningen, Pays-Bas)

6.1.5 Leadership within the Scientific Community

- Thomas Corpetti, Minh-Tan Pham, Sébastien Lefèvre: Chairs of the MACLEAN action within GDR MADICS
- Nicolas Courty: Chair of Optimal Transport and Signal Processing action within GDR ISIS

6.1.6 Scientific Expertise

- Sébastien Lefèvre: Member of the Expert Panel (Informatics & Knowledge Technology) of FWO (Belgium); Expert for the French Ministry of Higher Education and Research (CIR/JEI), the Czech Science Foundation (GACR), the German Space Agency (DLR)
- Nicolas Courty: expert for Norway Research Council (NRC).

6.1.7 Research Administration

- Sébastien Lefèvre: Head of OBELIX group; Member of the local committee of the doctoral school MathSTIC of UBL; Member of the Scientific Board of the "Human, Sea and Littoral" cluster within UBS; Member of the Scientific Council of the Natural Regional Park of the Gulf of Morbihan; Member of the Scientific Council of the Scientific Interest Group BreTel (Remote Sensing in Brittany); Chair of a Recruitment Committee in Computer Science (IUT Vannes). Member of a Recruitment Committee in Computer Engineering (ENSTA Bretagne).

6.2 Teaching, supervision

6.2.1 Teaching

For researchers, all activities are given. For professors and assistant professors, only courses at the M. Sc. level are listed.

- Chloé Friguet
  - Algorithmique des données, 12h, M1 INFO, Univ. Bretagne Sud, Vannes France
  - Biostatistique, 21h, M1 Biomolécules, Micro-organismes et Bioprocédés, Univ. Bretagne Sud, Lorient, France
- Romain Tavenard
  - programming, databases and deep learning, Univ. Rennes 2
- Luc Courtrai
  - concurrent programming, Master 1, Univ. Bretagne Sud, Vannes France
- Sébastien Lefèvre
  - image analysis and classification for topographic mapping, online course, EuroSDR EduServ program
  - deep learning for remote sensing, online course, EuroSDR EduServ program
  - head of the specialization track in GeoData Science (Master 2nd year) of the Copernicus Master in Digital Earth (Erasmus Mundus Joint Master Degree)
- Laetitia Chapel
  - Algorithmique des données, 12h, M1 INFO, Univ. Bretagne Sud, Vannes France
- Nicolas Courty
  - machine learning, Deep learning in Master in Computer science and Statistics engineering, Univ. Bretagne Sud, Vannes France
- Thomas Corpetti

  - Image processing, Univ. Caen
  - Image indexation, Univ. Rennes I
  - GIS and Image processing (ArcGis 10 / Python), Univ. Rennes II

6.2.2 Supervision

- PhD in progress:
  - Javiera Castillo Navarro, Semi-supervised semantic segmentation for large-scale automated cartography, 2019-2021, Sébastien Lefèvre, Alexandre Boulch (ONERA), Bertrand Le Saux (ONERA)
  - Florent Guiotte, Morphological characterization of full waveform airborne LiDAR data, 2017-2020, Thomas Corpetti, Sébastien Lefèvre
  - Manal Hamzaoui, Structured classification of structured data: application to remote sensing data, 2019-2022, Laetitia Chapel, Minh-Tan Pham, Sébastien Lefèvre
  - Mathieu Laroze, Active Learning for Object Detection in Aerial Images with Application to Environmental Science, 2016-2020, Romain Dambreville, Chloé Friguet, Sébastien Lefèvre, Ewa Kijak (Univ. Rennes 1)
  - Ahmed Samy Nassar, Learning geographic information from multi-modal imagery and crowdsourcing, 2017-2020, Sébastien Lefèvre, Jan Dirk Wegner (ETH Zurich)
  - Caglayan Tuna, Scale Spaces for Satellite Image Streams and Fast Pattern Detection, 2017-2020, Sébastien Lefèvre, François Merciol
  - Heng Zhang, Deep Learning on Multimodal Data for the Supervision of Sensitive Sites, 2018-2021, Sébastien Lefèvre, Elisa Fromont (Univ. Rennes 1)
  - Benjamin Lucas, Deep learning for the classification of Earth's Observation data, 2018-2021, Charlotte Pelletier, Geoffrey I Webb (Monash University, Australia), François Petitjean (Monash University, Australia), Daniel Schmidt (Monash University, Australia)
  - Ahmed Shifaz, Scalable and accurate time series classification algorithms, 2018-2021, Charlotte Pelletier, Geoffrey I Webb (Monash University, Australia), François Petitjean (Monash University, Australia)
  - Titouan Vayer, Optimal Transport for structured objects, 2017-2020, Nicolas Courty, Laetitia Chapel, Romain Tavenard
  - Kilian Fatras, Optimal Transport for deep learning, 2018–, with Rémi Flamary (OCA)
  - Claire Voreiter, Heterogeneous Domain Adaptation in Remote Sensing, 2018–

6.2.3 Juries

- Sébastien Lefèvre: PhD reviewer for cum laude of Diego Marcos Gonzalez (Wageningen Univ. & Research, Netherlands)

- Sébastien Lefèvre: PhD reviewer of Taibou Birgui Sekou (INSA Centre Val de Loire)
- Sébastien Lefèvre: PhD reviewer of Sébastien Villon (Univ. Montpellier)
- Sébastien Lefèvre: PhD reviewer of Dawa Derksen (Univ. Toulouse)
- Sébastien Lefèvre: PhD reviewer of Andrey Besedin (CNAM)
- Nicolas Courty: HDR jury member of Nicolas Bonneel (LIRIS, Lyon)
- Nicolas Courty: PhD reviewer of Benjamin Tardy (CESBIO)
- Nicolas Courty: PhD reviewer of esteban Bautista Ruiz (ENS Lyon)

6.3 Popularization

- Team : "Fête de la science" - Univ. Bretagne Sud
- Chloé Friguet:
  - Journée "Le numérique, des métiers en tous genres" - IUT Vannes
  - Journée "Filles et Maths, une équation lumineuse" - ENS, Rennes
  - Research Talks - IUT Vannes
- Sébastien Lefèvre:
  - Research Talks - IUT Vannes
- Laetitia Chapel:
  - Journée Femmes et science - Lorient
  - Research Talks - IUT Vannes
- Romain Tavenard:
  - Machine Learning Meetup, Rennes, France
- Nicolas Courty:
  - Machine Learning Meetup, Rennes, June 2019, France
  - Table Ronde ‘Qu’est ce que l’intelligence artificielle ?’, during ’Fête de la Science’, sept 2019, France

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