UMR IRISA

Activity Report 2021

Team OBELIX

Environment Observation through Complex Imagery

D5 – Digital Signals and Images, Robotics

CentraleSupélec · CNRS · ENS Rennes · IMT Atlantique Bretagne-Pays de la Loire École Mines-Télécom · Inria · INSA Rennes · Université Bretagne Sud · Université de Rennes 1

1 Team composition

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Université Bretagne Sud staff

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Associate/external members

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Post-docs

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Florent Guiotte, February-September 2021, 6P project
Hoàng-Ân Lê, since January 2021, OWFSOMM project
Behzad Mirmahboub, until February 2021, DeepTree & Semmacape projects
Deise Santana Maia, until August 2021, Semmacape project
Hugo Gangloff, since October 2021, Game of Trawls & Semmacape projects
Diego Di Carlo, since July 2021, Dynalearn project

PhD students

Javiera Castillo Navaro, CNES/ONERA grant, since January 2019
Florent Guiotte, RB/Tellus/OBELIX grant, until January 2021
Manal Hamzaoui, ANR grant, since November 2019
Heng Zhang, CIFRE Atermes with Lacodam team, since December 2018
Kilian Fatras, ANR grant, defended November 2021
Iris de Gelis, CNES/Magellium grant, since January 2020
François Painblanc, ANR grant, since January 2020
Jean-Christophe Burnel, RB/FEAMP grant, since September 2020
Huy Tran, ANR grant + chaire Polytechnique, from March 2021
Paul Berg, ANR grant, from November 2021
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Joachim Nybord, Aargus University, 1 week in November

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2 Overall objectives

2.1 Overview

The overall objective of the Obelix team is the analysis of remote sensing data. In such a context, available data form a massive amount of complex, multidimensional and structured observations. Our objectives are to design and exploit **new artificial intelligence techniques** to leverage on this type of data and develop tools that help in **providing a digital twin of the Earth and understanding critical aspects of the impact of human activities on Earth planet**, such as climate change, biodiversity decline, urban growth, disaster prevention/recovery or monitoring of human living conditions or activities. Expected scientific outputs cover both theoretical and computational aspects of machine learning and computer vision dedicated to those problems, as well as applied and thematic contributions in the field of remote sensing.

2.2 Scientific foundations

2.2.1 Handling the specific nature of Remote Sensing data.

The remote sensing data have a specific nature: they are usually available in large quantities, but generally with only few labels. Some parts of the data may be missing (*e.g.* because of cloud covering) or corrupted by noises. Associated labels can furthermore be inexact or inaccurate because labelling strategies are generally inaccurate; their inherent nature change between captors. Also, large discrepancies can be observed between learning datasets and testing sets for a large number of reasons (time of acquisition, atmospheric conditions, etc.). We plan to devote a significant part of our research to the fundamental learning problems involved in those specific learning settings. This include for instance domain adaptation, data imputation, robust learning with label noise, few-shot or multi-task learning. Learning architectures will be primarily deep neural networks but not restricted to, as they might not always be the best solution to tackle those problems.

Example: *In a context of semantic segmentation of remote sensing data, one option to build a learning set is to derive labels from existing cadastral vector plans, that may suffer from registration issues with the observed image. This induces noise in the learning set labels, which negative effect on the final accuracy can be mitigated provided that the learning loss is robust to such noise. Finding computationally tractable robust optimization schemes in deep architectures, together with theoretical conditions of success, is still an open-subject in the machine learning community, and calls for further developments.*

2.2.2 Structured data

Most of the data usually inherits from structured components, that highlight pre-existing links or correlations/causality mechanisms. Those can be found in the intrinsic nature of the data (such as time series, graphs or trees). Taking the structure into account in learning or prediction scenarii, by defining proper metrics (e.g. based on sound mathematical theories such as optimal transport), embedding schemes or deep architectures (such as graph convolutional neural networks) will be considered;

Example: *A popular way to analyse remote sensing images is to rely on the object-based image analysis (OBIA) framework, where at each spatial scale specific objects of interest are extracted through segmentation, before being classified usually with some rule-based approach. However, such a methodology requires to set a high number of parameters (thus preventing its transfer to another dataset) and does not lead to a pure multiscale framework. In this context, an appealing alternative is to represent an image through a tree-based structure embedding its nested segmentations, before applying a unique classification procedure able to cope with regions from multiple scales, possibly inferring multiple labels corresponding to the land use classes that can be observed at various spatial scales. However, classification of structured data such as trees remains an open problem, especially when the processed tree is very large and contains numeric attributes; furthermore, there is not yet any robust method able to build a relevant tree structure from any kind of image.*

2.2.3 Generative modeling (GANs and beyond)

Generative modeling with neural networks has received a lot of attention in the machine learning community over the last years, through models like Variational Auto-encoders, Generative Adversarial Networks or Normalizing flows. While the use of generative modeling is mainly focused toward the generation of samples of high-dimensional objects such as images, their practical use in real applications is still in its infancy. In the context of remote sensing, we plan to use those models to tackle problems such as transfer across modalities (heterogeneous domain adaptation, or multi-modal image fusion), super-resolution, or inverse reconstruction problem with deep priors (for cloud removal applications for instance). We also consider to use those architectures for modeling physical processes. In this last case, the generation process not only relies on statistical constraints, but also on physical ones (which can be the case in super-resolution for instance, where one makes physical assumptions between the observation scales);

Example: *In a context of learning from a dataset which was acquired from a different modality (e.g. spatial and spectral resolution) than the image over which the inference is conducted, one needs some ways to adapt the learning information to tackle the observed data. This problem, known as heterogeneous domain adaptation, can benefit from generative models such as cycleGANs or normalizing flows, provided that they can operate between different modalities (i.e. different metric spaces). This is a challenging task, for which barely no solution exist at the moment, from both theoretical and algorithmic standpoints.*

2.2.4 Physics-driven Machine learning

As far as the underlying observed phenomena are physical by nature, learning tasks can leverage on existing physical models (usually in the form of PDEs) to better conduct the analysis. Coupling physical models and deep architectures (either by construction, such as neural ODEs, or by regularization schemes) will be considered. Also, in a reverse direction, recent parallels between how information is flowing in deep neural networks and statistical physics/PDEs have been made. We plan to get a better understanding of machine learning models by modeling them as interacting physical systems;

Example: *We consider here the improvement of the spatial resolution (i.e. super-resolution) of satellite images of temperatures (in the ocean or in urban/rural areas). Though some approaches have enriched neural networks with "physical layers" able to ensure some basis of physics, they are not designed to properly handle physical quantities, which can be critical for real applications. In this super-resolution context, we plan to constrain the generation process by the introduction of basic differentiable blocks of physical laws.*

2.2.5 Computational aspects

Last but not least, we will focus on efficient computational schemes for processing and analyzing large scale remote sensing data, towards a goal of green AI. Expected outputs will include novel algorithmic tools for efficient and scalable processing of big earth data, energetic efficiency of the machine learning models (by quantizing or compressing neural nets for instance), and also initiating new research axes such as combining quantum computing and machine learning for remote sensing applications.

Example: *The success of deep networks is due, among other factors, to the complexity of their underlying models (millions of learnt parameters). Training such models requires the availability of high-performance GPUs, usually far more powerful than the more conventional or embedded hardware that can be used for their inference. Since generic models usually fail to achieve perfect results in real-life scenarios due to the domain shift between the training and testing data, being able of lightly retraining the model in the deployment environment is sought. Designing very lightweight networks and networks updating schemes running on conventional/embedded hardware are challenging tasks, still largely unexplored in the community.*

2.3 Application domains

OBELIX activities contribute to Digital Twin Earth and as such aim to visualize, monitor and forecast natural and human activity on the planet in support of sustainable development.

AI tools for Copernicus The EU's EO *Copernicus* Program aims to deliver massive amounts of open remote sensing data (Petabyte scale), that can be exploited especially in its six thematic services, namely atmosphere, marine environment, land monitoring, climate change, emergency management, and security. Copernicus offers new opportunities for EO analytics, but also raises challenges related to high spatial resolution, dense time series, multiple modalities, etc. In this context, the Obelix team will design and scale-up its AI tools to make them usable by Copernicus services, e.g. land and human-settlement monitoring and climate change study at large-scale.

Climate change monitoring AI can help the monitoring and forecasting of the impacts of climate change locally (inside cities for example) and can be an appealing solution to generate reliable simulations, diagnostics and forecasts of critical situations (heat waves, pollution events for example). The anticipation of such sudden climatic events is crucial for the protection of population (UN indeed expects that more than 70% of world population will live in cities by 2050). At the moment to understand the local climate, climatologists rely on *Local Climate Zones* (LCZ) introduced in 2012 by Steward and Oke. LCZ consist of a categorization of local morphology into 17 different classes (depending on imperviousness, density of housings, vegetation etc), each of them being specific in term of local climate. Though largely used, there is no consensus about the existing classification that has been defined on the basis of US landscapes. AI will help both in the definition of more consistent LCZ and in their cartography at global scale to help the prevention of local sudden events.

Coastal and Ocean monitoring Given its geographical location on the seaside, UBS has a long experience in research activities related to the sea and the coast, now structured in its centre of excellence "Sea & Coast". OBELIX plays an active role in these activities through collaborative projects focused on maritime megafauna monitoring from aerial, underwater, and in-situ observations with partners such as OFB (French Biodiversity Agency), IFREMER (French Research Institute for Exploitation of the Sea), and FEM (Institute for Energy Transition dedicated to Marine Renewable Energies); or coastal dynamics analysis in the context of global warming.

AI for social good Obelix team will actively seek and engage in projects which goals are focused toward using artificial intelligence to address societal issues and improve the well-being of the world (also known as AI for social good), through remote sensing. Such applications generally consider the challenges for developing countries to maintain sustainable development, food and water security, and disaster relief, as well as supporting humanitarian action. As a good example, mapping large-scale socioeconomic indicators, such as poverty or education level, from high-resolution satellite imagery, is challenging because the information is not directly observable from the image, and one need to consider more complicated inference schemes, involving structural or causal dependence, to perform such tasks.

3 Scientific achievements

3.1 Optimal Transport for machine learning and remote sensing

Participants: Jean-Christophe Burnel, Laetitia Chapel, Nicolas Courty, Kilian Fatras, Romain Tavenard, Huy Tran, Clément Bonet.

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 and ANR AI Chair OTTOPIA led by Nicolas Courty.

Unbalanced Mini-Batch Optimal Transport. Optimal transport distances have found many applications in machine learning for their capacity to compare non-parametric probability distributions. Yet their algorithmic complexity generally prevents their direct use on large scale datasets. Among the possible strategies to alleviate this issue, practitioners can rely on computing estimates of these distances over subsets of data, *i.e.* minibatches. While computationally appealing, we highlight in this paper some limits of this strategy, arguing it can lead to undesirable smoothing effects. As an alternative, we suggest that the same minibatch strategy coupled with unbalanced optimal transport can yield more robust behavior. We discuss the associated theoretical properties, such as unbiased estimators, existence of gradients and concentration bounds. Our experimental study shows that in challenging problems associated to domain adaptation, the use of unbalanced optimal transport leads to significantly better results, competing with or surpassing recent baselines. Published at ICML 2021 [9]

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.

- **Online Graph Dictionary learning**. Dictionary learning is a key tool for representation learning, that explains the data as linear combination of few basic elements. Yet, this analysis is not amenable in the context of graph learning, as graphs usually belong to different metric spaces. We fill this gap by proposing a new online Graph Dictionary Learning approach, which uses the Gromov Wasserstein divergence for the data fitting term. In our work, graphs are encoded through their nodes' pairwise relations and modeled as convex combination of graph atoms, i.e. dictionary elements, estimated thanks to an online stochastic algorithm, which operates on a dataset of unregistered graphs with potentially different number of nodes. Our approach naturally extends to labeled graphs, and is completed by a novel upper bound that can be used as a fast approximation of Gromov Wasserstein in the embedding space. We provide numerical evidences showing the interest of our approach for unsupervised embedding of graph datasets and for online graph subspace estimation and tracking. Published at ICML 2021 [36]

- **Subspace Detour for Gromov-Wasserstein**. In the context of optimal transport methods, the subspace detour approach was recently presented by Muzellec and Cuturi (2019). It consists in building a nearly optimal transport plan in the measures space from an optimal transport plan in a wisely chosen subspace, onto which the original measures are projected. The contribution of this paper is to extend this category of methods to the Gromov-Wasserstein problem, which is a particular type of transport distance involving the inner geometry of the compared distributions. After deriving the associated formalism and properties, we also discuss a specific cost for which we can show connections with the Knothe-Rosenblatt rearrangement. We finally give an experimental illustration on a shape matching problem. Published as a Journal in MDPI Algorithms [2]

Factored couplings in multi-marginal optimal transport Optimal transport (OT) theory underlies many emerging machine learning (ML) methods nowadays solving a wide range of tasks such as generative modeling, transfer learning and information retrieval. These latter works, however, usually build upon a traditional OT setup with two distributions, while leaving a more general multi-marginal OT formulation somewhat unexplored. In this paper, we study the multi-marginal OT (MMOT) problem and unify several popular OT methods under its umbrella by promoting structural information on the coupling. We show that incorporating such structural information into MMOT results in an instance of a different of convex (DC) programming problem allowing us to solve it numerically. Despite high computational cost of the latter procedure, the solutions provided by DC optimization are usually as qualitative as those obtained using currently employed optimization schemes. Published at NeurIPS workshop on optimal transport [44]

Optimal Transport for learning with label noise: Wasserstein Adversarial Regularization Noisy labels often occur in vision datasets, especially when they are obtained from crowdsourcing or Web scraping. We propose a new regularization method, which enables learning robust classifiers in presence of noisy data. To achieve this goal, we propose a new adversarial regularization scheme based on the Wasserstein distance. Using this distance allows taking into account specific relations between classes by leveraging the geometric properties of the labels space. Our Wasserstein Adversarial Regularization (WAR) encodes a selective regularization, which promotes smoothness of the classifier between some classes, while preserving sufficient complexity of the decision boundary between others. We first discuss how and why adversarial regularization can be used in the context of label noise and then show the effectiveness of our method on five datasets corrupted with noisy labels: in both benchmarks and real datasets, WAR outperforms the state-of-the-art competitors. This work was published in a IEEE TPAMI [30].

Defining new algorithms for unbalanced optimal transport The problem of Unbalanced Optimal Transport (UOT) is an OT problem in which the marginal conditions are relaxed (using weighted penalties in lieu of equality) and no additional regularization is enforced on the OT plan. In this context, we have shown that the corresponding optimization problem can be reformulated as a non-negative penalized linear regression problem. This reformulation allows us to propose novel algorithms inspired from inverse problems and nonnegative matrix factorization. In particular, we consider majorization-minimization which leads in our setting to efficient multiplicative updates for a variety of penalties. Furthermore, we derive for the first time an efficient algorithm to compute the regularization path of UOT with quadratic penalties. The proposed algorithm provides a continuity of piece-wise linear OT plans converging to the solution of balanced OT (corresponding to infinite penalty weights). We perform several numerical experiments on simulated and real data illustrating the new algorithms, and provide a detailed discussion about more sophisticated optimization tools that can further be used to solve OT problems thanks to our reformulation. This work was published at NeurIPS [26].

Generating Natural Adversarial Remote Sensing Images Over the last years, remote sensing image (RSI) analysis has started resorting to using deep neural networks to solve most of the commonly faced problems, such as detection, land cover classification, or segmentation. As far as critical decision-making can be based upon the results of RSI analysis, it is important to clearly identify and understand potential security threats occurring in those machine learning algorithms. Notably, it has recently been found that neural networks are particularly sensitive to carefully designed attacks, generally crafted given the full knowledge of the considered deep network. In this article, we consider the more realistic but challenging case where one wants to generate such attacks in the case of a black-box neural network. In this case, only the prediction score of the network is accessible, on a specific dataset. Examples that lure away the network's prediction, while being perceptually similar to real images, are called natural or unrestricted adversarial examples. We present an original method to generate such examples based on a variant of the Wasserstein generative adversarial network. We demonstrate its effectiveness on natural adversarial hyperspectral image generation and image modification for fooling a state-of-the-art detector. Among others, we also conduct a perceptual evaluation with human annotators to better assess the effectiveness of the proposed method. This work was published in a IEEE TGRS [3].

3.2 Deep Neural Networks for Complex Data

Participants: Abdelbadie Belmouhcine, Jean-Christophe Burnel, Javiera Castillo Navarro, Luc Courtrai, Thomas Corpetti, Iris de Gélis, Hugo Gangloff, Hoàng-Ân Lê, Sébastien Lefèvre, Minh-Tan Pham, Heng Zhang, Deise Santana Maia, Paul Berg.

The group is playing a leading role in the field of deep learning for Earth Observation (AI4EO) since 2015. We are pursuing this activity and deal with the specific challenges raised by EO data (e.g. low resolution, multiple modalities, non-standard image data, etc.). While our methodological developments are not limited to a given thematic area, we actually put a focus on marine and coastal environments [13].

Semi- and weakly-supervised learning A major issue with deep learning (and machine learning in general) is the need for labeled samples to train the supervised models. However, raw Earth Observation data are abundant and are worth being exploited. This requires to develop less supervised learning frameworks.

Semi-supervised learning has thus been specifically addressed in the context of Earth Observation. To do so, we have designed a novel dataset called MiniFrance that is built from open data sources (e.g. French IGN, EU Copernicus) that has been made publicly available to the community. We have also tackled the semi-supervised learning problem with multi-task networks, made of a supervised branch and an unsupervised (or self-supervised) one. We have shown in an extended study published in Machine Learning [4] that our BerundaNet network architectures is very competitive vs. supervised models. Furthermore, we have explored a specific class of generative models, energy-based models and more precisely the Joint Energy-based Model, in the context of semi-supervised learning of EO data. Despite computational issues, this model is appealing since it is capable of data generation, out-of-distribution detection, and calibration anaysis. This work has recently been published in IEEE Transactions on Geoscience and Remote Sensing [5].

In the context of the Semmacape project, deal to the lack of anotated data for training fully-supervised approaches, we also address the detection of marine animals as weakly-supervised anomaly detection approach. We study two approaches. The first one involves a modification of the patch distribution modeling method (PaDiM), which is currently one of the state-of-the-art approaches for anomaly detection and localization for visual industrial inspection. As a second approach, we investigate the vector-quantized variational autoencoder (VQ-VAE) by integrating an inner metric within its discrete latent space for anomaly detection.

Weakly towards strongly supervised learning framework for remote sensing. In recent years, fully supervised fully convolutional network (FCN)-based semantic segmentation models have achieved state-of-the-art performance in the semantic segmentation task. However, creating pixel-level annotations is prohibitively expensive and laborious, especially when dealing with remote sensing images. Weakly supervised learning methods from weakly labeled annotations can overcome this difficulty to some extent and achieve impressive segmentation results, but results are limited in accuracy. Inspired by point supervision and the traditional segmentation method of seeded region growing (SRG) algorithm, a weakly towards strongly (WTS) supervised learning framework is proposed in this study for remote sensing land cover classification to handle the absence of well-labeled and abundant pixel-level annotations when using segmentation models. In this framework, only several points with true class labels are required as the training set, which are much less expensive to acquire compared with pixel-level annotations through field survey or visual interpretation using high-resolution images. Firstly, they are used to train a Support Vector Machine (SVM) classifier. Once fully trained, the SVM is used to generate the initial seeded pixel-level training set, in which only the pixels with high confidence are assigned with class labels whereas others are unlabeled. They are used to weakly train the segmentation model. Then, the seeded region growing module and fully connected Conditional Random Fields (CRFs) are used to iteratively update the seeded pixel-level training set for progressively increasing pixel-level supervision of the segmentation model. This has been published in [20].

Dealing with 3D Point Clouds 3D points cloud require specific deep architectures to deal with their irregular sampling nature. While numerous works have been developed these last years for 3D object/scene classification or 3D semantic segmentation, detection and characterizing changes between pairs of point clouds remains largely unexplored. Besides, this task is still missing some public benchmark. To fill these gaps, we have developed a point cloud simulator to mimick data that could have been acquired with airborne LiDAR or satellite photogrammetry approaches. These data have been made publicly available and were used to fairly assess and compare existing methods, in a study published in Remote Sensing [7]. Furthermore, we have proposed during ISPRS 2021 the first (to the best of our knowledge) deep network able to cope with point cloud change detection and characterization [6].

Dealing with SAR data We enhance the use of CNNs for the classification of VHR polarimetric SAR data. Due to the significant appearance of heterogeneous textures within these data, not only polarimetric features but also structural tensors are exploited to feed CNN models. For deep networks, we use the SegNet model for semantic segmentation, which corresponds to pixelwise classification in remote sensing. Our experiments conducted on the airborne F-SAR data show that for VHR PolSAR images, SegNet could provide high accuracy for the classification task; and introducing structural tensors with polarimetric features as inputs could help the network to focus more on geometrical information to significantly improve the classification performance. This work has been presented at EUSAR 2021 [33].

Dealing with multiple modalities Object detection has received specific attention, and we have proposed several approaches to combine optical and thermal sources: GAFF [38], Guided Attentive Feature Fusion (published in WACV 2021), that uses attention mechanisms to identify parts of the image that are relevant for each source. We have also assessed the inconsistency between these data sources in the context of active learning, to identify images with disagreement that mostly need annotation. This work was presented at ICIP 2021 [37]. Another strategy relies on knowledge distillation, and we actually started with using this principle to deal with the imbalance between small foreground and large background when training deep object detectors. This work was presented in BMVC 2021 [39] and laid foundations on some applications on multi-modal data presented in WACV 2022.

Self-training was also used to deal with a multi-modal scenario where an additional modality is added after completion of the training of a deep network on the first modality. The question is then how to adapt the network to deal with this new modality, without retraining a full network from scratch. Assuming the new modality comes with large amount of unlabeled data, we propose to use self-training to predict both pseudo-labels for the unlabeled modality and pseudo-modality for the labeled data. This work was presented in ORASIS 20221 [22].

In the context of marine mammals detection within the OWFSOMM project, we study the capacity of deep neural networks performed on non-optical data modalities including acoustic and radar data. For acoustic signals, we exploit and adapt deep learning detectors to their spectrograms. Our preliminary results show that the network can recognize a large number of animal calls. However, the capacity in classifying call types is still limited. Our next target is to couple other modalities including optical and radar to perform more robust detection.

Dealing with uncertainty A well-known issue with deep neural networks is their overconfident behavior. Relying on Monte Carlo Dropout, we have coupled Bayesian learning and semantic segmentation, leading to the so-called Bayesian U-Net model published in Remote Sensing [8], and able to provide uncertainty measures together with the pixel labels. Such an information is very valuable to qualify the results of a semantic map (e.g. a land cover map) and to possibly correct errors in the reference data used to train a deep network. This was was achieved by Clément Dechesne during his postdoc at CNES supervised remotely by the group.

Object tracking In the context of the Game of Trawls project, we have addressed the problem of object tracking and improved the popular DeepSORT algorithm [21]. Specifically, we involve some attention mechanism between successive images, and use the detector component together with the Kalman filter to perform motion prediction.

Learning from historical data. We have studied different strategies to classify historical panchromatic images where reference data is often scarce or not available [15].

3.3 Hierarchical Models for Efficient Analysis of EO Data

Participants: Florent Guiotte, Sébastien Lefèvre, Behzad Mirmahboub, François Merciol, Minh-Tan Pham, Deise Santa Maia.

The group has brought numerous contributions in mathematical morphology, especially on tree-based representations from which efficient algorithms can be derived. This research axis is mainly supported through ANR MULTISCALE.

Median-tree for EO retrieval While efficient algorithms for analysing large-scale images can be derived from morphological hierarchies, one of the bottleneck is the construction of the hierarchy itself from the raw data. Among inclusion trees, the tree of shapes appealing due to its self-dual property, remains more complex to be computed than the standard min and max-trees. To counter this issue, we have designed a novel tree model, called median-tree, that approximates the tree of shapes (thus ensuring the self-dual property), at a cost only slightly higher than the max-tree. This work was published in the specialty journal in mathematical morphology [16].

Based on the aforementioned model, and in the context of a CNES R&T project, we have designed a novel content-based image retrieval system allowing to retrieve patchs in large-scale satellite images. Conversely to existing approaches, it does not come with a fixed input size. It relies on the pattern spectra (i.e. an histogram measure the distribution of components properties in the image) and the retrieval problem is stated as an (sub)histogram matching search. This method was presented in the speciality conference in mathematical morphology DGMM 2021[32].

Beyond attribute profiles In the previous years, the group has extensively contributed to the field of efficient image description of EO data with attribute profiles and introduced many variants of this popular feature. It was thus time to provide a survey to the field, highlighting current challenges and future directions. This survey was published in IEEE Geoscience and Remote Sensing Magazine, the first venue for such papers in the field [19], together with a public Python library (SAP).

Additionally, in order to elaborate more robust features, we have proposed to build the morphological hierarchy (e.g. hierarchical watershed) using some supervised classification using some training data for which the label is known a priori. From these supervised hierarchies can be derived supervised attribute profiles, that provide better characterization of the image content w.r.t. their original counterpart. This method was presented in the speciality conference in mathematical morphology DGMM 2021 [34].

Finally, in the context of Caglayan Tuna PhD defended late 2020, we have presented in ICPR 2021 [35] a way to compare hierarchies built from spatio-temporal data through some projection operators, showing the relevance of our space-time tree model published in 2020.

Learning with hierarchies Hyperbolic spaces have recently attracted attention in the machine learning community as they better handle hierarchical data than Euclidean spaces. Consequently, several popular machine learning models, such as Graph Neural Networks (GNNs) and Variational Auto-Encoders (VAEs), have been successfully generalized for data embedding in hyperbolic spaces. In this paper, we investigate whether the promises given by the various works that use hyper bolic spaces can be fulfilled in a remote sensing data con text. To our knowledge, this is the first evaluation of the benefits of the hyperbolic spaces in the Remote Sensing community. We specifically focus on the remote sensing image scene classification problem, in which samples are images whose semantic labels usually have an intrinsic hierarchical structure. We use a Variational Auto-Encoder to project the data in a hyperbolic latent space and study the structure of the induced space w.r.t. the structure of the labels. We also supervise the VAE training in order to drive the latent space construction according to the class hierarchy. We carry out experiments on the remote sensing dataset PatternNet and perform an evaluation on a classification task, taking into account the inter-class hierarchical distance. Experimental results show that the Hyperbolic Space does not improve the global classification accuracy when compared with an Euclidean Space, but allows one to slightly improve the deviation among the misclassified examples when taking into account the distance between the predicted and the actual label in the label hierarchy. This work was presented in the ORASIS conference [31].

3.4 Time series analysis

Participants: Charlotte Pelletier, Laetitia Chapel, Chloé Friguet, Sébastien Lef‘evre, Romain Tavenard.

Satellite image time series analysis The group pursues its work on learning with less supervision from time series data. In this context, we have proposed a new semi-supervised domain adaptation technique, Sourcerer, which uses a regularized loss [14] to learn from satellite image time series. We also proposed TimeMatch, which demonstrates state-of-the-art results to solve cross-region unsupervised domain adaptation tasks [42]. To make the most of different modalities, we have also studied various fusion strategies to combine optical and SAR time series for crop-type mapping [17].

Multivariate time series Elastic measures have been widely used to compare univariate time-series data. We have extended eleven elastic measures to the multivariate case [43].

Scalable clustering of trajectories within a continuous time framework 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. In this paper, 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. It partitions a trajectory into sub-trajectories, or movement modes, allowing a clustering of both individuals' movement patterns and trajectories. 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, hence providing a scalable method in an easy-to-distribute framework. Performance is assessed on both simulated data and on our motivational large trajectory dataset from the automatic identification system, used to monitor the world maritime traffic: the clusters represent significant, atomic motion-patterns, making the model informative for stakeholders. This work has been published in [11].

Object-based change detection Our ongoing collaboration with TU Kenya on the topic of object-based image analysis of satellite image time series led to a novel development presented at ISPRS 2021 [18] where we propose to analyse time series of polarimetric radar data from an object perspective, with the objects being extracted from a Landsat optical image. The method was successfully applied to Acacia degradation monitoring in Lake Nakuru, Kenya.

3.5 Knowledge-driven Machine learning

Participants: Diego di Carlo, Thomas Corpetti, Nicolas Courty.

Physically driven machine learning. We have worked on the reconstruction of high dimensional turbulent fields from sparse low resolution measurements. This task, crucial in many applications spanning from geoscience to compute vision and medicine, has recently been addressed with fully convolutional deep neural network models. Though efficient, they suffer from a lack of physical consistency and they require spatial data and a large numer of pairs for training. This is sometimes incompatible with practical data (sparse like in *Particle Tracking Velocimetry*, or few fully resolved data in *Direct Numerical Simulations*). We have worked on the use of small neural networks, trained only using location coordinates and that estimate the underlying function to reconstruct the velocity. Once trained, the reconstruction at any resolution can be performed. We have explore the reconstruction using various basis (random fourier in particular) coupled with physics-based soft and hard constraints intended to minimize PDEs residuals. This work has started with Diego di Carlo's post doc and has been submitted in [40]

Knowledge driven classification. Land cover mapping over large areas is essential to address a wide spectrum of socio-environmental challenges. For this reason, many global or regional land cover products are regularly released to the scientific community. Yet, the remote sensing community has not fully addressed the challenge to extract useful information from vast volumes of satellite data. Especially, major limitations concern the use of inadequate classification schemes and "black box" effect of neural methods sometimes still limits the use by experts. In this work, we have introduced a knowledge-driven methodological approach to automatically process Sentinel-2 time series in order to produce pre-classifications that can be adapted by end-users to match their requirements. The approach relies on a conceptual framework inspired from ontologies of scientific observation and geographic information to describe the representation of geographic entities in remote sensing images. The implementation consists in a three-stage classification system including an initial stage, a dichotomous stage and a modular stage. At each stage, the system firstly relies on natural language semantic descriptions of time series of spectral signatures before assigning labels of land cover classes. The implementation was tested on 75 time series of Sentinel-2 images (i.e. 2069 images) in the Southern Brazilian Amazon to map natural vegetation and water bodies as required by a local end-user, i.e. a non-governmental organization. This has been published in [1].

4 Software development

4.1 The killer platform

Participants: Prénom Nom....

The killer platform does super smart things. Over the period, we have...

4.2 Software development

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

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

4.2.1 POT

Participants: Nicolas Courty, Laetitia Chapel, Romain Tavenard, Kilian Fatras, Huy Tran.

`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 500k downloads and 1300 stars on github. In 2021, we have received a support from CNRS to develop this software in the context of the national AI plan, with two engineers working part time on the development of the toolbox. We have also published a paper on it in JMLR Software [10]

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

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

4.2.2 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`.

4.2.3 Triskele

Participants: FranÃ§ois Merciol, Charles Deltel.

`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. It also includes

usefull fonctionnalities to produce sobel or NDVI layers and Pantex index as well. (CeCILL-B licence)

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

4.2.4 Broceliande

Participants: FranÃ§ois Merciol, Charles Deltel.

`Broceliande` is a software for classification of remote sensing images. It uses TRISKELE and Random Forests. This software is used in industrial environnements to produce land cover mapping drive by EU projects. (CeCILL-B licence).

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

4.2.5 Korrigan

Participants: FranÃ§ois Merciol, Charles Deltel.

`Korrigan` is a software to search patches in remote sensing databases based on Pattern Spectra.The goal is to offer data mining on big remote sensing image data bases. (CeCILL-B licence)

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

5 Contracts and collaborations

5.1 International Initiatives

5.1.1 MULTISCALE - PCRI 2019-2022

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

- Project type: ANR PRCI Tubitak
- Dates: 2019–2022
- 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.

5.1.2 OBIATS (Phase 2) - PHC Pamoja

Participants: Sébastien Lefèvre, Minh-Tan Pham, Hoàng Ân Lê.

- Project type: PHC Pamoja
- Dates: 2019–2021
- 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 SESURE - SEntinel time series SUper REsolution

Participants: Charlotte Pelletier (project coleader).

- Project type: CNRS GdR ISIS - Projet exploratoire
- Dates: 2021–2023
- PI institution: IRISA
- Other partners: Nicolas Audebert (Cnam)

The SEntinel time series SUper REsolution (SESURE) project is interested in developing super-resolution approaches for satellite image sequences that make the most of the temporal structure of the data. By exploiting deep learning on the mass of Sentinel-2 data acquired in France since 2015, SESURE will make it possible to infer a subpixel structure of pixels in different colours. Unlike methods of the current state of the art, which is often limited to evaluations on synthetic data, the project will rely on SPOT-6 and -7 open data as a reference for high-resolution images and Sentinel-2 for low-resolution image series. SESURE aims to quantify the informational gap between Sentinel-2 time series and very high-resolution RGB SPOT acquisitions. In particular, we will study the existence of transformations, reversible or not, allowing to pass from one modality to another, and thus to solve the frequency-resolution dilemma currently faced by the computer vision community in remote sensing.

5.2.2 ANR JCJC DeepChange

Participants: Charlotte Pelletier.

- Project type: ANR JCJC
- Dates: 2021–2025
- PI institution: CESBIO
- Other partners: Silvia Valero (CESBIO)

Accurate and up-to-date land cover information constitutes key environmental data for developing efficient policies in this era of resource scarcity and climate change. New Satellite Image Times Series offer new opportunities for detecting land cover class transitions. Nevertheless, the challenges of the "Big Data" have become imminent for the exploitation of this massive flow of data. Deep generative models are one of the most promising tools for big data analysis. The use of such models has just started to emerge in the remote sensing. In this project, Generative Adversarial Networks and Variational Autoencoders want to be explored to face common remote sensing challenges, which are the lack of reference data and the exploitation of complex and heterogeneous information. The originality of the project relies on the development of new online change detection methodologies by using generative models, which incorporate the temporal dynamics of the data and physical knowledge constraints.

5.2.3 MATS - ANR/JCJC 2019-2023

Participants: Romain Tavenard (leader), Laetitia Chapel, Thomas Corpetti, Nicolas Courty, Chloé Friguet, Francois Painblanc (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.

5.2.4 6P - ANR/PRCE 2019-2023

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

- 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

SixP aims: 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 PyrÃ©nÃ©es 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.

5.2.5 Game of Trawls - FEAMP 2019-2022

Participants: Luc Courtrai, Sébastien Lefèvre, Jean-Christophe Burnel (PhD), Abdelbadie Belmouhcine (Postdoc), Hugo Gangloff (Postdoc).

- Project type: FEAMP 2014-2020 : 39 5 (Fonds europeen pour les affaires maritimes et de la peche).
- Dates: 2019–2022
- PI institution: Ifremer (Lorient)
- Other partners: Marport France SAS, ComitÃ© 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

5.2.6 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.

5.2.7 OWFSOMM - ANR/FEM 2020-2023

Participants: Sébastien Lefèvre (scientific cochair), Minh-Tan Pham.

- Project type: PIA (CORED MRE-ITE 2019)
- Dates: 2019–2022
- PI institution: UBS
- Other partners: FEM, OFB, CEFE, Pelagis, WIPSEA, EDF Renewables, ENGIE Green, EOLFI, RWE Renewables, Ifremer
- Principal investigators: Georges Safi (FEM), Sébastien Lefèvre, AurÃ©lien Besnard (CEFE / CNRS)
- web: www.france-energies-marines.org/projets/owfsomm

The project OWFSOMM (Offshore Wind Farm Surveys Of Marine Megafauna: standardization of tools and methods for monitoring at OWF scales) aims to provide, (i) a method for conducting a robust inter-calibration of surveys at sea from mobile platforms using historical and novel technologies and, (ii) an AI suite to optimize the use of multiple sensors in order to improve their efficiency in detecting, identifying and characterizing marine megafauna.

5.2.8 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.

5.2.9 DynaLearn - Labex CominLabs 2020-2023

Participants: Nicolas Courty (project leader), Clément Bonet, Diego di Carlo, Thomas Corpetti.

- Project type: Labex CominLabs
- Dates: 2020–2023
- PI institution: UBS
- Other partners: IMT Bretagne, LMBA
- Principal investigator: Nicolas Courty, François Rousseau (IMT)
- web: https://project.inria.fr/dynalearn/

Neural networks are powerful objects used in machine learning, but poorly understood from a theoretical point of view. A recent line of research consist in studying the flow of information through or in these networks through the lens of dynamical systems and their associated Physics. The Dynalearn project aims at contributing on those aspects in a two-fold way:

- By exploring how dynamical formulation of learning process can help in understanding better learning deep neural architectures, as well as proposing new learning paradigms based on the regularization of the flows of information;
- By leveraging on novel neural architectures and available data to devise new data-driven dynamical simulation models, with applications in Earth Observation and Medical Imaging.

5.2.10 OTTOPIA - ANR Chair on AI 2021-2025

Participants: Nicolas Courty (project leader), Chloé Friguet, Minh-Tan Pham, Charlotte Pelletier, Huy Tran, Paul Berg, Renan Bernard.

- Project type: ANR Chair on AI
- Dates: 2021–2025
- PI institution: UBS
- Other partners: CNES, PicTerra, Wipsea, Ecole Polytechnique, EPFL
- Principal investigator: Nicolas Courty

Earth Observation, whether it be by satellites, airborne captors or drones, allows a better understanding of the dynamics of environmental systems or our human society. It is a decisive tool to measure the impact of mankind on earth. In the last 50 years, the fast development of spatial missions and of the technology of the associated captors yields an unprecedented amount of data, largely under-exploited. Artificial intelligence can become a major help toward exploiting this wealth of information, by automatizing tasks cantoned to human operators, or even combining them to produce novel knowledges. Yet, the earth observation data come with specific challenges not only related to their volume but also their complexity. The OTTOPIA Chair project proposes to tackle some of them through the prism of Optimal Transport theory applied to machine learning. This mathematical tool makes it possible to apprehend the data through their distributions, and no longer as a sum of distinct individuals. Following significant advances in computational aspects, it has recently emerged as a tool of choice for multiple learning problems. We propose to exploit its principles on four challenges: 1. multi-modality and considering the heterogeneity of the data at transfer of learning, 2. Learning with few data, possibly corrupted by label noise, 3. Security of AI algorithms in Earth observation; and 4. Visual Question Answering, i.e. interacting with remote sensing data through natural language questions. The contributions of the Chair will naturally aim at fundamental developments in AI but also new applied methodologies for which a strong industrial transfer potential is envisaged.

5.3 Bilateral industry grants

- Atermes, Montigny-le-Bretonneux, through a CIFRE Ph.D. (Heng Zhang)
- Magellium, Toulouse, through a Ph.D. (Iris de Gélis) co-funded with CNES

5.4 Collaborations

National collaborations

- Cnam through the exploratory SESURE projecy
- CESBIO through the ANR JCJC DeepChange
- LMBA (Univ. Bretagne Sud) through an internship co-supervision
- DTIS team from ONERA, through a collaboration (PhD cosupervision of Javiera Castillo Navarro) with Bertrand Le Saux (CR ONERA, now ESA) and Alexandre Boulch (CR ONERA, now Valeo.ai)
- LITIS (Université de Rouen Normandie, Université du Havre Normandie and INSA Rouen Normandie), through a collaboration (supervision of the Phd of Guillaume Mahey and the internship of Haoran Wu) with Gilles Gasso.
- AgroParisTech and MIA, Paris, through a scientific collaboration with Pierre Gloaguen (MCF Statistics)
- INSA and IRMAR, Rennes, through a scientific collaboration with ValÃ©rie GarÃ¨s (MCF Statistics) (supervision of the Phd of Renan Bernard and the internship of Marion Jeamard)
- LITIS (Rouen), ENS (Lyon), Ecole Polytechnique / CMAP (Palaiseau), UJM (Saint-Etienne), and Equipe Projet PANAMA (INRIA Rennes) in the context of the OATMIL and OTTOPIA projects

International collaborations

- Univ. Salzburg through several internship cosupervisions in the context of the Master Copernicus in Digital Earth
- Aarhus University through the visit of Joachim Nyborg
- Monash University (Australia), Faculty of Information Technology, through two Ph.D. co-supervisions with Geoffrey I. Webb (Professor in computer science)
- ETH Zurich through the Ph.D. co-supervision/co-hosting of Ahmed Samy Nassar with Jan Dirk Wegner (Ass. Prof.)
- EPFL (Sion), collaboration with Devis Tuia

6 Dissemination

6.1 Promoting scientific activities

6.1.1 Scientific Events Organisation

General Chair, Scientific Chair

- Charlotte Pelletier: EarthVision: Large Scale Computer Vision for Remote Sensing Imagery 2021 - `http://www.classic.grss-ieee.org/earthvision2021/`
- Thomas Corpetti, Minh-Tan Pham, Sébastien Lefèvre: MACLEAN'21 (online): ECML-PKDD Workshop on Machine Learning for Earth Observation
- Thomas Corpetti, Minh-Tan Pham, Sébastien Lefèvre: Journées inter-GdR CNRS MAGIS-MADICS-IGRV. Observation 3D : outils et verrous
- Sébastien Lefèvre co-chair, special session on Computer Vision and Machine Learning for Remote Sensing Data Analysis (IEEE ICIP 2021)
- Sébastien Lefèvre session chair, 2 sesssions at IEEE IGARSS 2021
- Laetitia Chapel: Optimal Transport and Machine Learning workshop at NeurIPS'21 (online) `https://otml2021.github.io/`.
- Romain Tavenard: ECML/PKDD Workshop on Advanced Analytics and Learning on Temporal Data (AALTD, `https://project.inria.fr/aaltd21/`.
- Nicolas Courty: Journée d'action Transport Optimal pour le traitement du signal, GDR ISIS

Member of the Organizing Committees

- Chloé Friguet : JPS'21 (Oleron, France) : colloque Jeunes Probabilistes et Statisticiens – *24-29 / 10 / 2021*

6.1.2 Scientific Events Selection

Chair of Conference Program Committees

Member of Conference Program Committees

- Sébastien Lefèvre: ECML-PKDD 2021 (area chair), DGMM, BiDS, Earthvision, CBMI, IGARSS, BMVC, PRRS, JURSE; EGC, ORASIS
- Nicolas Courty: ICML, ICLR, NeurIPS,CVPR Earthvision workshop, ECML-PKDD 2021 (area chair), Orasis, Gretsi, CAP

Reviewer

- Charlotte Pelletier: ECML-PKDD, MACLEAN, ISPRS, IGARSS
- Sébastien Lefèvre: Eurographics, ICIP, BMVC
- Nicolas Courty: ICML, ICLR, CVPR Earthvision workshop, ECML-PKDD 2019 (area chair), Orasis, Gretsi, CAP
- Laetitia Chapel: NeurIPS, ICML, ICLR, AISTATS, IGARSS, ECML-PKDD, CAp
- Romain Tavenard: NeurIPS, ICML, AALTD, CAp, OTML
- Minh-Tan Pham: ICIP, IGARSS, Earthvision
- Chloé Friguet: JournÃ©es de Statistiques 2020 (SFdS)
- Thomas Corpetti: ECML-PKDD, MACLEAN, ISPRS, IGARSS, ICIP, ICRA

6.1.3 Journal

Member of the Editorial Boards

- 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 special issues: "Paving the way for the future of Urban Remote Sensing" in the IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, "Machine Learning for Earth Observation Data" in Machine Learning Journal, Springer
- Chloé Friguet : Associate Editor of *Statistique et Société* (Société Francaise de Statistique)
- Thomas Corpetti : Associate Editor of *Remote Sensing*, *Earth* and Revue FranÃ§aise de PhotogrammÃ©trie et TÃ©lÃ©dÃ©tection.

Reviewer - Reviewing Activities

- 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; International Journal of Applied Earth Observations and Geoinformation, Elsevier; IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing
- Sébastien Lefèvre: IEEE Access, European Journal of Remote Sensing, Remote Sensing of Environment, ACM Computing Reviews

- Laetitia Chapel: Machine Learning, Springer; Data Mining and Knowledge Discovery, Springer;
- Romain Tavenard: Journal of Machine Learning Research
- Minh-Tan Pham: IEEE Transactions on Geoscience and Remote Sensing; IEEE Geoscience and Remote Sensing Letters; IEEE Geosciences and Remote Sensing Magazines; MDPI Remote Sensing; ISPRS Journal of Photogrammetry and Remote Sensing
- François Merciol: Remote Sensing MDPI, ISPRS Remote Sensing and Spatial Information Sciences, Forests MDPI
- Nicolas Courty: ISPRS Journal of Photogrammetry and Remote Sensing, IEEE Transactions of Geoscience and Remote Sensing, IEEE Transactions on Pattern Analysis and Machine Intelligence, IEEE Transactions on Neural Networks and Learning Systems
- Chloé Friguet : Statistique et société
- Thomas Corpetti : ISPRS Journal of Photogrammetry and Remote Sensing, IEEE JSTARS, IEEE TGRS, Remote Sensing of Environment, Revue FranÃ§aise de PhotogrammÃ©trie et TÃ©lÃ©dÃ©tection

6.1.4 Invited Talks

- Sébastien Lefèvre: Univ. Paris Dauphine – ENS Paris – Mines ParisTech, Master IASD, online (February)
- Sébastien Lefèvre: GDR-ISIS, online (May)
- Sébastien Lefèvre: IEEE GRSS Summer School, online (August)
- Sébastien Lefèvre: Université Libre de Bruxelles, Belgique (September)
- Sébastien Lefèvre: UBS, Master AIDN (November)
- Sébastien Lefèvre: Arctic University of Tromsø, Norway (December)
- Charlotte Pelletier: ISPRS Geospatial Lecture Day (June)
- Charlotte Pelletier: INARE (MIAT) seminar (October)
- Romain Tavenard: Séminaire de Mathématiques Appliquées, Université d'Artois (Lens)
- Minh-Tan Pham: Seminar, ML and Remote Sensing Discussion Group, USA (August)
- Nicolas Courty: journée du groupe thématique SIGMA (Signal-Image-Géométrie-Modélisation-Approximation) de la SMAI, Paris, France

- Nicolas Courty: Atelier "Domain Adaptation in Earth Observation" (MADICS Symposium) (online)
- Thomas Corpetti: “la tÃ©lÃ©dÃ©tection pour le suivi du milieu urbain”, journÃ©e de lancement du SNO (SystÃ¨me National d’Observation) "Observil"

6.1.5 Leadership within the Scientific Community

- Charlotte Pelletier: cochair of the Technical Committee 7 - Remote Sensing and Mapping for International Association for Pattern Recognition (IAPR)
- 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 German Research Foundation (DFG), the Cyprus Research Foundation (RIF), the Belgium Research Foundation (FNRS), the French Agency for Research and Technology (ANRT), the French Ministry of Higher Education and Research (CIR/JEI).
- Laetitia Chapel: member of the *comité d’évaluation scientifique* 23 (Intelligence Artificielle) for ANR ; member of the *comité d’évaluation scientifique* for the bilateral call CREST / ANR (Japan).
- Nicolas Courty: Expert for National Science Center, Poland
- Thomas Corpetti: expert french company kermap, for CNES (evaluation of TOSCA projects)

6.1.7 Research Administration

- Sébastien Lefèvre: Head of OBELIX group until March 2021; 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 the French Society for Pattern Recognition AFRIF; Member of a Recruitment Committee in Computer Science (INSA Centre Val de Loire) and in Geomorphology (UBS).
- Nicolas Courty: Head of OBELIX group from March 2021
- Laetitia Chapel: member of a Recruitment Committee in Computer Science (UBS - Ecole St Cyr).

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.

- Charlotte Pelletier
  - Master in computer science and statistics engineering (Univ. Bretagne Sud): algorithmique des données (42h)
  - Master Copernicus in Digital Earth - geodata science specialization (Univ. Bretagne Sud): Machine Learning (12h), Deep Learning (18h)
- Sébastien Lefèvre
  - head of the specialization track in GeoData Science (Master 2nd year) of the Copernicus Master in Digital Earth (Erasmus Mundus Joint Master Degree)
  - computer vision, 36h, Copernicus Master in Digital Earth, Univ. Bretagne Sud, Vannes France
- Laetitia Chapel
  - Master Copernicus in Digital Earth - geodata science specialization (Univ. Bretagne Sud): Machine Learning (12h), Deep Learning (13.5h)
- Minh-Tan Pham
  - Computer vision, 18h, Copernicus Master in Digital Earth, Univ. Bretagne Sud, Vannes France
- François Merciol
  - computer vision, 6h, Copernicus Master in Digital Earth, Univ. Bretagne Sud, Vannes France
- Nicolas Courty
  - machine learning, Deep learning in Master in Computer science and Statistics engineering, Univ. Bretagne Sud, Vannes France
  - Deep Learning and High-Performance computing, Copernicus Master in Digital Earth, Univ. Bretagne Sud, Vannes France
- Chloé Friguet
  - Biostatistique, 20h, M1 Biomolécules, Micro-organismes et Bioprocédés, Univ. Bretagne Sud, Lorient, France
- Frédéric Raimbault
  - Big Data, Master Copernicus in Digital Earth, Univ. Bretagne Sud, Vannes France,
  - Head of the first year of Master in Computer science, Univ. Bretagne Sud, Vannes France,

  - High Performance Computing for Big Data, Master in Computer science, Univ. Bretagne Sud, Vannes France,
  - Distributed Programming, Master in Computer science, Univ. Bretagne Sud, Vannes France,

- Luc Courtrai
  - concurrent programming, Master 1, Univ. Bretagne Sud, Vannes France

- Thomas Corpetti
  - Image processing, Univ. Caen
  - Image indexation, Machine Learning, Univ. Rennes I
  - GIS and Image processing (ArcGis 10 / Python), Univ. Rennes II
  - Machine Learning, copernicus master, UBS.

6.2.2 Supervision

- PhD in progress:
  - Javiera Castillo Navarro, Semi-supervised semantic segmentation for large-scale automated cartography, 2019-2022, Sébastien Lefèvre, Alexandre Boulch (Valeo.ai), Bertrand Le Saux (ESA)
  - Manal Hamzaoui, Structured classification of structured data: application to remote sensing data, 2019-2022, Laetitia Chapel, Minh-Tan Pham, Sébastien Lefèvre
  - François Painblanc, Classification algorithms for time series, 2019-2022, Romain Tavenard, Laetitia Chapel, Chloé Friguet
  - Iris de Gélis, Deep learning for time series of 3D point clouds, 2020-2022, Sébastien Lefèvre, Thomas Corpetti
  - Jean-Christophe Burnel, Deep learning for Remote Sensing with Limited Resources, 2020-2023, Sébastien Lefèvre, Luc Courtrai
  - Guillaume Mahey, Unbalanced Optimal transport for out-of-sample detection, 2021-2024, Laetitia Chapel, Gilles Gasso (INSA Rouen)
  - Paul Berg, Robust representation learning from self-supervised distillation and domain adaptation in remote sensing, 2021-2024, Nicolas Courty, Minh-Tan Pham
  - Clément Bonet, Optimal Transport Flows in machine learning, Nicolas Courty with LMBA (Francois Septier) and IMTB (Lucas Drumetz)
  - Huy Tran, Comparison of incomparable spaces, 2021–2024, Nicolas Courty with Karim Lounici and Rémi Flamary (Ecole Polytechnique/CMAP)
  - Renan Bernard, Causality and Optimal Transport, 2021–2024, Nicolas Courty Chloé Friguet and Valérie Garès (INSA Rennes/IRMAR)

- PhD defended during the year

- Benjamin Lucas, Deep learning for the classification of Earth's Observation data, 2018-2021, Charlotte Pelletier, Geoffrey I Webb (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)
- Florent Guiotte, Morphological characterization of full waveform airborne LiDAR data, 2017-2021, Thomas Corpetti, Sébastien Lefèvre
- Ahmed Samy Nassar, Learning geographic information from multi-modal imagery and crowdsourcing, 2017-2021, Sébastien Lefèvre, Jan Dirk Wegner (ETH Zurich)
- Heng Zhang, Deep Learning on Multimodal Data for the Supervision of Sensitive Sites, 2018-2021, Sébastien Lefèvre, Elisa Fromont (Univ. Rennes 1)
- Kilian Fatras, Optimal Transport for deep learning, 2018–2021, with Rémi Flamary (Ecole Polytechnique/CMAP)

6.2.3 Juries

- Charlotte Pelletier: PhD jury member of Émilien Alvarez-Vanhard (Univ. Rennes 2, France)
- Sébastien Lefèvre: PhD reviewer of Hoàng-Ân Lê (Univ. Amsterdam, Netherlands),
- Sébastien Lefèvre: PhD reviewer of Qinghui Liu (Univ. TromsÃ¸, Norway),
- Sébastien Lefèvre: PhD reviewer of Ding Lei (Univ. Trento, Italy),
- Sébastien Lefèvre: PhD reviewer of Nicholus Mboga (ULB, Belgium),
- Sébastien Lefèvre: PhD reviewer of Mohamed Chelali (Univ. Paris),
- Sébastien Lefèvre: PhD reviewer of Thanh Xuan Nguyen (Univ. Gustave Eiffel),
- Sébastien Lefèvre: PhD reviewer of Younes Zegaoui (Univ. Montpellier),
- Sébastien Lefèvre: PhD reviewer of David Duque (UnivMines ParisTech),
- Sébastien Lefèvre: PhD jury chair of Leonardo Gigli (Mines ParisTech),
- Sébastien Lefèvre: PhD jury chair of Baptiste Lafabrègue (Univ. Strasbourg),
- Sébastien Lefèvre: PhD jury chair of Philippe Caudal (CNAM)
- Laetitia Chapel: PhD jury member of François-Pierre Paty (ENSAE CREST)
- Laetitia Chapel: PhD jury member of Kimia Nadjahi (Telecom Paris)
- Laetitia Chapel: PhD jury member of Kilian Fatras (UBS)
- Romain Tavenard: PhD reviewer of Julien Audibert (Sorbonne UniversitÃ©)

- Romain Tavenard: External member of the PhD examination committee of David Guijo (Universidad de Cordoba)
- Minh-Tan Pham: PhD jury member of Sara Akodad (Univ. de Bordeaux)
- Nicolas Courty: PhD reviewer of Eduardo Hugo Sanchez (IRIT)
- Nicolas Courty: PhD reviewer of Rosanna Turrisi (Institut Polytechnique Milano)
- Nicolas Courty: PhD reviewer of Emmanuel de Bézenac (PSL)
- Nicolas Courty: PhD jury member of Raphael Duroselle (LORIA)
- Nicolas Courty: PhD reviewer of Kimia Nadjahi (Telecom ParisTech)
- Nicolas Courty: PhD reviewer of anguy Kerdoncuff (LHC, Université Jean Monnet)
- Nicolas Courty: PhD jury member of Gabriel Jouan (Université de Rennes 1)
- Thomas Corpetti: PhD reviewer of Chi-Nguyen Lam (Univ. Bretagne Occidentale)
- Thomas Corpetti: PhD jury member of Jean Eudes Gbodjo (Univ. Montpellier)
- Thomas Corpetti: PhD jury president of Ronan Rialland (Univ. Paris Saclay)
- Thomas Corpetti: PhD reviewer of Simon Rebeyrol (Univ. Toulouse)
- Thomas Corpetti: PhD jury member of Yousra Hamrouni (Univ. Toulouse)

6.3 Popularization

- Charlotte Pelletier - Interviewed for the podcast "Women in Copernicus"
- Chloé Friguet - Interviewed for the podcast "printemps de l'entreprise : data-scientist"
- Nicolas Courty Introductory conference in 'Séminaire sur l'éthique et les enjeux sociétaux de l'Intelligence Artificielle', IMT, BRain

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