A Topological Data Analysis Based Feature Engineering for Automatic Target Recognition User Interface (tda2tru)

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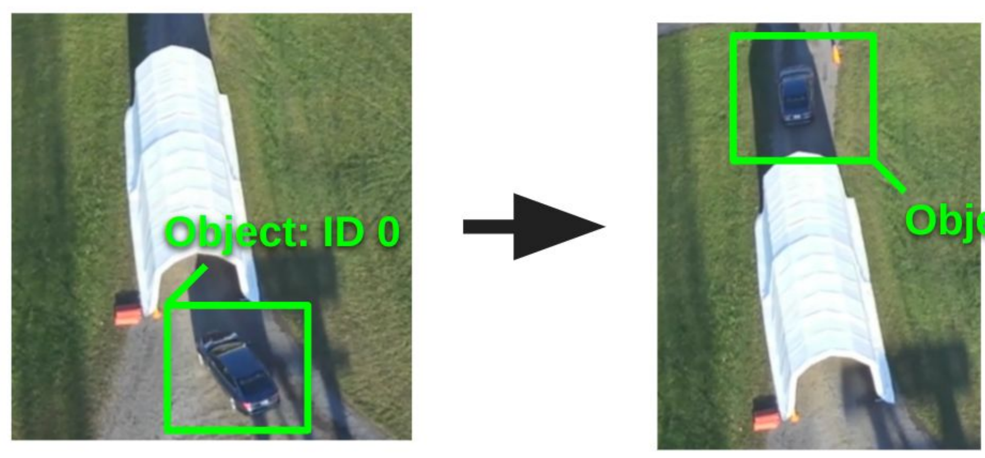
INTRODUCTION

A monitored contested environment such as a metropolitan area or battlefield produces an incredible volume and variety of data from a mix of target sensors contributing to an observer's situational awareness (SA). The effective management and interpretation of this digital information for (near) real-time decision processes have become increasingly difficult. The mathematical structures of sensor data, such as its topology, provides alternative information spaces to exploit. Recent successes in topological data analysis (TDA) for a wide array of scientific applications demonstrate its classification capability for target capture and continuous custody.

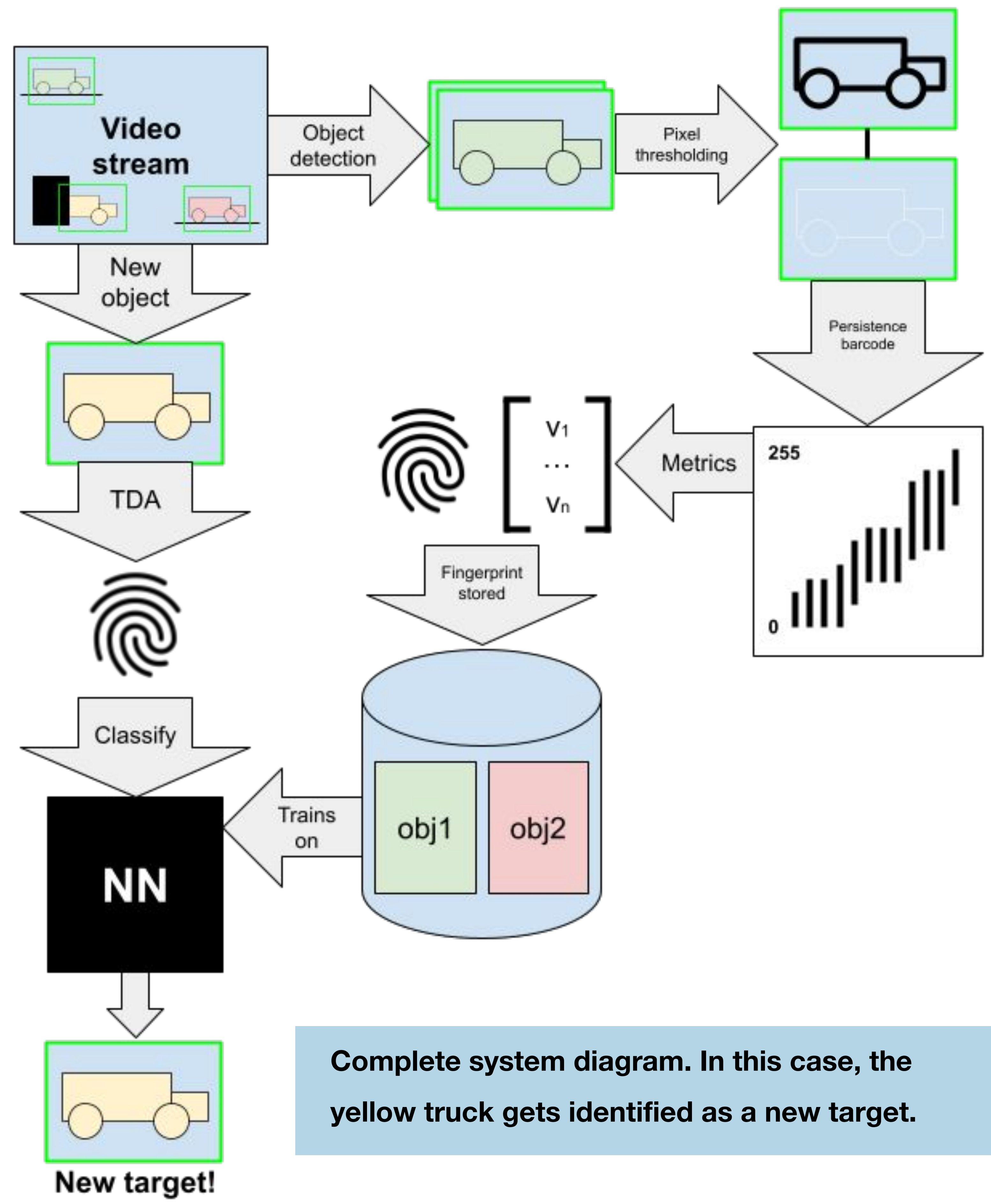


While modern convolutional neural network (CNN)-based computer vision systems are highly effective at identifying and tracking objects which are continuously in frame, they fail to persistently reidentify targets which become occluded by static objects in the environment, such as trees or buildings. TDA methodologies provide a potential solution to this problem, as a classifier can be rapidly trained on topological features of an object.

In his recent works, Dr. Schrader has used TDA methodologies to construct a "topological fingerprint" (TF) from an array of topological metrics on generated persistent diagrams from targets in multiple modalities. These metrics have shown built-in clustering for unique targets which may assist in its analytics and support decision speed in AFRL (Air Force Research Lab.) mission spaces [1, 2]. The goal of this project was to implement these strategies in an application capable of tracking non-persistent objects from a real time video.

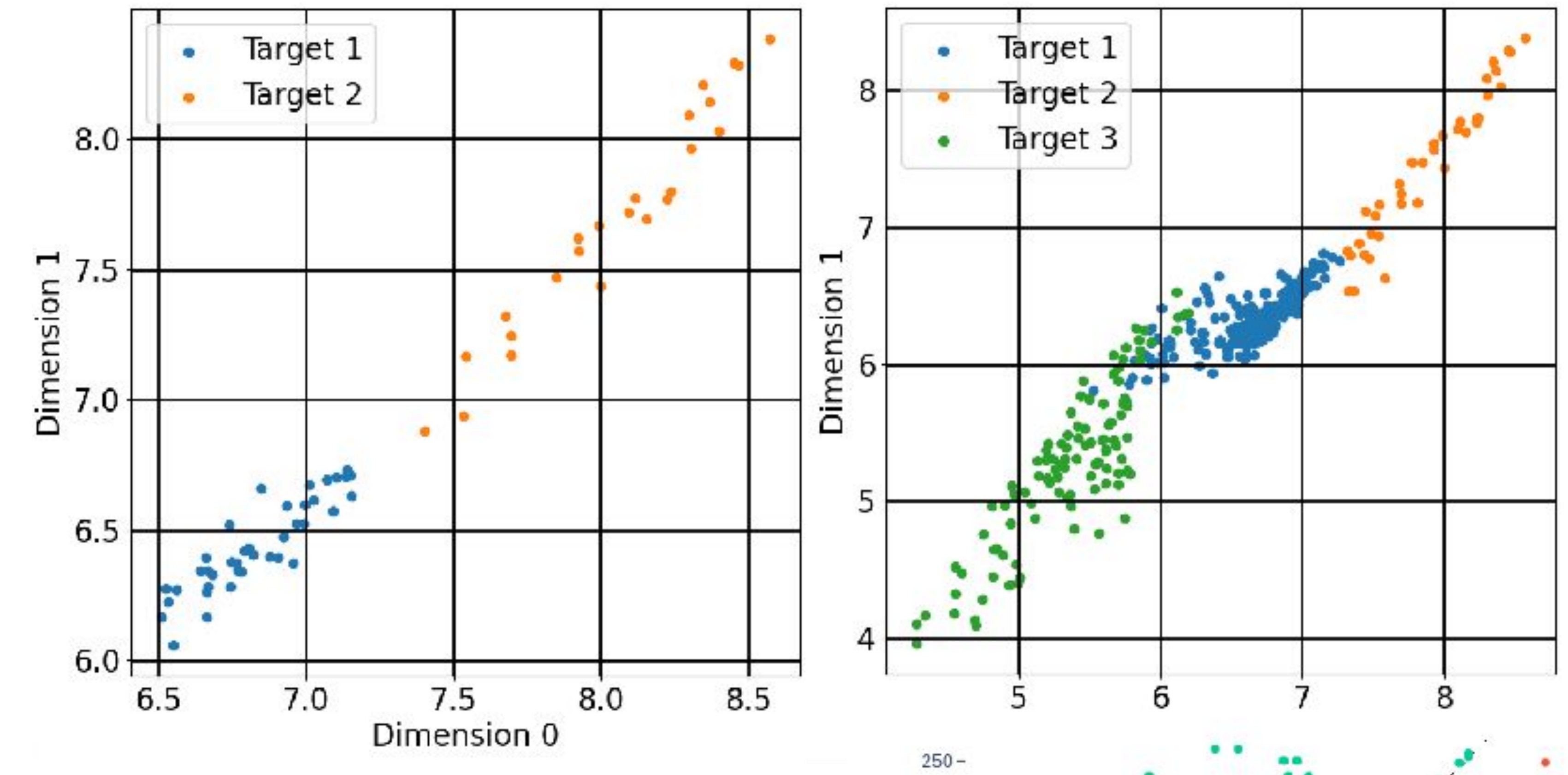
METHODS

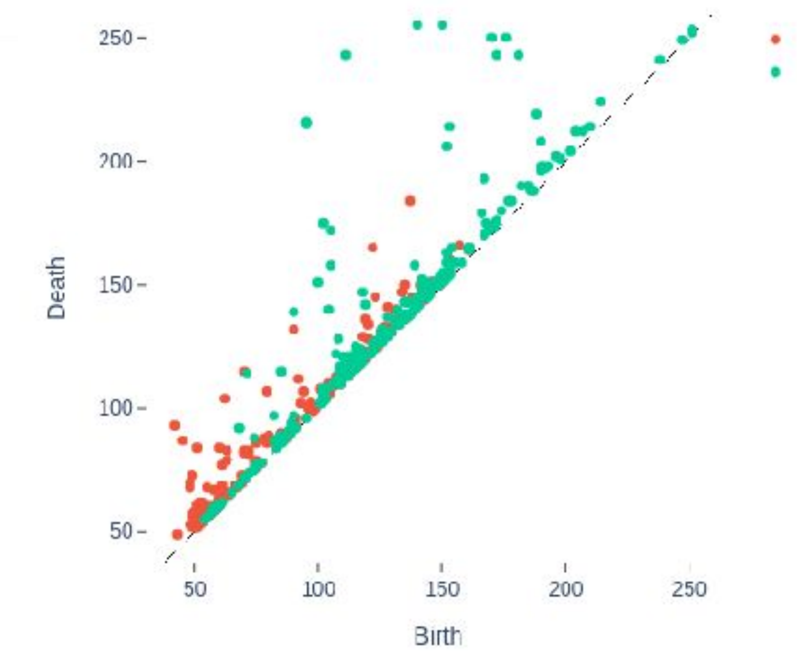
Frames from the selected video are sent to a YOLOv8 model [3] for CNN based object detection. Cubical persistence is used to filter cropped target images to generate a persistence barcode. This involves thresholding the image by pixel intensity and analyzing for which thresholds "holes" or "voids" in the image appear and disappear. From the persistence barcode, 9 metrics, including persistent entropy and Wasserstein distance, are computed which constitute the image's "topological fingerprint" (TF). Once a new target is identified, a neural network is trained on stored TFs and a prediction is made on the new target's TF.



Complete system diagram. In this case, the yellow truck gets identified as a new target.

RESULTS & CONCLUSION





Our system demonstrated target reidentification on a drone-shot test video where three vehicles entered tent tunnels and reemerged in a different order. The figure to the right shows a persistence diagram of an image of a Ford Fusion, with the birth of each hole plotted on the x-axis and the death plotted on the y-axis for both 0 and 1 dimensional holes. This persistence data is aggregated by persistence metrics into a topological footprint. One such metric is persistent entropy. The top two figures show clustering of the persistent entropy metric among the three targets in sampled video frames, boding well for our neural-network based classifier. This also demonstrates the real time identification capability of our system, as the left scatter plot depicts all collected data points at frame 111, at which point target 3 has not yet entered the frame, while the right scatter plot depicts collected data points at frame 641. In short, this project demonstrated the operational viability of topological data analysis (TDA) for real-time target identification and integrated these methodologies into a user-friendly system.

REFERENCES

1. Paul T. Schrader, "Topological multimodal sensor data analytics for target recognition and information exploitation in contested environments," Proc. SPIE 12547, Signal Processing, Sensor/Information Fusion, and Target Recognition XXXII, 125470C (14 June 2023); https://doi.org/10.1117/12.2662383
2. Paul T. Schrader, "Interfacing topological data analysis (TDA) with AI/ML for multimodal data fusion and automatic target recognition (ATR)," Proc. SPIE 13057, Signal Processing, Sensor/Information Fusion, and Target Recognition XXXIII, 130570B (7 June 2024); https://doi.org/10.1117/12.3009160
3. Ultralytics, "YOLOv8: Real-Time Object Detection," 2024. Available: https://github.com/ultralytics/ultralytics.