Scale Spaces for Satellite Image Streams and Fast Pattern Detection.

Scientific Context

With the launch of new Earth Observation programs and satellites, spatial resolution of remote sensing images has considerably increased. While allowing many applications in various domains, it also brings strong constraints related to the efficiency of the algorithms in use (both in terms of memory and computational resources). Hierarchical representations through trees (describing level sets: min and max-trees, tree of shapes; or multi-scale segmentation: alpha- and omega-tree, binary partition tree) have proven from several years their interest in modelling and processing satellite and aerial images (Dalla Mura et al., 2010; Pesaresi et al., 2013; Florczyk et al., 2015). Besides, some recent works have shown their scalability (Carlinet et al., 2014; Havel et al., 2016; Wilkinson et al., 2016). These representations thus offer a framework particularly interesting for image analysis in a scale-space, whose interest in remote sensing is well known (Liu, 2007).

However, the improvement in spatial resolution is not the only evolution faced recently by spatial remote sensing. Indeed, new programs such as those launched by Copernicus (Sentinel) or Google (Skyview) aim to increase very significantly observation frequencies of a given geographical site, with a revisiting time decreased to a few days. In this context, the available information is not only spatial but temporal too. Efficient tools are still required to deal with this data volume (several terabytes for Sentinel), but they have to go beyond a purely spatial processing of the processed images. Scale-spaces can then be built to represent spatio-temporal data, following former developments on spatio-temporal graphs for spatio-temporal segmentation (Héas, 2005; Le Men, 2009).

From an application point of view, it is important to recall that tree-based representations have been mainly used to describe the spatial neighbourhood of pixels in the context of land cover mapping (Dalla Mura et al., 2010; Pesaresi et al., 2013; Florczyk et al., 2016). However, information brought by the trees can be used to solve other tasks, in particular fast detection of patterns or objects of interest.

Objectives and novelty of the project

The aim of this doctoral project is to adapt the tree-based image representation paradigm to the case of multi-temporal images or satellite image time series, and to use it in the context of pattern or object detection from remote sensing. Different strategies will be studied: describing each pixel by a time series before constructing the corresponding tree, building a tree for each image of the series before merging the trees, etc.

Every tree node will thus be equipped with descriptors able to characterize its content. Spatial and spectral information that are commonly used will thus be coupled with temporal information. Besides, since the tree is providing a multi-scale analysis framework, applying it to time series will allow the analysis to be conducted at several spatial and/or temporal scales.

Finally, we will adapt methodologies in machine learning / pattern recognition commonly used in remote sensing to the case of tree-based representations, in order to design original and fast object detection methods. Several methods will be considered to underline the generic behaviour of the proposed representation: indexation by local descriptors, rule-based classification, and deep learning will be among the targeted choices.

Novelty of this project is brought by several factors:

1) While numerous algorithms exist to build trees from still images, their extraction from time series remains largely unexplored (beyond the recent PhD thesis of Alonso-González at UPC Barcelona, 2014). Updating such a representation in an online framework (able to cope the arrival of new images) has never been taken into account yet. Spatio-temporal representations are still limited to a single spatial scale (spatio-temporal graphs).

2) In order to characterize the tree content, the description of each single node still only deals with spatial or spectral information (Bosilj et al., 2015; Aptoula et al., 2016). Analysis of satellite image time series could rely on such spatial-spectral descriptors, but also on (temporal) complementary information that will benefit from dedicated descriptors, able to take into account the specificity of such temporal signals (missing, noisy, low-sampling data). Besides, it is possible to combine this temporal dimension with spatial and spectral ones in order to offer a more precise characterization of image content.

3) Trees are most often used to compute a description of the image or its pixels, a segmentation or image partition, or a filtering through removal of elements that do not fulfil certain criteria. Very few studies are dealing with using the trees in an object detection task. Works conducted in the OBELIX team are among the first ones in this context, and have mainly dealt with local descriptors (PhD in 2016 of Petra Bosilj; Bosilj et al., 2016), kernel methods (PhD in progress of Yanwei Cui; Cui et al., 2016) or with probabilistic graphical models (MSc of Abdullah Al-Dujaili, 2014; Al-Dujaili et al., 2015). In this doctoral project, we would like to explore different complementary strategies for pattern/object detection in time series in order to cope with the various use cases that can be encountered:

- Relying on local descriptors within an indexing scheme, similarly to those used in content-based image retrieval. In this context, the goal will be to extend our previous works dedicated to still images (Bosilj et al., 2016);

- Using a ruleset within a decision-tree approach: given a set of rules predefined by the user, the goal is to scan the tree in order to identify nodes (or spatio-temporal patterns) for which the different rules hold. Applying such an approach with successive rules on tree-based representations remains rarely explored (Merciol et Lefèvre, 2015b), and even unexplored for satellite image time series; while it would allow enriching this methodology with a multi-scale analysis;

- Studying neural nets for deep learning. While being promising, coupling such models with tree-based representations has not been widely studied and remains an open problem. We will rely here on recent developments in deep learning of structured data, such as structural-RNN for spatio-temporal graphs (Jain et al., 2016).

These different strategies will benefit from the underlying tree-based structure to present appealing properties. Indeed, they will lead to fast and scalable solutions, without requiring any assumptions on the analysis scale where objects are to be sought, conversely to most existing works on spatio-temporal graphs.

Research environment

Within IRISA, the OBELIX team (www.irisa.fr/obelix) deals with (image) data analysis and mining for environmental purposes. Data considered are massive, multidimensional (multi or hyperspectral), noisy, heterogeneous (multi-source), and show a spatiotemporal behaviour (satellite image time series).

Among the models explored by the team, morphological trees provide an image representation at several spatial scales, and have been addressed in several works (see references). However, each tree is currently built (and processed) from a single image (single-date satellite observation). On the opposite, the team is conducting researches on analysis of satellite image time series (e.g. PhD of Adeline Bailly) but these works do not take into account the spatial information.

Some studies have been conducted in the team to built and exploit alpha-trees from video sequences. We have thus mapped a video by a 3D volume (Merciol and Lefèvre, SITIS 2012), before suggesting updating a 2D tree in an incremental or online framework (Merciol and Lefèvre, ACIVS 2015). However, these works have not been applied to satellite image time series but to low-resolution videos (few pixels, few frames) containing low information (few objects).

In the context of pattern or object detection, the team has demonstrated the relevance of such tree-based representation for still images, given several detection strategies: indexation and aggregation of local descriptors (Bosilj et al., 2016), classification with kernel-based (Cui et al., 2016) or rule-based (Merciol et Lefèvre, 2015b) methods. These previous developments will thus bring research directions to adapt object/pattern detection to the case of satellite image time series. Besides, the team benefits from some expertise in deep learning (PhD of Nicolas Audebert; Audebert et al., 2016) that could be exploited to adapt this paradigm to tree-based representations.

Within the scope of the SESAME collaborative project (see below), the TOMS team of Lab-STICC (R. Fablet) will contribute to PhD supervision. It will bring its expertise in satellite image processing (both optical and radar), motion data analysis, multi-scale statistical modelling, and will ease the integration of the PhD work into the collaborative project SESAME for which it acts as the main coordinator.

National and international collaborations
This project is closely related to the SESAME project (ANR/DGA ASTRID program, 2017-2020), which aims to analyse multisource data streams (optical and radar Sentinel images, AIS data) for maritime security applications. This project and its partners (Lab-STICC, IRISA-Obelix et Myriads, CLS) will provide the data required by the study (satellite image such as Sentinel-1, Sentinel-2; reference data and expert knowledge to validate the results in pattern detection), a dedicated computing infrastructure to ensure scalability, and also some additional financial support (e.g. to allow travelling and attending conferences).

Beyond the SESAME project, the PhD will benefit from the national and international network of the supervising team. In this context, a doctoral mobility to the team of Jón Atli Benediktsson in Reykjavik or of Philippe Salembier in Barcelona could be considered.

Impact
Current and future Earth Observation spatial programs, such as Copernicus (www.copernicus.ue) at the European level, require scalable analytics tools (high spatial and spectral resolution, spatial coverage, increasing temporal revisiting) that are still missing. The works to be conducted in this project are particularly adapted to satellite image time series freely provided by the Copernicus program (Sentinel data). Besides, technology transfer towards SIRS, a partnering SME specialized in production of geographic maps from remote sensing (in particular using Copernicus data such as SIRS or CLS SMEs), could be pursued depending on the achieved results.

Supervision
Sébastien Lefèvre (Full Professor, Université Bretagne Sud), sebastien.lefevre@irisa.fr
François Merciol (Ass. Professor, Université Bretagne Sud), francois.merciol@irisa.fr

PhD project will be conducted within the OBELIX team at IRISA, Vannes (Brittany, France).

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Candidate Profile

The applicants are expected to be graduated in computer science and/or signal & image processing and/or applied mathematics, and show an excellent academic profile and demonstrated ability to conduct research works.

More precisely, following skills are required:
- image processing
- graph (tree) theory and algorithms
- strong programming ability in C++ or Java

Beyond, knowledge in one or several of the following topics would be appreciated:

- classification (rule-based, decision trees, neural networks, etc.)
- analysis/processing of time series
- remote sensing
- parallelism
- data analytics
- multimedia communication / streaming