DE LA RECHERCHE À L'INDUSTRIE

Deep Learning and Image Processing for the Automated Analysis of Thermal Events on the First Wall and Divertor of Fusion Reactors

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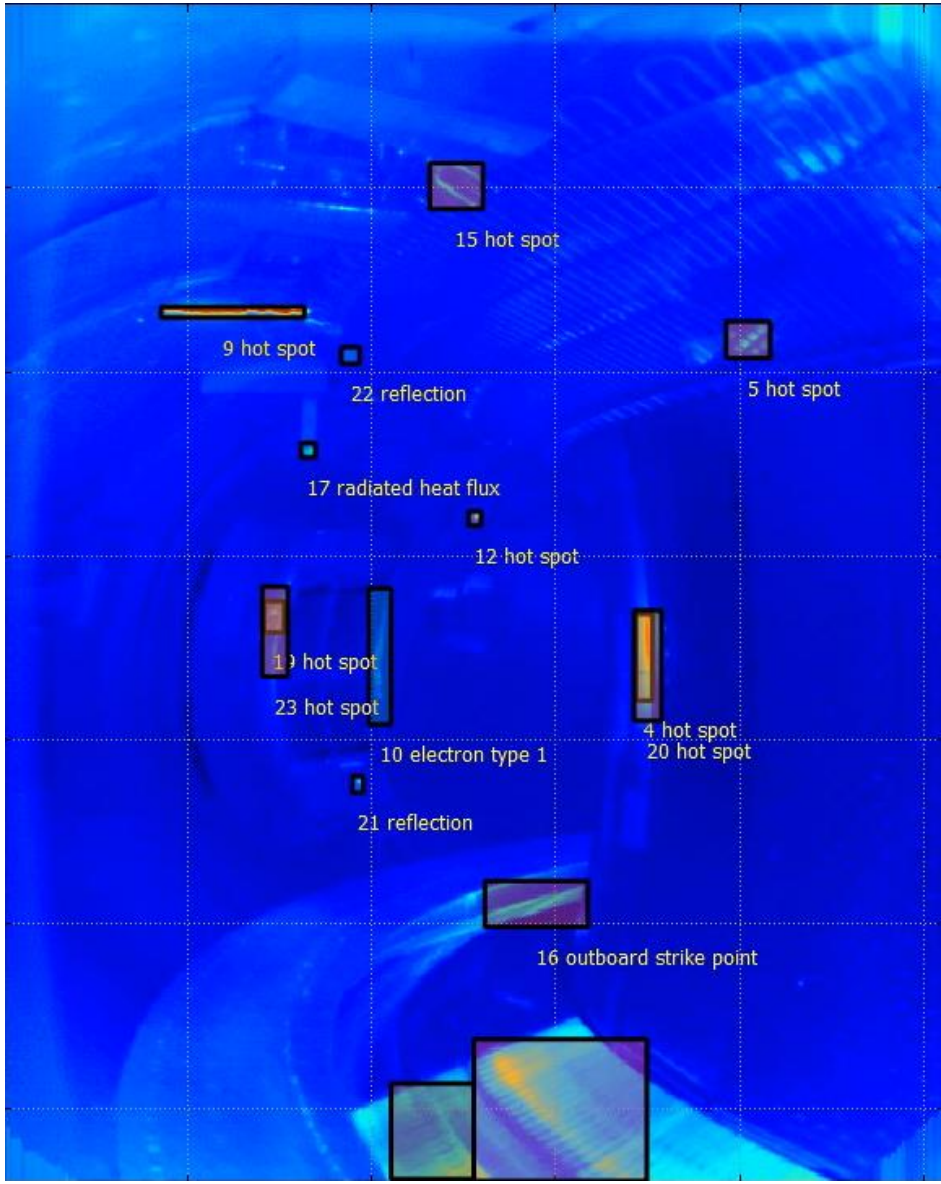
Introduction

- Automated process for the detection, tracking, and classification of thermal events in infrared movies
- Compatible with a real-time use during fusion machine operation, for machine monitoring and protection
- Trained and tested on data from the WEST tokamak, located in Cadarache, in the South of France, right next to ITER



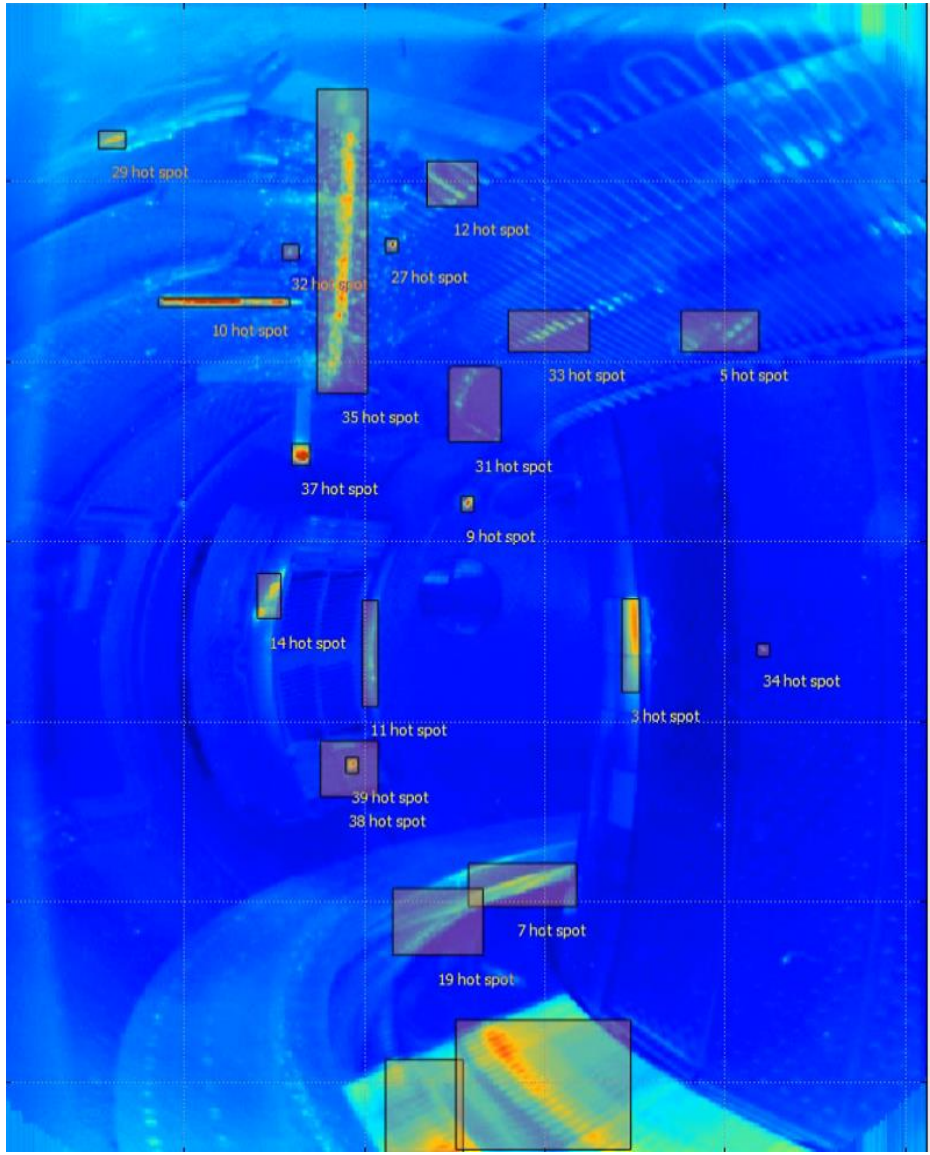
- Object detection in images using bounding boxes

Cascade R-CNN

Cai, Z., & Vasconcelos, N. (2019). Cascade r-cnn : High quality object detection and instance segmentation. *arXiv:1906.09756 [cs]*. http://arxiv.org/abs/1906.09756

- Implementation of Cascade R-CNN: Detectron2, relying on PyTorch, both developed by Facebook AI
- Actively maintained, network architecture and hyperparameters can be changed quickly, and it trains and runs faster than other implementations
- 56.1M parameters
- Hyperparameters based on the original article, slightly tweaked

Detectron2 PyTorch



2. Tracking of thermal events in infrared movies

- Cascade R-CNN performs detection one image at a time

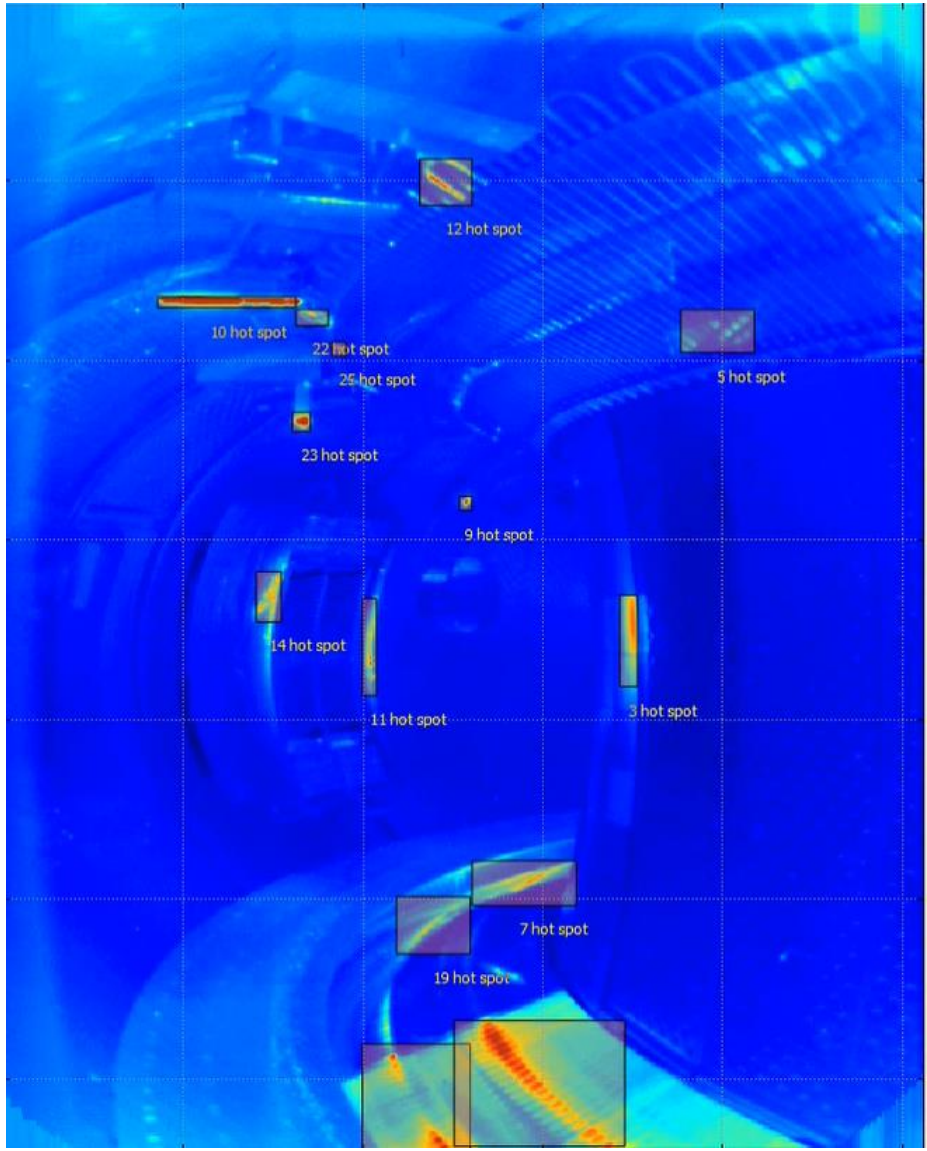
→ Need to use a tracking algorithm to infer thermal events from hot spots

SORT (Simple Online and Realtime Tracking)

Bewley, A., Ge, Z., Ott, L., Ramos, F., & Upcroft, B. (2016). Simple online and realtime tracking. *2016 IEEE International Conference on Image Processing (ICIP)*, 3464-3468. https://doi.org/10.1109/ICIP.2016.7533003

- Estimates the displacement of the hot spots between frames
- Handles the intermittent vanishing of hot spots (obstruction, flicker)
- Compatible with a real-time application

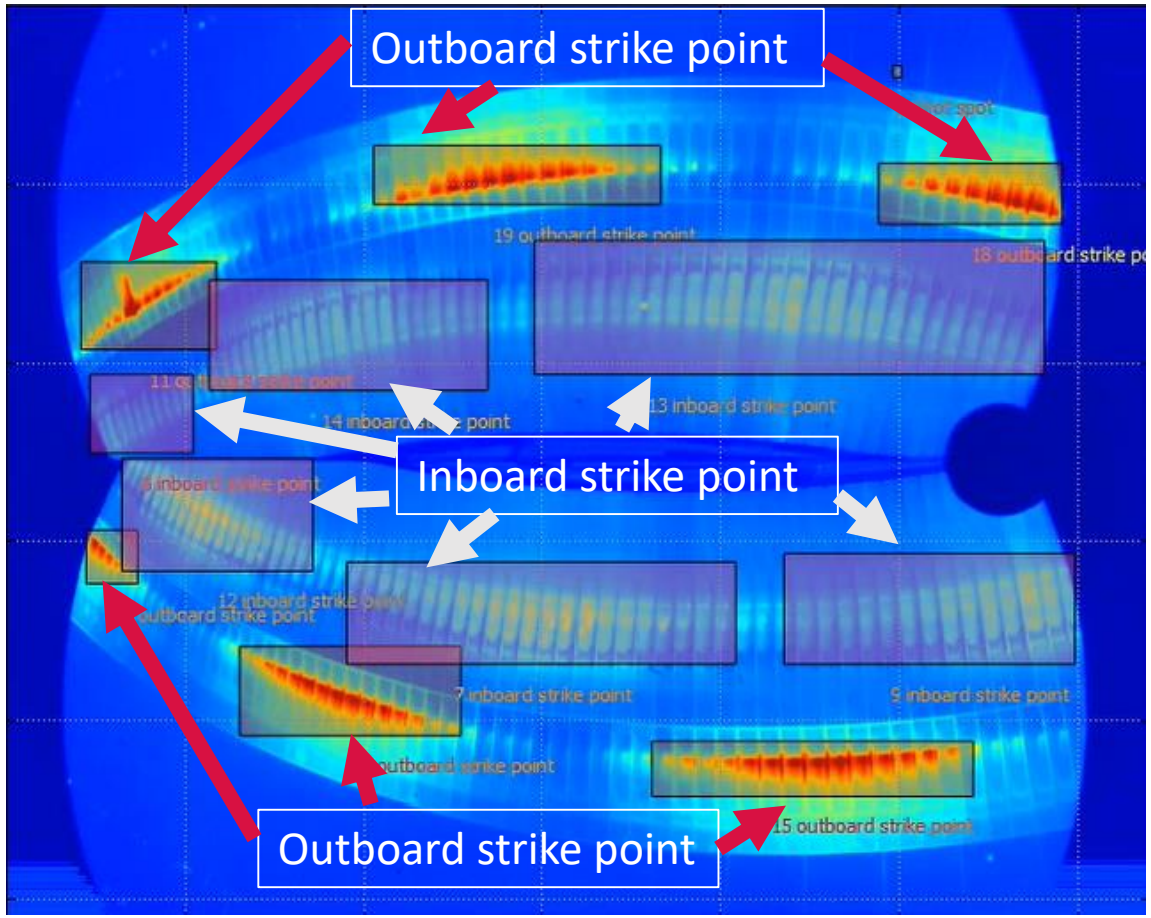
- Can fail on complicated trajectories, such as with UFOs → specific tracking solutions needed to handle these complicated events



- Simple ontology:

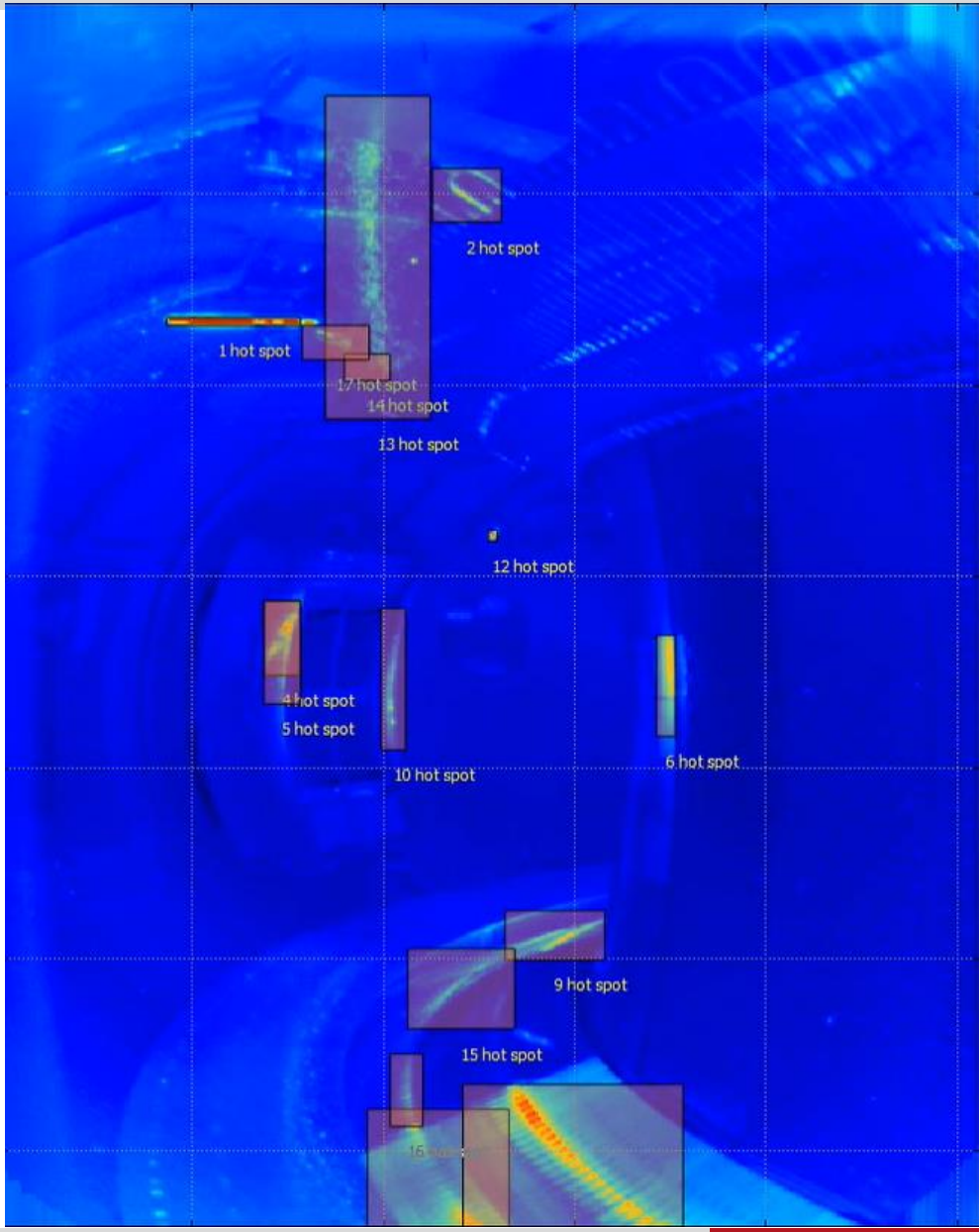
“electron type 1”	“radiated heat flux”
“inboard strike point”	“UFO”
“outboard strike point”	“reflection”
“hot spot” (catchall class)	

- Label: maximum of the cumulative moving average of the confidence scores predicted by Cascade R-CNN, to avoid prediction flickering
- A correspondence pixel ↔ component in the vessel can be used to rule out incompatible labels
- Possible in real-time → can be used for feedback control (*e.g.* by monitoring the temperature on the strike line, instead of on fixed RoIs)



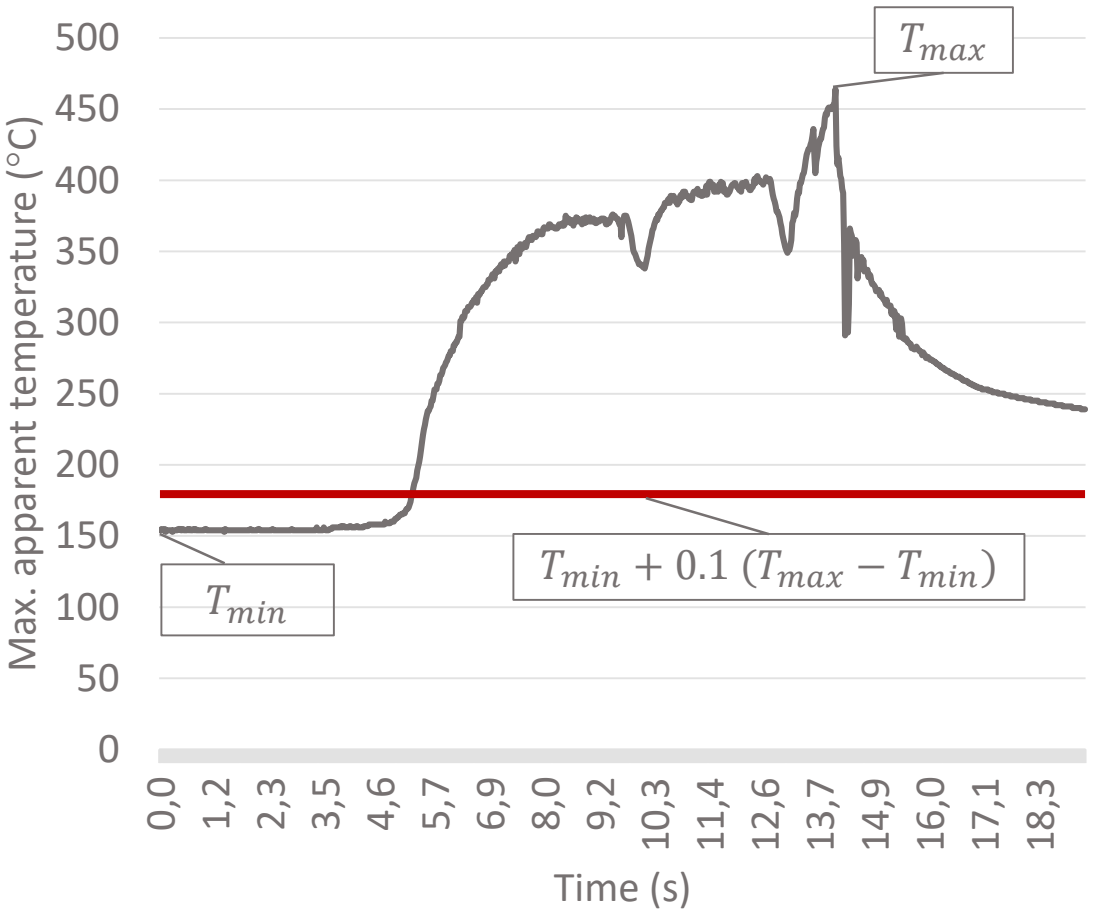
Manual annotation of thermal events in infrared videos

- Need to annotate manually movies, from different pulses and lines of sight
- Very cumbersome task, risks of inconsistency between annotators
- Annotation tool → Reduces the annotation time and the inconsistencies
- Only one rectangle needs to be created to fully annotate a thermal event
- Two aspects to consider:
  - The time span of the thermal event (when it begins and ends)
  - The spatial span of the hot spot (the way the rectangle encompasses it)

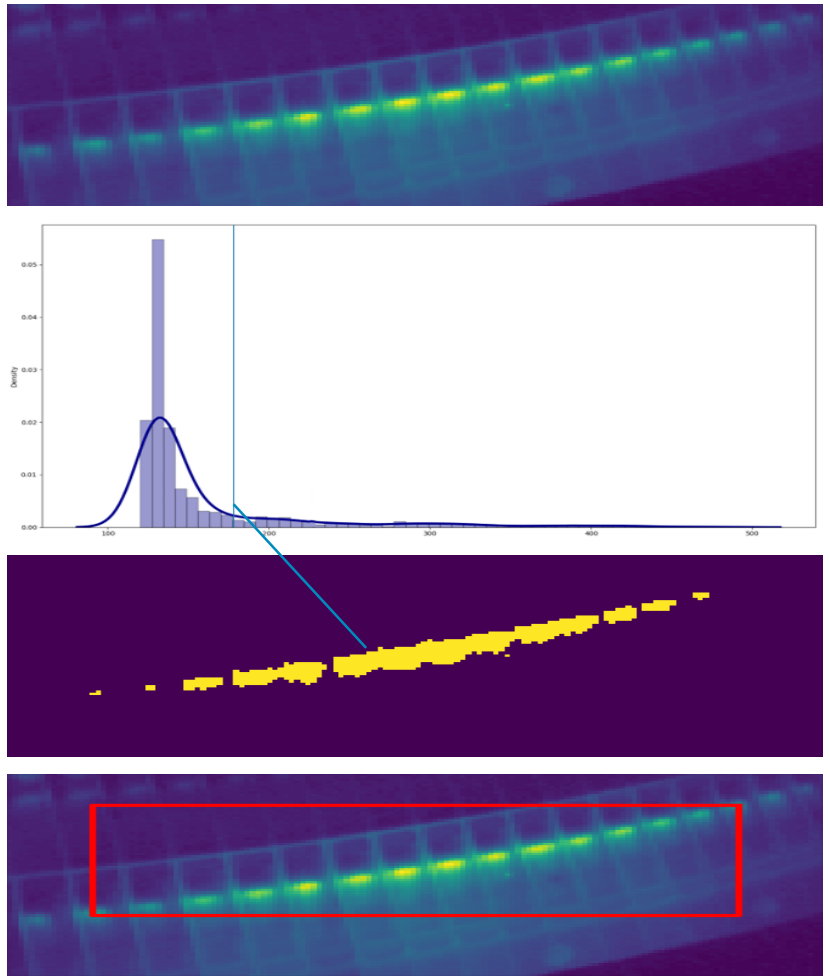


Annotation tool for the annotation of thermal events

Time span determination

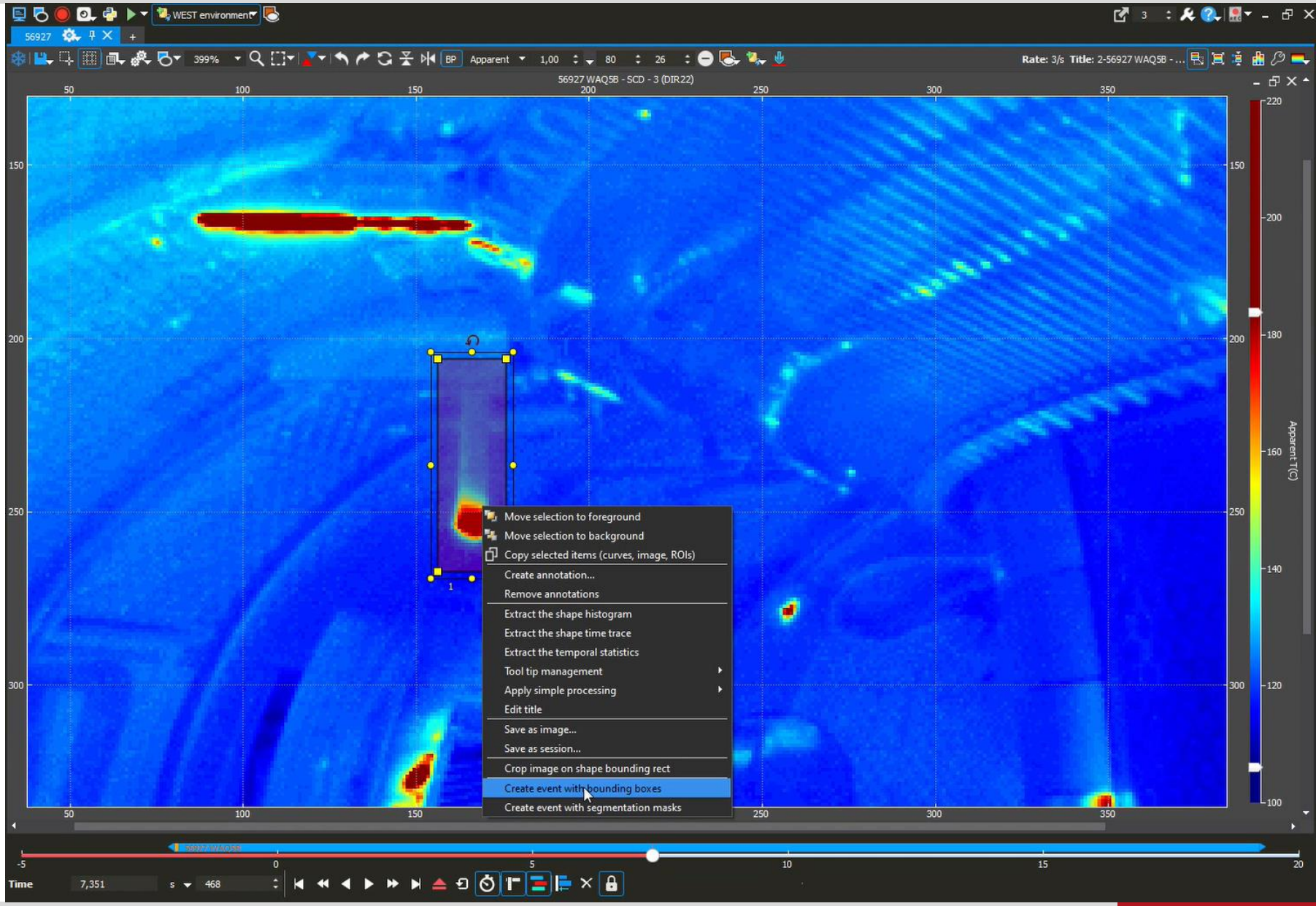


Spatial adaptation



Annotation tool for the annotation of thermal events

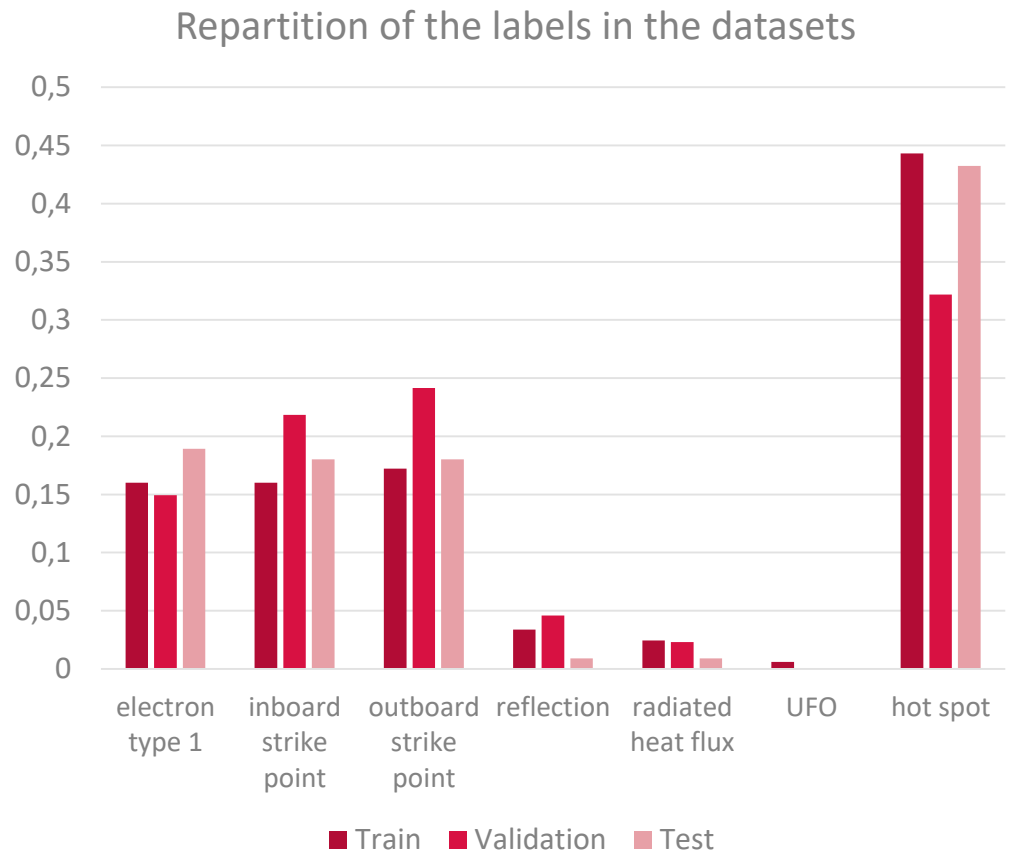
- Annotation tool usable directly from the ThermaVIP software
- Enables the full annotation of an infrared movie in minutes, instead of hours



Dataset of infrared movies from the WEST tokamak

- 33 movies chosen from 3 types of lines of sight (tangential, divertor, lower hybrid antenna) and 2 experimental campaigns (C4 & C5)
- 523 thermal events in total

- Training: 325 thermal events in 20 movies
- Validation: 87 thermal events in 6 movies
- Test: 111 thermal events in 7 movies



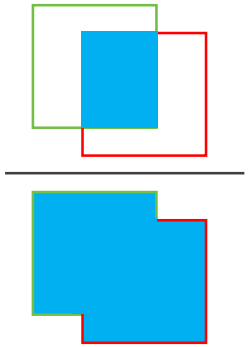
Quantification of the performance of the automated process

A detection D is a true positive if there exists a ground truth T such that

- the intersection over union (IoU) between D and T is greater than a threshold τ

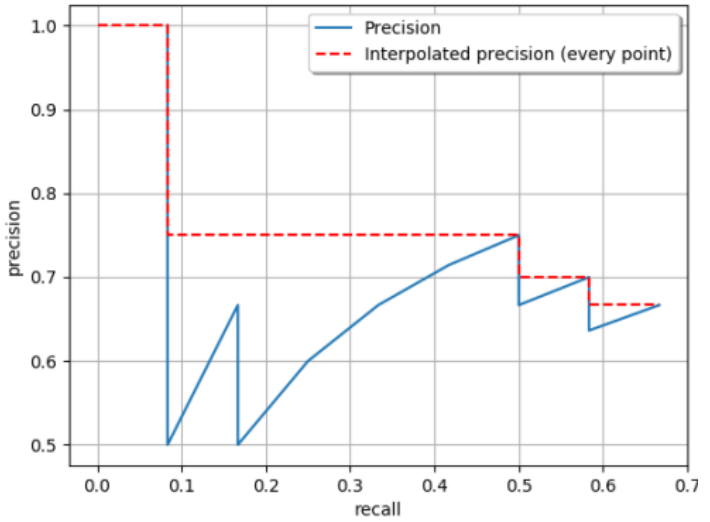
and

- D and T belong to the same class



$$Precision@\tau = \frac{\#\ \text{true positives}}{\#\ \text{detections}} \qquad Recall@\tau = \frac{\#\ \text{true positives}}{\#\ \text{ground truths}}$$

Average precision ($AP@\tau$): measure of the area under the Precision x Recall curve

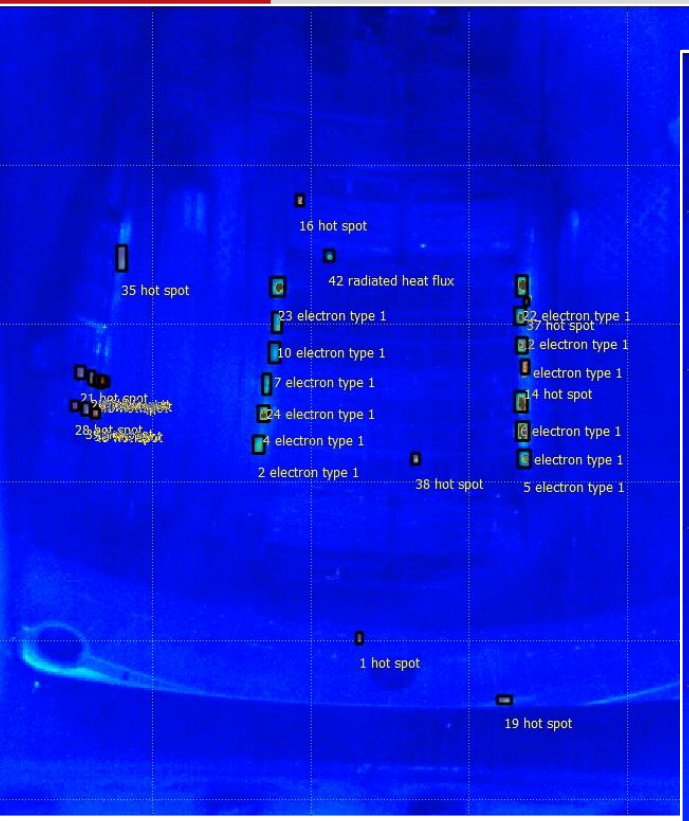


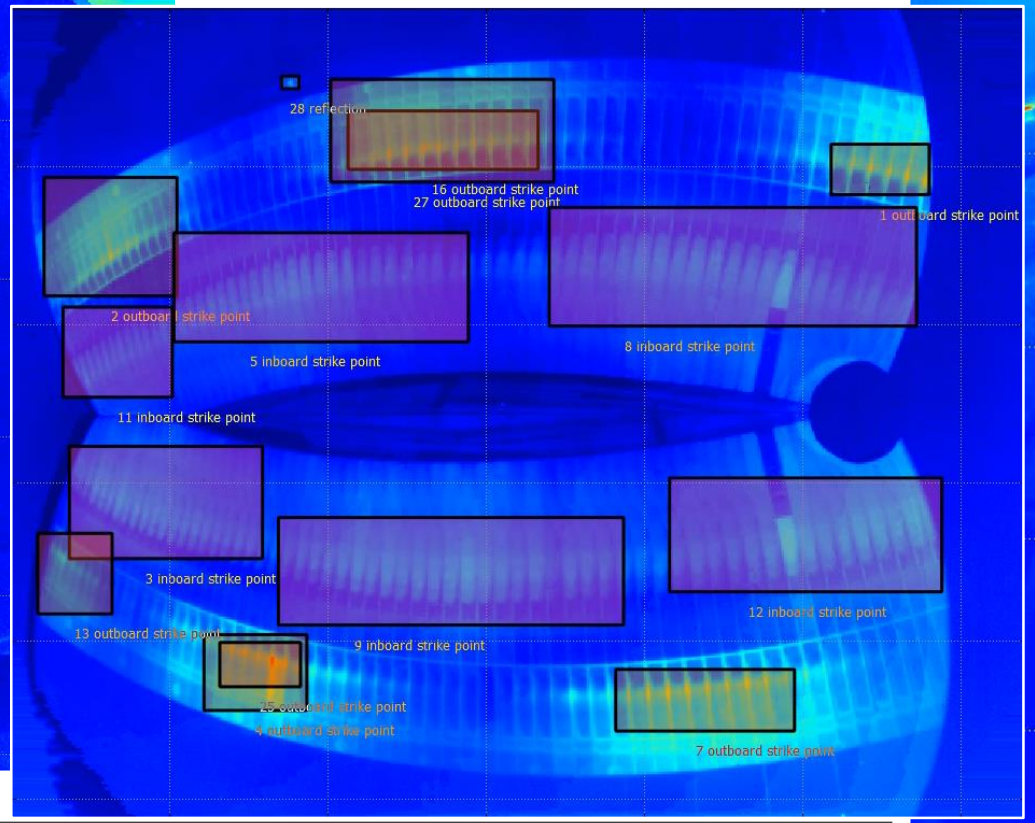
[https://github.com/rafaelpadilla/review_object_detection_metrics]

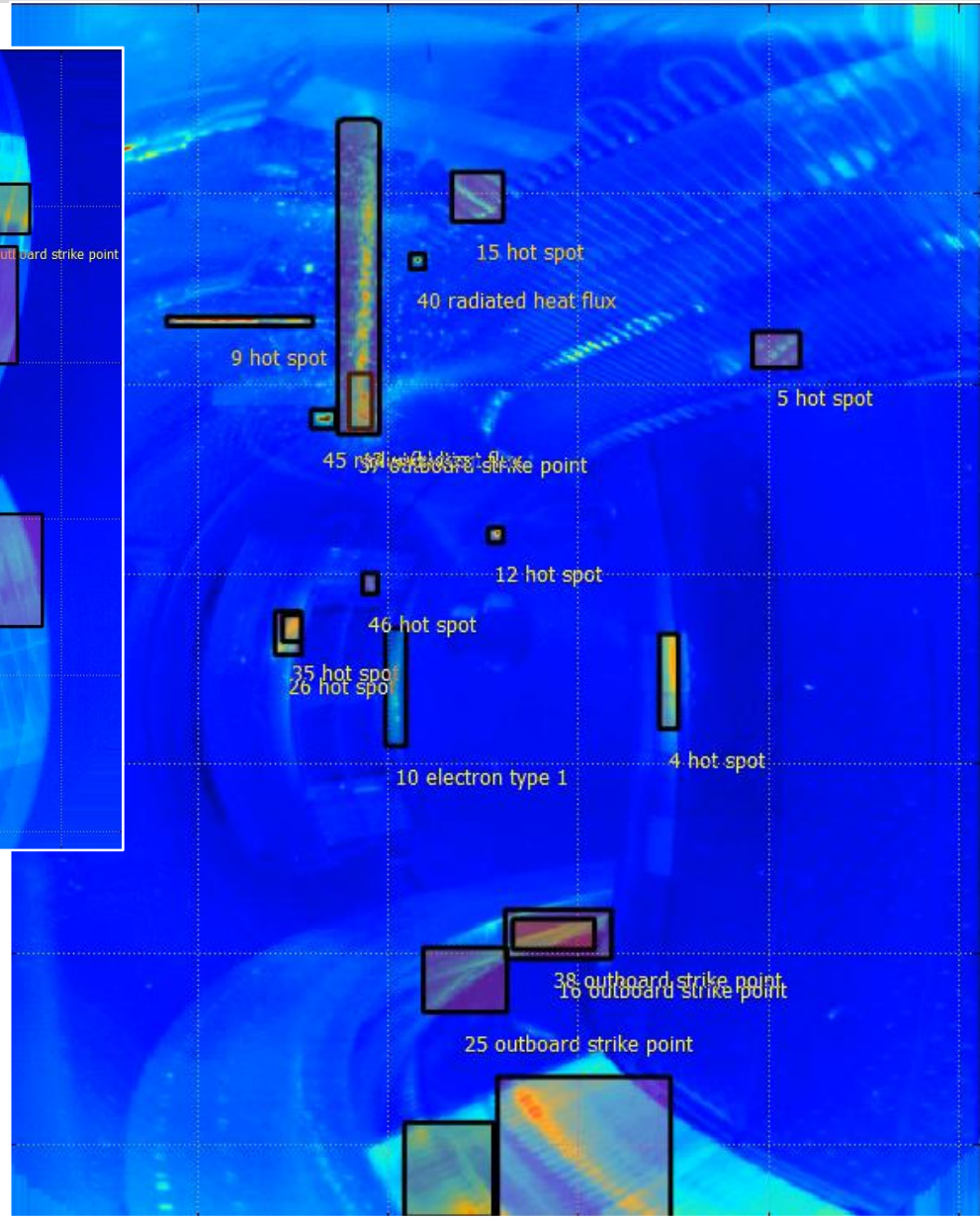
The mean average precision, mean recall and mean precision are obtained by averaging the original criteria over all the classes

To emphasize the importance of the detection of the hottest zones of the ground truth, the IoU is modified, so that it is equal to 0 if D does not contain the 10% hottest pixels of T

Obtained results







Line of sight	divertor	lower hybrid antenna	tangential	all
$mRecall@0.5$	44%	67%	36%	55%
$mPrecision@0.5$	35%	82%	31%	44%
$mAP@0.5$	36%	66%	26%	49%
$mAP@0.5:0.95$	20%	37%	15%	27%

Conclusions and outlooks

- Automated process for the detection, tracking and classification of thermal events in infrared movies
- Semi-automatic tool for the annotation of thermal events in infrared movies
- Custom performance indicators
- Encouraging performance which shows potential for the real-time monitoring of fusion reactors
- Automated process and annotation tool usable directly from the software ThermaVIP

- Fusion of data coming from thermography and other diagnostics to increase the classification performance
- Definition of performance indicators with the operational teams of fusion machines, which are the end users of the process

Thank you for your attention

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