Activity Report 2018

Team OBELIX

Environment Observation through Complex Imagery

D5 – Digital Signal & Images, Robotics

1 Team composition

Head of the team

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Associate/external members

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Post-docs

Bharath Bhushan Damodaran, DeepOT project
Pierre Gloaguen, SESAME project, until August 2018
Behzad Mirmahboub, DeepTree project, since August 2018
Min-Tan Pham, DELORA project, then DeepDetect project, since October 2018

PhD students

Nicolas Audebert, ONERA grant, started in Oct. 2015, defended on Oct. 17th, 2018
Adeline Bailly, RB/ANR grant, started in Feb. 2015, defended on May 25th, 2018
Jamila Mifdal, UBS grant (with LMBA and UIB), since October 2015
Florent Guiotte, RB/Tellus grant, since October 2017
Mathieu Laroze, CIFRE Wipsea, since June 2016
Arthur Le Guennec, UR1 grant, started in Sep. 2016, withdrawn on May 31st, 2018
Ahmed Samy Nassar, OBELIX/ETH Zurich grant, since September 2017
Caglayan Tuna, CNES/CLS grant, since October 2017
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Claire Voreiter, CNES/Thalès grant, since October 2018
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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. Following the PhD of Petra Bosilj defended in 2016, we have published a survey paper on morphological hierarchies [2]. Moreover, we have shown that such hierarchies could be extracted not only from raw data but also from derived channels capturing the texture information, thus ensuring some robustness to textured images [8]. Application of hierarchies on 3D point clouds and satellite image time series are respectively addressed in the PhD of Florent Guiotte and Caglayan Tuna. Large-scale mapping initiated in 2017 was pursued [21].

We have also continued to propose and review extensions of the well-known attribute profile. While the original formulation consists in gathering the pixel values reconstructed from the multiple filtering steps, we have proposed to replace these values by some advanced features, thus leading to the so-called feature profiles [7]. We then compare these features with our previous LFAP [23], and offered a review on the field in [24].

Note that these researches on hierarchical image analysis are going to be continued within an ANR PRCI project MULTISCALE held by the team that has been accepted this year (for a starting date in 2019).

3.2 Deep Learning for Remote Sensing

Participants: Sébastien Lefèvre, Luc Courtrai, Nicolas Audebert, Minh Tan Pham, Ahmed Samy Nassar.

The Ph.D. of Nicolas Audebert jointly with ONERA on semantic segmentation was completed. During this last year, the work on data fusion was consolidated (journal publication [1]) and several new directions were taken, including: the addition of an ancillary task (distance map regression) to improve the edges of objects [9] with a satisfactory use in building detection [14], the use of generative adverserial networks to counter the lack of training samples in hyperspectral imagery [10].

In the context of the DELORA project, we start some work on object detection with the aim to detect buried networks in ground-penetrating radar data. The proposed solution was based on fine-tuning a standard Faster-RCNN network with both real and simulated data [25, 26]. Object detection (but from multiple views) is also the topic of the Ph.D. of Ahmed Samy Nassar cosupervised with Jan Dirk Wegner from ETH Zurich.

3.3 Change detection and time series analysis

Participants: Adeline Bailly, Thomas Corpetti, Romain Tavenard, Zheng Zhang, Chloé Friguet, Laetitia Chapel, Pierre Gloagen.

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. Continuing a line of work about metric learning, we have studied the use of these techniques for nearest neighbour search [11].

Scalable clustering of trajectories In the context of the surveillance of the maritime traffic, a major challenge is the automatic identification of traffic flows from a set of observed trajectories, in order to derive good management measures or to detect abnormal or illegal behaviours for example. We propose a new modelling framework to cluster sequences of a large amount of trajectories recorded at potentially irregular frequencies. The model is specified within a continuous time framework, being robust to irregular sampling in records and accounting for possible heterogeneous movement patterns within a single trajectory. The clustering is performed using non parametric Bayesian methods, namely the hierarchical Dirichlet process, and considers a stochastic variational inference to estimate the model's parameters.

Clustering of Time Series has also been explored to analyse rainfall situations in South America [6].

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.

The main results regarding the classification rate along with the chosen re-training strategy and the number of interactions with the user have been published in two conferences [17, 16].

3.5 Optimal Transport for machine learning and remote sensing

Participants: Nicolas Courty, Laetitia Chapel, Romain Tavenard.

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.

Domain adaptation and computer vision. Following our early works on domain adaptation with optimal transport, we proposed novels methods adapted to deep computer vision settings:

- **DeepJDOT: Deep Joint Distribution Optimal Transport for Unsupervised Domain Adaptation**. In computer vision, one is often confronted with problems of domain shifts, which occur when one applies a classifier trained on a source dataset to target data sharing similar characteristics (e.g. same classes), but also different latent data structures (e.g. different acquisition conditions). In such a situation, the model will perform poorly on the new data, since the classifier is specialized to recognize visual cues specific to the source domain. In this work we explore a solution, named DeepJDOT, to tackle this problem: through a measure of discrepancy on joint deep representations/labels based on optimal transport, we not only learn new data representations aligned between the source and target domain, but also simultaneously preserve the discriminative information used by the classifier. We applied DeepJDOT to a series of visual recognition tasks, where it compares favorably against state-of-the-art deep domain adaptation methods. Published at ECCV 2018 [13].
- **Detecting Animals in Repeated UAV Image Acquisitions by Matching CNN Activations with Optimal Transport**. Repeated animal censuses are crucial for wildlife parks to ensure ecological equilibriums. They are increasingly conducted using images generated by Unmanned Aerial Vehicles (UAVs), often coupled to semi-automatic object detection methods. Such methods have shown great progress also thanks to the employment of Convolutional Neural Networks (CNNs), but even the best models trained on the data acquired in one year struggle predicting animal abundances in subsequent campaigns due to the inherent shift

between the datasets. In this paper we adapt a CNN-based animal detector to a follow-up UAV dataset by employing an unsupervised domain adaptation method based on Optimal Transport. We show how to infer updated labels from the source dataset by means of an ensemble of bootstraps. Our method increases the precision compared to the unmodified CNN, while not requiring additional labels from the target set. Work done in collaboration with Wagenningen University (Prof. Tuia group), published at IGARSS 2018 [15]

Wasserstein Discriminant Analysis. Wasserstein Discriminant Analysis (WDA) is a new supervised method that can improve classification of high-dimensional data by computing a suitable linear map onto a lower dimensional subspace. Following the blueprint of classical Linear Discriminant Analysis (LDA), WDA selects the projection matrix that maxi- mizes the ratio of two quantities: the dispersion of projected points coming from different classes, divided by the dispersion of projected points coming from the same class. To quantify dispersion, WDA uses regularized Wasserstein distances, rather than cross-variance measures which have been usually considered, notably in LDA. Thanks to the the underlying principles of optimal transport, WDA is able to capture both global (at distribution scale) and local (at samples scale) interac- tions between classes. Regularized Wasserstein distances can be computed using the Sinkhorn matrix scaling algorithm; We show that the optimization of WDA can be tackled using automatic differentiation of Sinkhorn iterations. Numerical experiments show promising results both in terms of prediction and visualization on toy examples and real life datasets such as MNIST and on deep features ob- tained from a subset of the Caltech dataset. Published in the Springer Machine Learning journal [4].

Learning Wasserstein Embeddings. The Wasserstein distance received a lot of attention recently in the community of machine learning, especially for its principled way of comparing distributions. It has found numerous applications in several hard problems, such as domain adaptation, dimensionality reduction or generative models. However, its use is still limited by a heavy computational cost. Our goal is to alleviate this problem by providing an approximation mechanism that allows to break its inherent complexity. It relies on the search of an embedding where the Euclidean distance mimics the Wasserstein distance. We show that such an embedding can be found with a siamese architecture associated with a decoder network that allows to move from the embedding space back to the original input space. Once this embedding has been found, computing optimization problems in the Wasserstein space (e.g. barycenters, principal directions or even archetypes) can be conducted extremely fast. Numerical experiments supporting this idea are conducted on image datasets, and show the wide potential benefits of our method. Published at ICLR 2018 [12]

Large-Scale Optimal Transport and Mapping Estimation. This work presents a novel two-step approach for the fundamental problem of learning an optimal map from one distribution to another. First, we learn an optimal transport (OT) plan, which can be thought as a one-to-many map between the two distributions. To that end, we propose a stochastic dual approach of regularized OT, and show empirically that it scales better than a recent related approach when the amount of samples is very large. Second, we estimate a *Monge map* as a deep neural network learned by approximating the barycentric projection of the previously-obtained OT plan. This parameterization allows generalization of the mapping outside the support of the input measure. We prove two theoretical stability results of regularized OT which show that our estimations converge to the OT plan and Monge map between the underlying continuous measures. We showcase our proposed approach on two applications: domain adaptation and generative modeling. Work done in collaboration with Kyoto University, published at ICLR 2018 [27]

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` for reproducibility purposes.

4.1.1 Triskele

Participants: François Merciol.

`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/`

4.1.2 Broceliande

Participants: François Merciol.

`Broceliande` is a software for classification remote sensing image. It use TRISKELE and Random Forest. (CeCILL-B licence).

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

4.1.3 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

Website and documentation: `https://tslearn.readthedocs.io` (BSD-2-Clause license)

4.1.4 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`

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).

5.2 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, Pierre Gloaguen, 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, Romain Dambreville, Chloé Friguet, Sébastien Lefèvre (WP leader), Minh-Tan Pham.

- 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 DELORA - Pôle I&R AAP PME 2016-2018

Participants: Sébastien Lefèvre, Minh-Tan Pham (Post-doc).

- Project type: Pôle Images & Réseaux, AAP PME
- Dates: 2016–2018
- PI institution: Tellus (Bruz)
- Other partners: Artefacto (Betton)
- Principal investigator: Geoffroy Etaix (Tellus)

To meet the new requirements of major accounts such as ERDF, GRDF, Suez Environnment, La Lyonnaise des Eaux, ... who would like to perform a precise geolocation and diagnosis of their networks, TELLUS Environment wants to propose with its partners Artefacto and IRISA (OBELIX) a new product ranging from network diagnosis to operational re-geolocation by augmented reality of networks and their defects for the operators of these customers. The aim of the DELORA project is to propose a packaged product including new sensors, 3D decision support software, new multi-source data processing and augmented reality hardware.

5.2.5 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.

5.2.6 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.

- 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.

5.3 Bilateral industry grants

- Wipsea, Rennes, through a scientific collaboration with Romain Dambreville (research engineer) and a CIFRE Ph.D. (Mathieu Laroze)
- 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
- Thalès EAS, Toulouse, starting through the PhD of Claire Voreiter, co-funded with CNES

5.4 Collaborations

National collaborations

- Agrocampus Ouest and IRMAR, Rennes, through a scientific collaboration with Mathieu EMILY (MCF-HDR Statistics) [3]
- Rennes 1 University / IRISA (team LINKMEDIA) through a Ph.D. co-supervision with Ewa KIJAK (MCF) [16, 17]
- Geosciences Rennes, through a collaboration (PhD cosupervision of Arthur Le Guennec) with Dimitri Lague (DR CNRS)
- CNES, through the scientific supervision of Antoine Masse (CNES postdoc) on image denoising [20, 19, 5]
- DTIS team from ONERA, through a collaboration (PhD cosupervision of Nicolas Audebert [9, 10, 1]) with Bertrand Le Saux (CR ONERA)
- DYNAFOR, through a scientific collaboration initiated with David Sheeren (MCF ENSAT) during the ASTERIX project (ended in 2017) [18]
- LITIS (Rouen), Observatoire de la Côte d'Azur (Nice), UJM (Saint-Etienne), in the context of the OATMIL ANR (e.g. [12]).

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) [15]

- ETH Zurich through the Ph.D. co-supervision/co-hosting of Ahmed Samy Nassar 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 [7, 23, 24]
- University of Trento, Italy: Lorenzo Bruzzone (Prof.) has collaborated with the team for a survey paper on attribute profiles [24]
- TU Kenya: Anne Osio (PhD student) is regularly visiting the group to benefit from methodological expertise on image processing. A joint work has been published in GEOBIA 2018 [22]
- Université des Iles Baléares (UIB), Spain, with Bartomeu Coll (Full Prof.). We are co-supervising the PhD of Jamila Mifdal on image fusion
- University of Kyoto (collaborations with Vivien Seguy, Antoine Rolet) and NTT Japan (Matthieu Blondel) [27]

6 Dissemination

6.1 Promoting scientific activities

6.1.1 Scientific Events Organisation

General Chair, Scientific Chair

- Sébastien Lefèvre: Co-chair of the workshop "TerraData: pattern recognition and machine learning applied to Earth observation and large-scale remote sensing" within RFIAP/CFPT 2018

Member of the Organizing Committees

- Chloé Friguet:
  - Statlearn'18 (Nice): challenging problems in statistical learning
  - JPS'18 (Oleron): Jeunes probabilistes et statisticiens

6.1.2 Scientific Events Selection

Chair of Conference Program Committees

- Sébastien Lefèvre: Co-chair of the special session "Indexing, Retrieval, Annotation and Mining in Earth Observation" within CBMI 2018

Member of Organizing Committees

- Romain Tavenard: AALTD'18 (Dublin): time series workshop at ECML

Member of Conference Program Committees

- Chloé Friguet:
  - Statlearn'18 (Nice): challenging problems in statistical learning
  - JPS'18 (Oleron): Jeunes probabilistes et statisticiens
- Sébastien Lefèvre: VISAPP 2018 (Funchal), GEOBIA 2018 (Montpellier), ICISP 2018 (Cherbourg), CBMI 2018 (La Rochelle), ACIVS 2018 (Poitiers); EOFusion and DLT workshops within SAGEO 2018 (Montpellier), CFPT 2018 (Marne-la-Vallée), EGC 2018 (Saint-Denis)
- Nicolas Courty: ICLR, ICML, ECML, NIPS, CAP

Reviewer

- Sébastien Lefèvre: PRRS, ICASSP, DeepGlobe, ICIP, IGARSS, ICPRAI
- Laetitia Chapel: ICML, IGARSS, ICLR, AISTATS, NIPS
- Nicolas Courty: ICLR, ICML, ECML, NIPS, CAP, ICPR

6.1.3 Journal

Member of the Editorial Boards

- Chloé Friguet: Associate Editor of *Statistique et Société* (Société Francaise de Statistique)
- Sébastien Lefèvre: Associate Editor of Transactions on Geosciences and Remote Sensing, IEEE; Editorial Board Member of Remote Sensing, MDPI

Reviewer - Reviewing Activities

- Chloé Friguet: International Journal of Remote Sensing; Statistique et enseignement; IEEE Transactions on Computational Biology and Bioinformatics; Statistique et société
- Romain Tavenard: Journal of Machine Learning Research, Springer Data Mining and Knowledge Discovery
- Sébastien Lefèvre: Mathematical Morphology – Theory and Application, IEEE Journals of Selected Topics for Applied Earth Observations and Remote Sensing, International Journal of Remote Sensing, IEEE Transactions on Big Data, IEEE Transactions on Cybernetics, ISPRS International Journal of Photogrammetry and Remote Sensing, PLOS One
- Nicolas Courty: IEEE Transactions on Pattern Analysis and Machine Intelligence, Springer Machine Learning
- François Merciol: Sustainability MDPI, Remote Sensing MDPI, Water MDPI, Sensors MDPI

6.1.4 Invited Talks

- Romain Tavenard: An introduction to deep learning – Journées R – Rennes, France
- Sébastien Lefèvre: Deep Learning for Earth Observation – Φ-lab, ESA – Frascati, Italy
- Sébastien Lefèvre: Université Libre de Bruxelles (Belgium); Leuphana, University of Lüneburg (Germany); TU Berlin (Germany).

- Nicolas Courty, Sébastien Lefèvre: Northern Lights Deep Learning Workshop, Tromsø
- Nicolas Courty: SIGIMA Seminar, IRISA/INRIA, 2018
- Nicolas Courty: tutorial at StatLearn 2018: Optimal Transport and Machine Learning
- Nicolas Courty: Course at Polytechnic Data Science Summer School (DS3) 2018: Optimal Transport and Machine Learning, with Marco Cuturi and Rémi Flamary
- Nicolas Courty: keynote speaker, ECCV CVTask Workshop, Munich (2018)
- Nicolas Courty: keynote speaker, AI4GeoDyn Workshop, Brest (2018)
- Nicolas Courty: keynote speaker, Deep Learning Workshop, Rennes (2018)

6.1.5 Leadership within the Scientific Community

6.1.6 Scientific Expertise

- Romain Tavenard: Reviewer for the COMUE Paris Sciences Lettres call for project proposal
- Sébastien Lefèvre: Expert for the French Ministry of Higher Education and Research (CIR/JEI), the French National Research Agency (ANR), the Belgium National Research Agency (FWO), the Polish National Science Centre (NCN)

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); Member of a Recruitment Committees in Management (UBS) and in Computer Science (UBS).

6.2 Teaching, supervision

6.2.1 Teaching

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

- Chloé Friguet
  - Algorithmique des données, M1 INFO, Univ. Bretagne Sud, Vannes France

- Biostatistique, 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
- Laetitia Chapel
  - Algorithmique des données, 12h, M1 INFO, Univ. Bretagne Sud, Vannes France
- Nicolas Courty
  - programming, data mining, databases, multimedia coding, machine learning, Master in Computer science, Univ. Bretagne Sud, Vannes France

6.2.2 Supervision

- PhD in progress:
  - Jamila Mifdal, Image fusion in remote sensing images, Nicolas Courty, Jacques Froment (LMBA), Bartomeu Coll (Université des Baléares)
  - Florent Guiotte, Morphological characterization of full waveform airborne LiDAR data, 2017-2020, Thomas Corpetti, 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)
  - Titouan Vayer, Optimal Transport for structured objects, 2017-2020, Nicolas Courty, Laetitia Chapel, Romain Tavenard
- PhD defended during the year:

  - Nicolas Audebert, Machine Learning for Classification of Big Remote Sensing Data, 2015-2018, Sébastien Lefèvre, Bertrand Le Saux (ONERA)
  - Adeline Bailly, Classification de séries temporelles avec applications en télédétection, 2015-2018, Romain Tavenard, Laetitia Chapel, Sébastien Lefèvre

6.2.3 Juries

- Sébastien Lefèvre: HDR defense committee of Benoit Naegel (Univ. Strasbourg)
- Sébastien Lefèvre: PhD reviewer of Mateus Habermann (Univ. Tech. Compiègne)
- Sébastien Lefèvre: PhD reviewer of Lionel Pibre (Univ. Montpellier)
- Sébastien Lefèvre: PhD reviewer of Thierry Erudel (ISAE)
- Sébastien Lefèvre: PhD reviewer of Micael Carvalho (Univ. Pierre & Marie Curie)
- Sébastien Lefèvre: PhD reviewer of Jean Ogier du Terrail (Univ. Caen)
- Sébastien Lefèvre: PhD reviewer of Praveer Singh (Ecole des Ponts ParisTech)
- Romain Tavenard: PhD committee of Vera Shalaeva (Univ. Grenoble Alpes)
- Sébastien Lefèvre: PhD committee of Carlos Eduardo Rosar Kos Lassance (Institut Mines Telecom Atlantique)
- Sébastien Lefèvre: PhD committee of Cécile Bernard (UBS)

6.3 Popularization

- 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:
  - Journée "Mer & Numérique / Pêche" - Pôle Mer Bretagne Atlantique et Pôle Images & Réseaux, UBO, Quimper
- Laetitia Chapel:
  - Research Talks - IUT Vannes
- François Merciol:
  - Journée "Assises de la pêche durable" - Auray

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