Robust event detection for complex data

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Summary

The detection of events in signals of various types (sound, image, video, ...) plays a key role in many critical applications, ranging from health (fall detection) to disaster prevention (earthquake detection) or critical situations (pedestrian detection). A major issue of detection systems based on artificial intelligence and data is the control of uncertainties related to the predictions of these models, in particular to limit the error rates.

The goal of this thesis is to develop generic methods to quantify the uncertainty and to control in a fine way the various prediction errors, whether they are false positives (for example, recognizing an obstacle when there is none) or false negatives (not reporting obstacles when there are). By generic, we mean that we can apply these methods to any type of predictor, whether it is a deep neural network or not. We also intend to focus on structured and complex data, such as images, videos or multidimensional temporal signals.

Thesis description

1) The research topic and its context

Modern artificial intelligence tools allow to obtain predictive models with astonishing performances, with accuracy levels that would have been difficult to imagine a few years ago. This is particularly true for complex and structured signals such as spatio-temporal signals (images, video, frequency recordings). Nevertheless, recent artificial intelligence tools do not generally quantify the uncertainty associated with their predictions, which can lead to errors of judgement with serious consequences (one can think of accidents caused by autonomous cars having misrecognized their environment).

Equipping AI-based predictive tools and models with the ability to quantify their uncertainty as accurately as possible is therefore essential, on the one hand, to guarantee the proper functioning of these tools, and on the other hand, to make their use acceptable in high-stakes situations.

If such a quantification seems difficult and still far away for some domains such as natural language (one can think of chatGPT, which despite its impressive performances can provide false information while claiming to be certain), it is not the same for other types of tasks with important social and economic stakes. One such task that we propose to address in this thesis concerns the detection of events from complex signals, be they images, sounds, frequency spectra, etc. Indeed, the problem of event detection plays important roles in many domains: in health with for example the detection of signs of premature deliveries from EEG signals, or the fall of elderly people from sounds; in environment with for example the prevention of disasters via the early detection of earthquakes via sounds or forest fires via images (taken by drones); in transport with the detection of obstacles for autonomous vehicles (train or car) or with the detection of failures.

It is only recently that uncertainty quantification tools such as conformal prediction [1] or belief function approaches [2] have been combined with modern artificial intelligence approaches such as neural networks, and there are still many tasks where these methods need to be developed and adapted. Addressing this last need is the core of the chosen thesis topic.

2) Foreseen results

We expect the thesis work to achieve some of the following goals:

- **Development of generic event detection methods** for complex spatiotemporal signals, with uncertainty quantification of the obtained predictions. Our priority will be to develop and test new methods based on conformal prediction, a tool now developed and integrated by most of the most recent uncertainty quantification libraries, such as MAPIE from the start-up Quantmetry or the FORTUNA library developed by AMAZON. Beyond publications in recognized AI journals and conferences, a factor of success would therefore be the integration of the approaches developed within such libraries.

- **Object recognition in images and videos,** with control of recognition error rates. This first playground mastered in the Heudiasyc laboratory will allow us to validate the approaches, as well as to apply them to a task present in many problems, such as obstacle recognition for an autonomous car, traffic light recognition from aerial images, or recognition of unusual behaviors in a public place. Given the state of the art in the lab and on uncertainty quantification, we will first focus on static images, before adding the temporal dimension via videos. Beyond publications in recognized AI journals and conferences, a factor of success would be for example the integration of our algorithms and methods in the cars of Renault, a historical partner of the laboratory already interested by these methods.

3) Topic state in the laboratory.

The research conducted at the Heudiasyc laboratory, and more generally at the University of Technology of Compiègne, is at the heart of the concerns we have just mentioned. The laboratory is indeed recognized for its strong expertise on the problems of uncertainty quantification within AI. We can for example mention the invited intervention at COPA of Sébastien Destercke on the subject [3], or the industrial chair SAFE AI (https://www.hds.utc.fr/en/research/projets-et-contrats/safe-ia-chair.html) that finance the present proposal.

On the theoretical aspects of the foreseen subject, the laboratory has a very strong expertise on two formal frameworks which will be retained as two potential solutions: on the one hand, belief functions [4], which generalize probabilities and allow to differentiate in their quantification the different natures of uncertainty (for example, the one due to a natural variability from the one due to a lack of knowledge), on the other hand, conformal prediction, which allows to provide predictions in the form of a set while guaranteeing that the error rate will not exceed a given value. This last approach has recently been the subject of laboratory work (in partnership with SOPRA/STERIA) in the case where the model had to predict several outputs simultaneously [5], and has been implemented by the company Q-park in order to jointly control performance indicators. It should be noted that this type of approach is only beginning to be implemented in event detection problems such as object detection in images [6], and that the Heudiasyc laboratory has the ideal skills to develop these approaches and provide new solutions.

On the more finalized aspects, the presence of platforms dedicated to autonomous vehicles and of the joint laboratory SIVA-lab with Renault designates the recognition and localization of obstacles in images as an ideal task to be tackled, due to the joint presence of data, field expertise and the possibility of conducting experiments within the Heudiasyc laboratory and the supervisory team (in the person of Philippe Xu). In order to test the generality of our methods, we will however be interested in other types of tasks that naturally find their place in the SAFE AI chair, such as the detection of falls in retirement homes, using data from the e-biomed chair (http://ebiomed.bmbi.utc.fr/equipe/).

5) Potential collaborations

We have already mentioned the possible collaborations within the laboratory as well as within other laboratories of the UTC (BMBI). In addition to these, we can mention other collaborations that could benefit from the methods developed in this thesis, for example:

- Collaborations with the Roberval laboratory, also a partner of the SAFE AI Chair, on the problems of defect recognition (subject of a thesis co-supervised by Heudiasyc and Roberval)
- Collaborations with the bioinformatics department of Cranfield University, in England. We plan to collaborate with Maria Anastasiadi on a problem of honey quality recognition based on weak signals (https://www.stfcfoodnetwork.org/blog/sweet-success-a-new-technology-to-help-honey-producers).

Beyond these collaborations, which concern rather finalized or applied subjects, let us mention the existence of an existing international collaboration network that meets regularly during the WUML (Worskhop on Uncertainty in Machine Learning) workshops, the next iteration of which will take place in Ghent (https://sites.google.com/view/wuml2023) and which were initiated by Sébastien Destercke, among others. The existence of this network makes it possible to envisage collaborations, at least punctually, with the universities of Ghent, Munich or Eindhoven, in teams specialized in machine learning and uncertainty quantification. The quantification of different types of uncertainties is indeed an object of collaboration already active between the members of the network [7],[8].

6) Application detailsand sought profile

We are looking for students having a master degree in computer science and/or mathematics, with demonstrably good skills in one or multiple of the following fields: machine learning, statistics, uncertainty quantification, signal or image processing

Applications must include the following items:

- a letter of motivation detailing explicitly what are the interest of the applicant in the proposed topic;
- a curriculum vitae which clearly shows how the candidate profile matches the above requirements and highlights how the candidate experience relates to the proposed topic;
- contact information of at least one reference (two or more would be appreciated).
- transcripts and existing theses;

Any application not containing these items, or not tailored to this proposal, will not be considered further. In addition, the following optional items may be included:

- existing scientific papers;
- any link to significant realisations (e.g., software, . . .).

7) references

[1] Angelopoulos, A. N., & Bates, S. (2021). A gentle introduction to conformal prediction and distribution-free uncertainty quantification. arXiv preprint arXiv:2107.07511.

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[4] Tong, Z., Xu, P., & Denoeux, T. (2021). An evidential classifier based on Dempster-Shafer theory and deep learning. Neurocomputing, 450, 275-293.

[5] Messoudi, S., Destercke, S., & Rousseau, S. (2021). Copula-based conformal prediction for multi-target regression. Pattern Recognition, 120, 108101.

[6] de Grancey, F., Adam, J. L., Alecu, L., Gerchinovitz, S., Mamalet, F., & Vigouroux, D. (2022). Object detection with probabilistic guarantees: A conformal prediction approach. In International Conference on Computer Safety, Reliability, and Security (pp. 316-329). Springer, Cham

[7] Hüllermeier, E., Destercke, S., & Shaker, M. H. (2022, August). Quantification of credal uncertainty in machine learning: A critical analysis and empirical comparison. In Uncertainty in Artificial Intelligence (pp. 548-557). PMLR.

[8] Hüllermeier, E., & Waegeman, W. (2021). Aleatoric and epistemic uncertainty in machine learning: An introduction to concepts and methods. Machine Learning, 110(3), 457-506