Sensing and Big Data Analytics for Natural Disaster Management

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Version 4.3

Artificial Intelligence & Information Analysis Lab

Big Data Analytics for Natural Disaster Management

- **Natural Disaster Management**
- NDM Concept and Objectives
- NDM Sensing
- Big NDM Data Analytics
- Horizon Europe R&D project TEMA

Natural Disaster Management

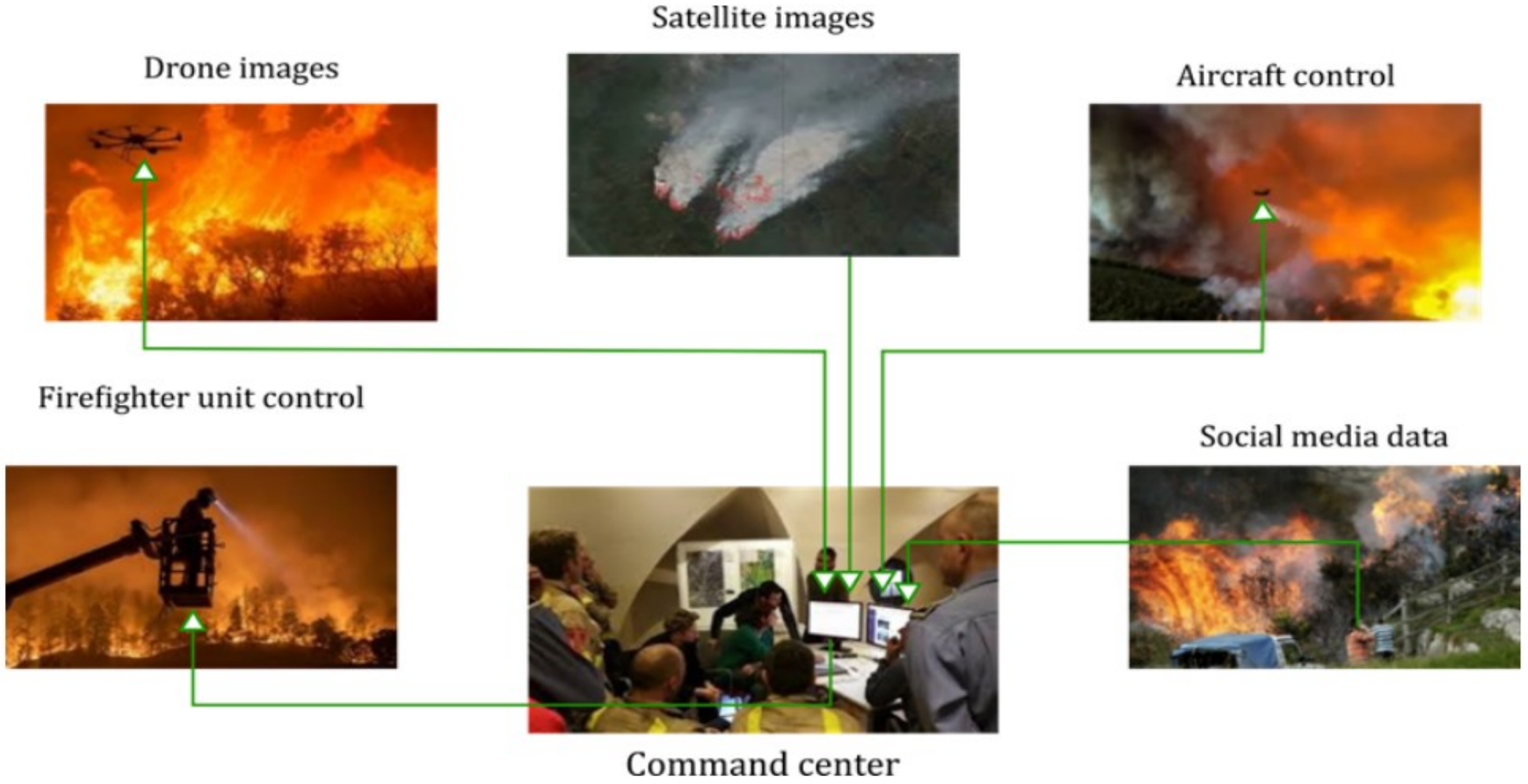
Natural Disaster Management (***NDM***) examples:

- forest fires, floods.

Big data issues in NDM:

- precise semantic mapping and phenomenon evolution predictions in ***real-time.***
- ***Heterogeneous extreme data sources***:
    - AI-capable autonomous devices and smart sensors at the edge
    - satellite images,
    - topographical data,
    - official meteorological data and predictions/warnings published in the Web
- ***Multilingual data***
    - geosocial media data (including text, image and videos).

Natural Disaster Management



NDM Overview.

Big Data Analytics for Natural Disaster Management

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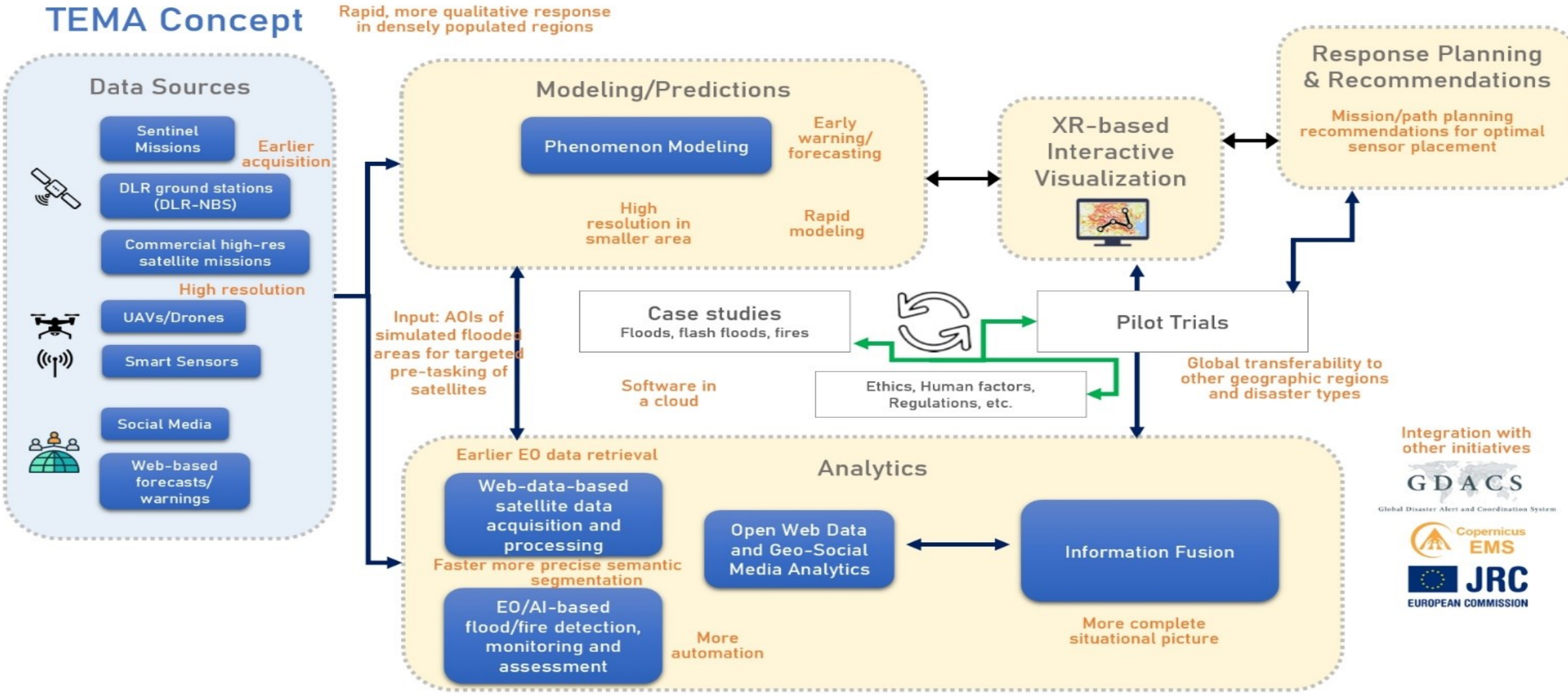
NDM Concept and Objectives



TEMA NDM Architecture.

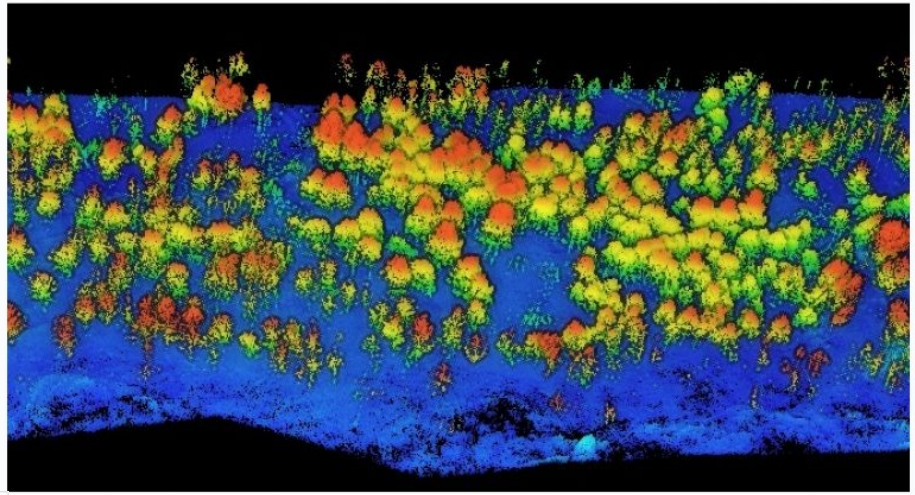
NDM Concept and Objectives

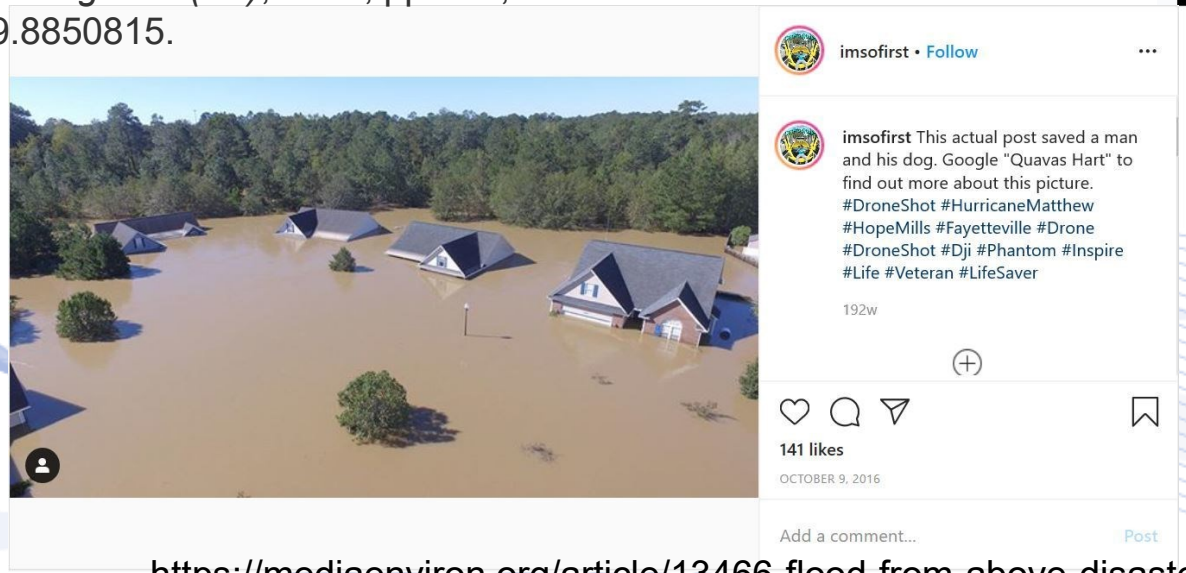
Improve and accelerate extreme data analytics

- ***Increase trustworthiness of extreme data analysis algorithms***
  - Speed of local & global XAI explanations.
- ***Increase accuracy of extreme data analysis algorithms***
  - Semantic/instance segmentation, object detection, Image recognition
- ***Increase responsiveness/speed of extreme data analysis algorithms***
  - Visual analysis, social media analysis speed.
- ***Reduce latency by innovative federated data analysis on a cloud-to-edge continuum***
  - Reduce computational latency, data migration.

NDM Concept and Objectives

Z. Jiao *et al.*, "A Deep Learning Based Forest Fire Detection Approach Using UAV and YOLOv3," *2019 1st International Conference on Industrial Artificial Intelligence (IAI)*, 2019, pp. 1-5, doi: 10.1109/ICIAI.2019.8850815.





https://mediaenviron.org/article/13466-flood-from-above-disaster-mediation-and-drone-humanitarianism

NEWS

Predicting Fire Risk with UAV Lidar

https://www.gim-international.com/content/news/predicting-fire-risk-with-uav-lidar

NDM Concept and Objectives

Improve and accelerate emergency phenomenon modeling, evolution predictions, simulation and interactive visualization

- ***Increase model-based prediction responsiveness/speed for evolving phenomena***
  - Increase dispersion model, flood model update rates.
- ***Increase model-based prediction accuracy for evolving phenomena***
  - Fire simulation, estimated smoke plume and concentration distribution, flood simulation.

NDM Concept and Objectives

TSYL Wildfire Analyst®

NS 3Di ® Flood forecasting

Simulation and visualization.

NDM Concept and Objectives

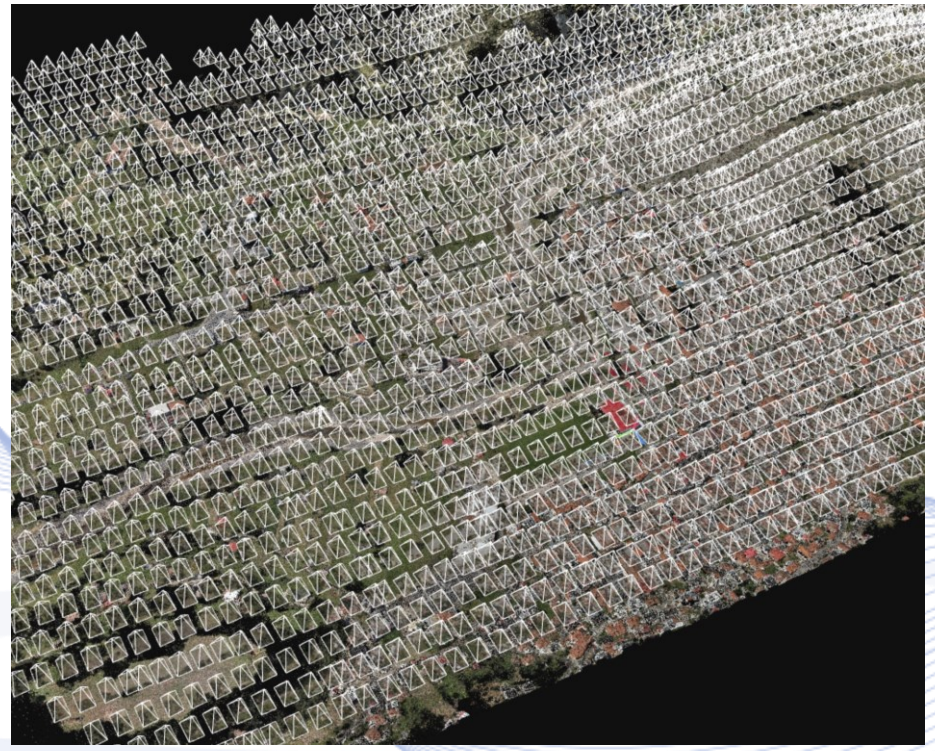
Improve and accelerate emergency phenomenon modeling, evolution predictions, simulation and interactive visualization

- ***Improve responsiveness and interactivity of visualization mechanisms for evolving phenomena***
  - Responsiveness of visualization mechanisms, content customization increase in Augmented Reality Immersion score).
- ***Improve accuracy of visualization mechanisms for evolving phenomena***
  - Digital Twin accuracy, merged spatial 3D map resolution increase.

NDM Concept and Objectives

Generating georeferenced 3D digital twin models (Northdocks)

- Use of drone images/videos and historical data.



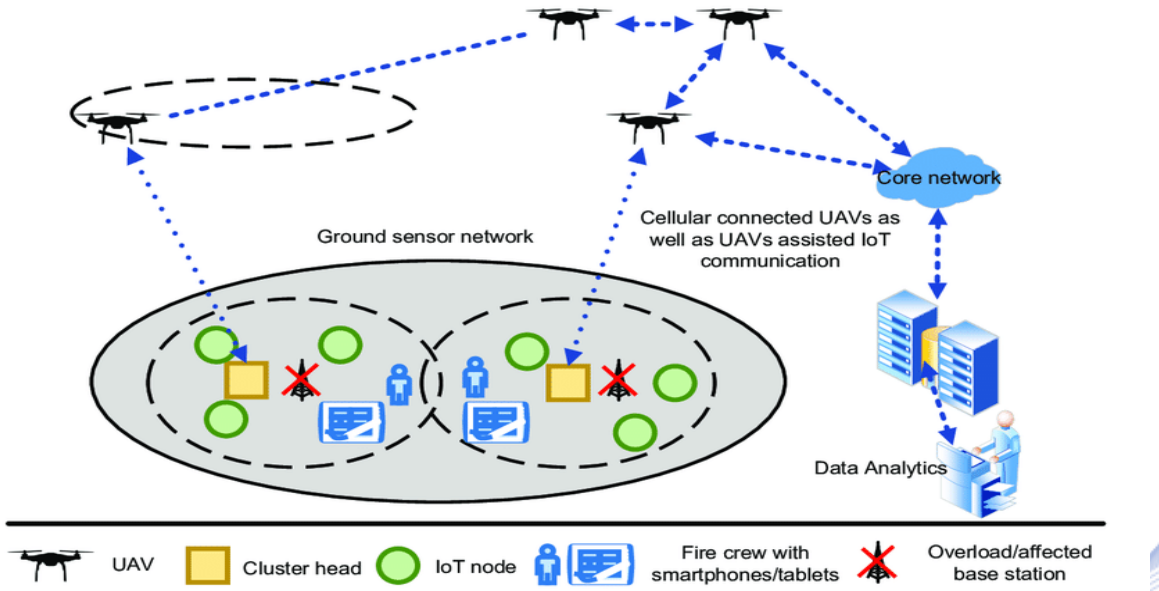
Drone image acquisition and digital twin of Larissa floods (Greece, 9/2023).

NDM Concept and Objectives

Improve NDM using new digital technologies and extreme data analytics.

- ***Reduce latency in NDM***
  - Speed of satellite-based crisis mapping, Frequency of wildfire burnt area product availability, reduction of time between sensing and satellite data availability.
- ***Increase situational awareness in NDM***
  - Heterogeneous data sources/modalities to semantically annotate the 3D map, Evaluation of contingent response alternatives ,Temporal resolution of map updates.
- ***Reduce mental load for human operators in NDM***
  - Workload from retrieval of satellite position and acquisition data, Transparency, automation and improvement of communication.
- ***Prototype a proof-of-concept TEMA system for NDM in forest fires, flash floods, and regional floods.***

NDM Concept and Objectives



Sun H, Dai X, Shou W, Wang J, Ruan X. An Efficient Decision Support System for Flood Inundation Management Using Intermittent Remote-Sensing Data. *Remote Sensing*. 2021; 13(14):2818. https://doi.org/10.3390/rs13142818

Ejaz, Waleed & Azam, Muhammad Awais & Saadat, Salman & Iqbal, Farkhund & Hannan, Abdul. (2019). Unmanned Aerial Vehicles enabled IoT Platform for Disaster Management. Energies. 12. 10.3390/en12142706.

NDM predictions and decision-making.

Big Data Analytics for Natural Disaster Management

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Monocular images

- A single monocular image does not convey depth information.
- But it can detect points at any range.

https://www.youtube.com/watch?v=8LWZSGNjuF0

Stereo imaging

- Two cameras in known locations.
- Calibrated cameras.
- Stereo images can create a disparity (depth) map.
- Their range (in m) is limited, when high accuracy is desired.

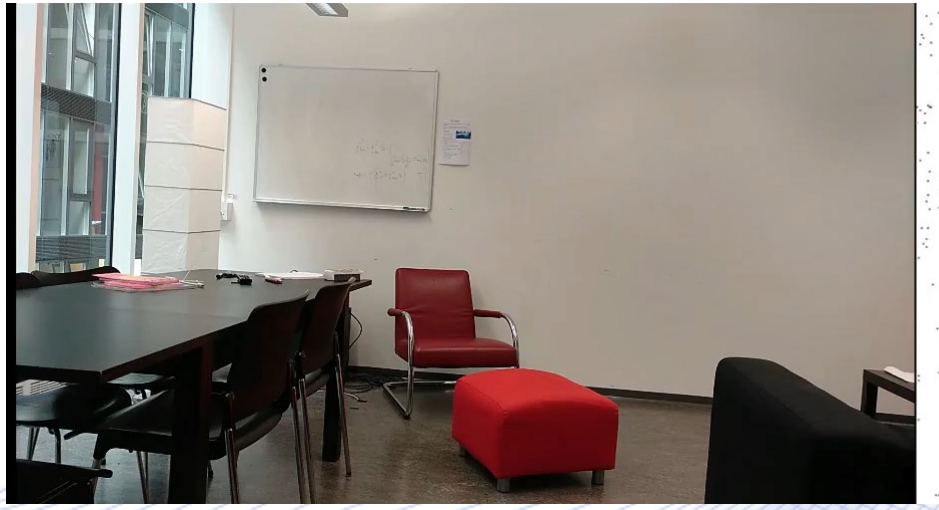
Stereo image pair of a forest road.

Event cameras

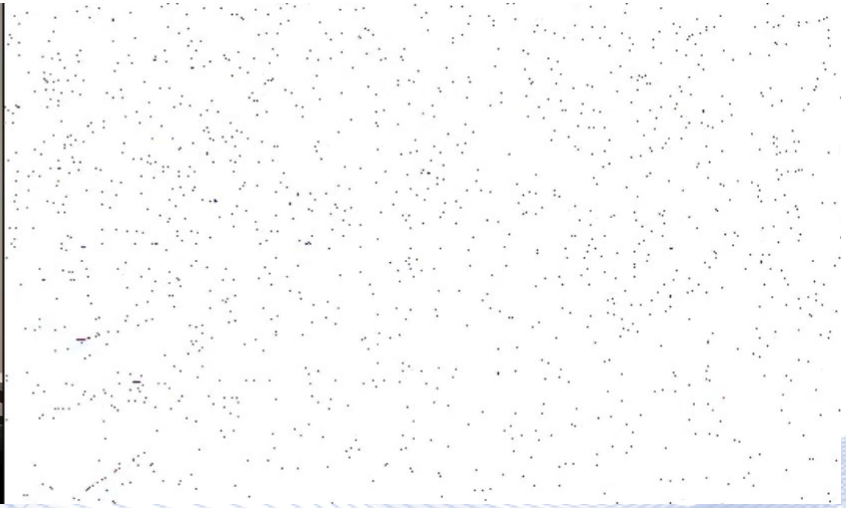
- Novel sensor that measures only ***scene motion***.
- Low-latency (~ 1 μs).
- No motion blur.
- High dynamic range (140 dB instead of 60 dB).
- Ultra-low power (1mW vs 1W).
- Traditional vision algorithms do not work!

Event cameras

Standard Camera



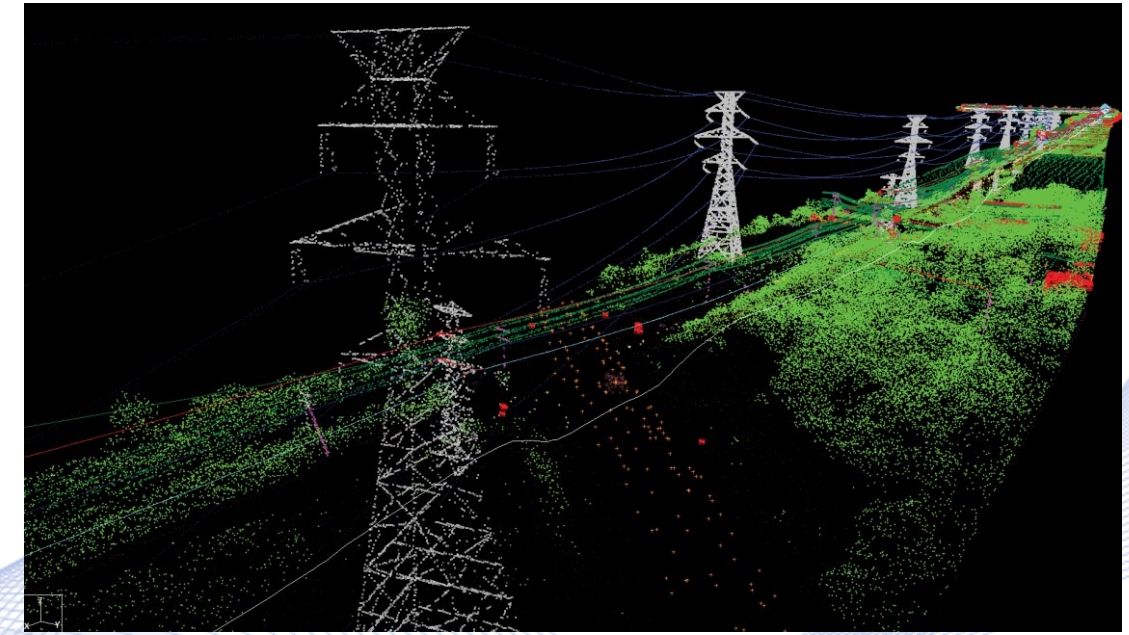
Event Camera (**ON**, **OFF** events)



Δt = 40 ms.

Lidars

- Lidar measures the distance to a target by illuminating the target with laser light and measuring the reflected light with a sensor.
- Differences in laser return times and wavelengths can then be used to make digital 3D representations of the target.

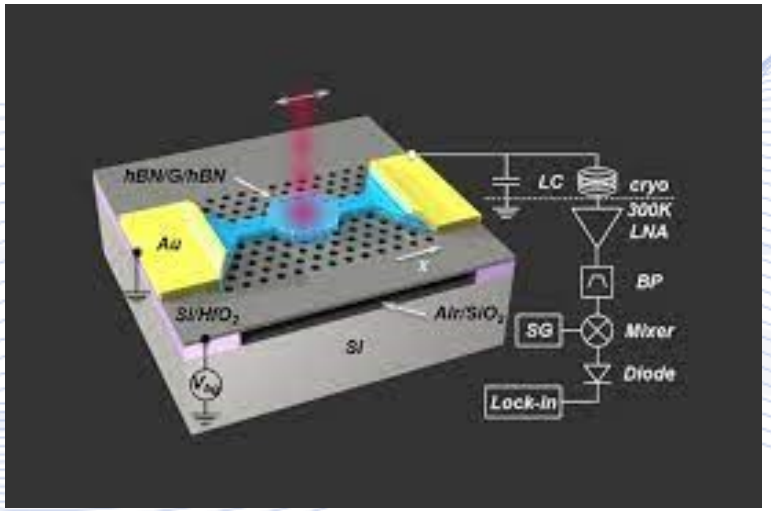


http://eijournal.com/print/articles/understanding-the-benefits-of-lidar-data?doing_wp_cron=1517767340.6914100646972656250000

IR measurement and imaging

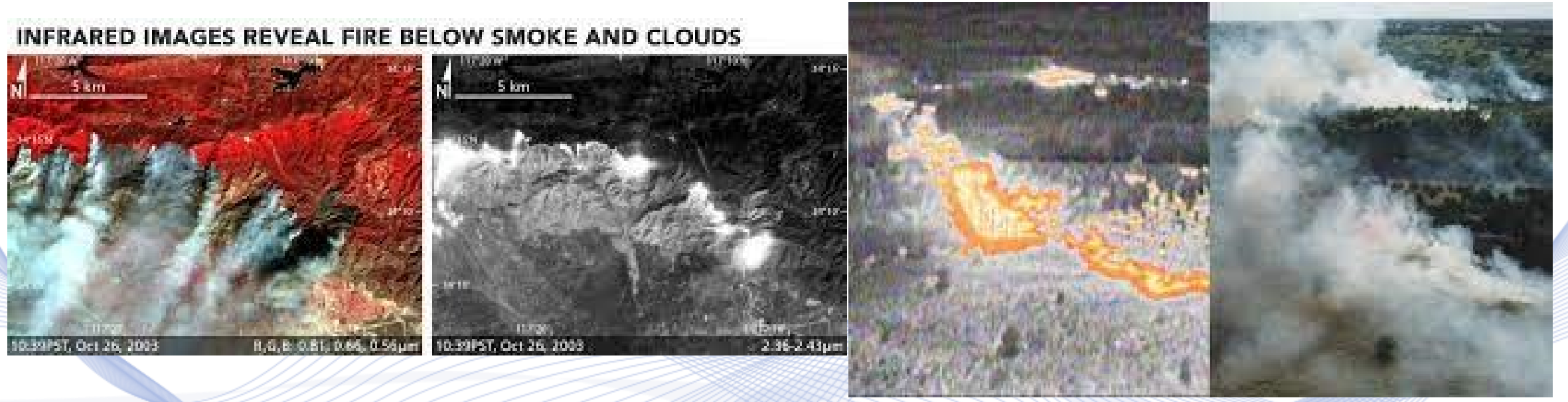
- ***IR cameras*** produce thermal images of an object.
- ***Bolometer*** measures the radiant heat.

https://www.phase1vision.com/blog/understanding-the-benefits-of-infrared-imaging-cameras



https://phys.org/news/2018-06-bolometer-faster-simpler-wavelengths.html

IR measurement and imaging



IR imaging of forest fires.

Optical Fire Detection Systems

InsightFD Wildfire Detection System (Insight Robotics).

ADELIE (Alert Detection Localization of Forest Fires, Paratronic).

Optical beam smoke detection

Detecting absorption or scattering of light.

- It consists of a light transmitter and a photosensitive receiver.
- Portable, can be used for in-situ and remote measurements.
- Prone to false alarms (dust/dirt).

Smoke detector.

Ionization smoke detection

- It uses radioactive element (Americanium-241) to ionize air.
- ***Fire aerosoles change the ionization current***, triggering a detection.
- They are widely used in consumer market for fire detection.
- They provide in-situ measurements only.

Ionization smoke detector.

Lidar smoke detection

It detects smoke instead of fire.

- Remote 3D monitoring.
- Area with ~5 km radius.
- Spatial resolution 15 meters, temporal resolution 5 minutes.

Lidar smoke detector.

Meteorological Sensors

- ***Wind sensors*** determine the wind speed, direction and temperature.
  - Temperature range: [-20°C, +70°C].
  - Altitudes up to 4000m.
  - Lightweight, low power design.

- ***Temperature sensors.***
- ***Humidity sensors.***

UAV Wind sensor.

Drones for ND observation

- External hardware can be attached to drones (e.g., PEC, XR cameras).
- ***Optimal sensor placement.***
- Obstacle Detection technologies.
- SDK for high-level UAV control.
- IP45 ISO Protection level for flight resilience.

Drones for ND observation

UAV Sensors

DJI ZENMUSE H20T and Gimbal.

- Visual Camera: 23x zoom, 20 Mpx, Focal Length (FL): 7-120 mm.
  - Video: 3840×2160(px) @ 30 fps
  - Images: 5184×3888(px)
- Wide angle camera: 12 Mpx, FL 24mm.
- Radiometric Thermal Camera: 640x512px, FL: 13.5 mm, 30Hz
- Laser RangeFinder: 1200m Range.

Drones for ND observation

UAV Sensors

WIRIS PRO camera+ gimbal.

- Full HD 10x Optical Zoom Camera
- IR Camera Resolution px, 18º,32º,45 and 69º IR Lenses
- 7,5-13.5um Vox microbolometer.

Drones for ND observation

Fotokite Sigma

Actively tethered drones

Pros :

- Thermal camera
- Autonomous flight
- Robust Wind Performance
- 24 hour capacity.

Cons :

- Wired connection
- Does not provide 3D information

https://fotokite.com/situational-awareness-system/

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Big NDM Data Analytics

Underlying DNN and CV technologies

- Object detection
- Region segmentation

NDM cases

- Fire detection/segmentation
- Flood detection/segmentation

Big NDM Data Analytics

Social Media Analytics

- Geosocial analytics
- Semantic topic extraction
- Text sentiment analysis

Fast NDM Data Analytics

- DNN acceleration

Big NDM Data Analytics

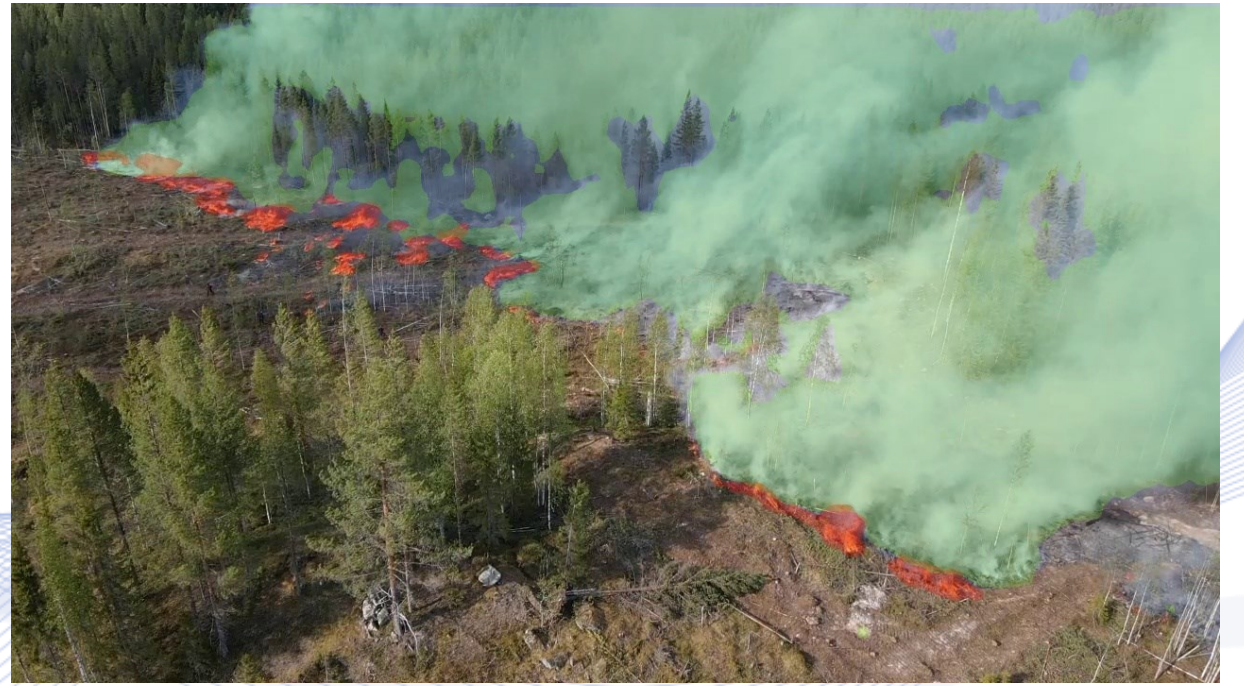
Trustworthy NDM Data Analytics

- DNN robustness
- Privacy protection
- DNN Explainability

Other NDM Data Analytics Issues

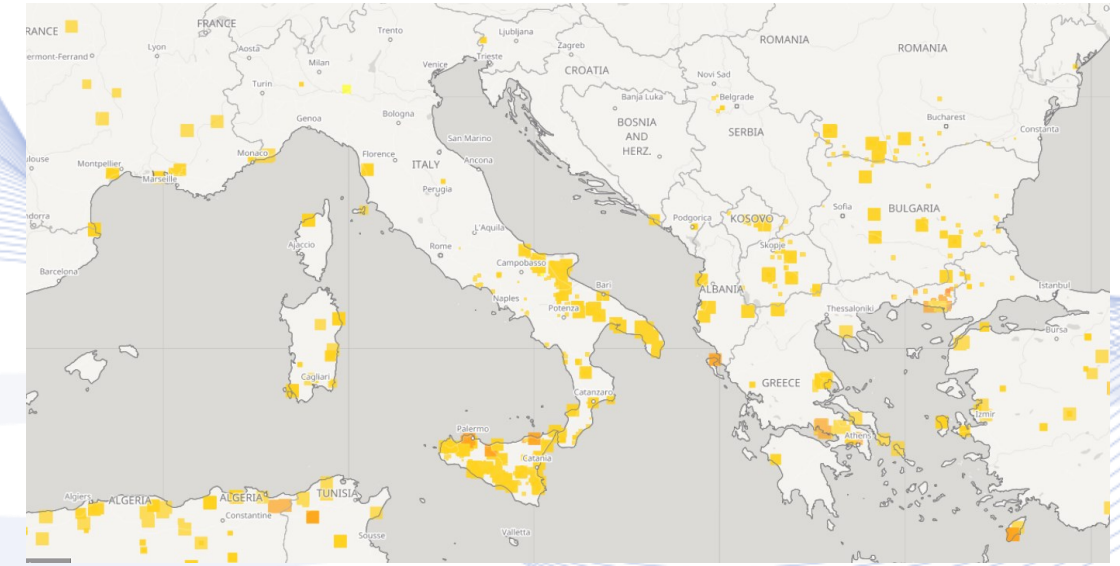
- Information fusion
- Visualization tools

Fire segmentation

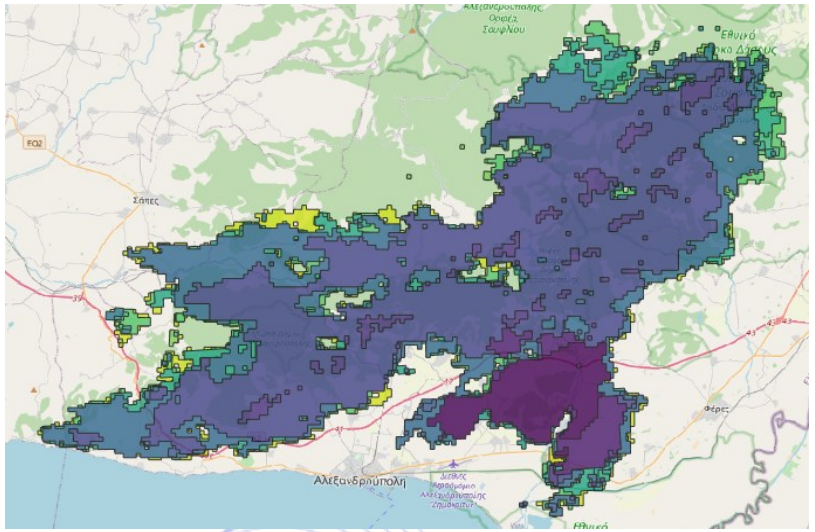


Satellite-based Burnt Area Detection

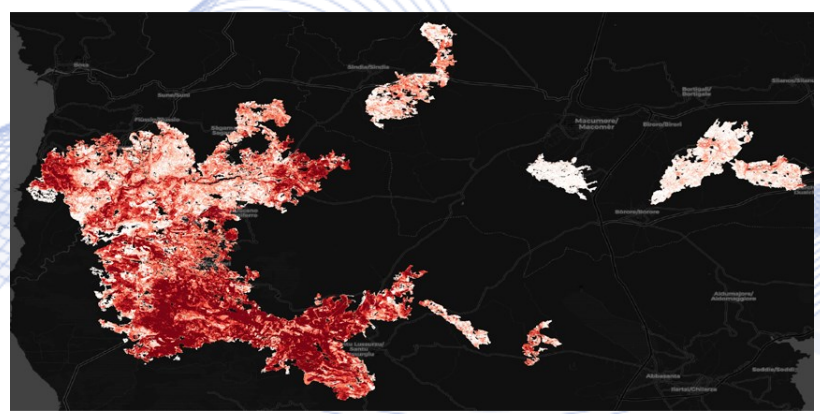
- **Near-real time AI-based burnt area monitoring** with Copernicus Sentinel-3 and MODIS satellite imagery (DLR-DFD)
- Burnt areas, burn severity, fire evolution over time
- It allows monitoring of current wildfire activity throughout Europe (four overpasses per day)



Wildfires South East Europe, from August 01 to September 03, 2023



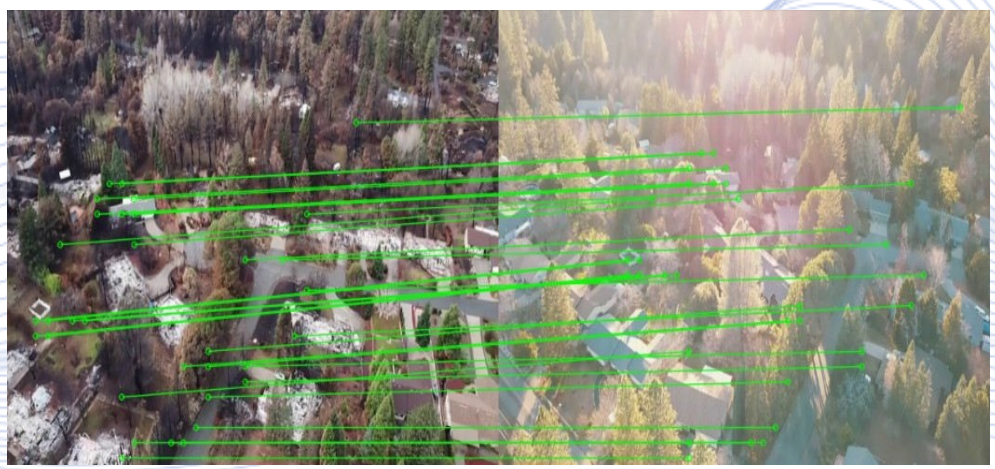
Wildfire Greece, temporal evolution from August 20 to 30, 2023



TEMA Use case: Montiferru Fire, Sardinia / Italy Sentinel-2, 2021-08-14 10:20:31, Burn Severity

Georegistration

Burnt region georegistration.



Burnt region, pre-fire image, and their correspondences.

Georegistration

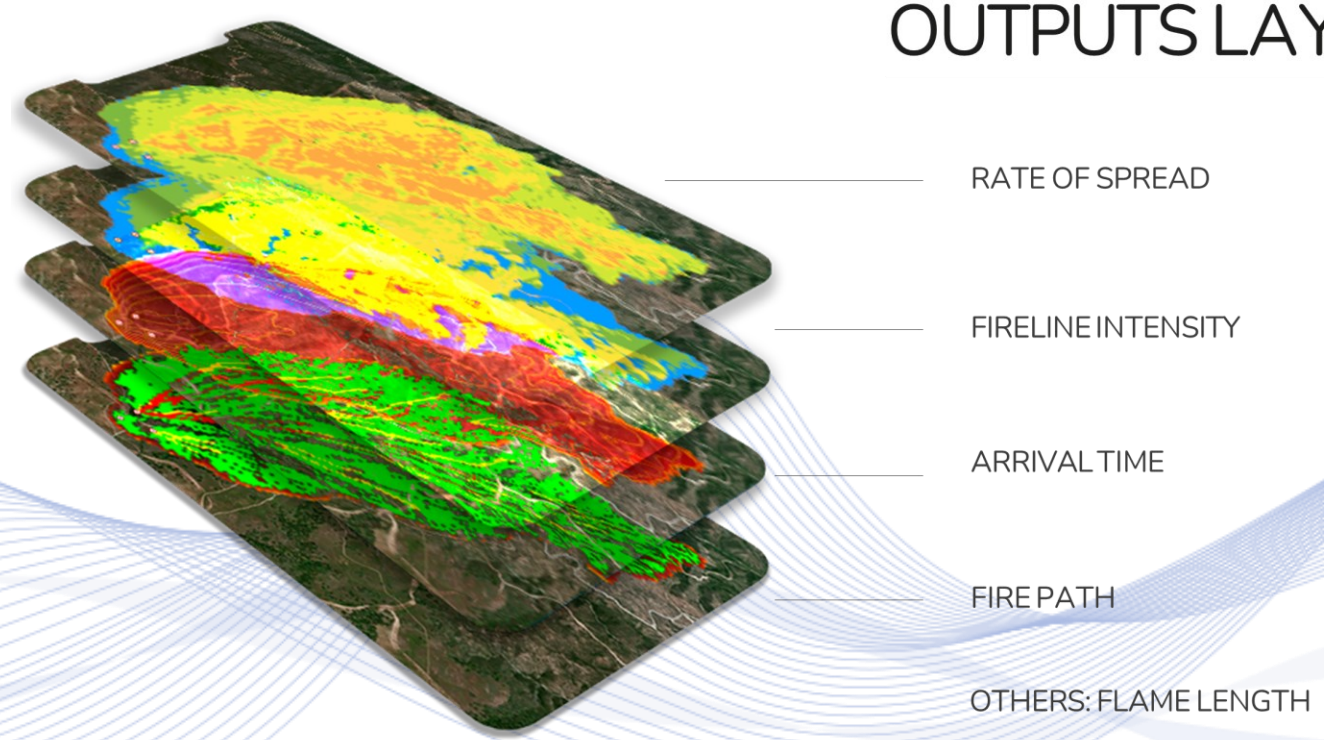
Burnt region georegistration.

Burnt region, pre-fire image, and their similarity map.

Forest Fire Modeling

Simulation of the ***wildfire spread and behavior*** in space and time (Technosylva).

- Effect of meteorological factors and forest modeling.
- Real-time analysis of wildfire behavior.
- Decision making for suppression activities, resource allocation and population evacuation.

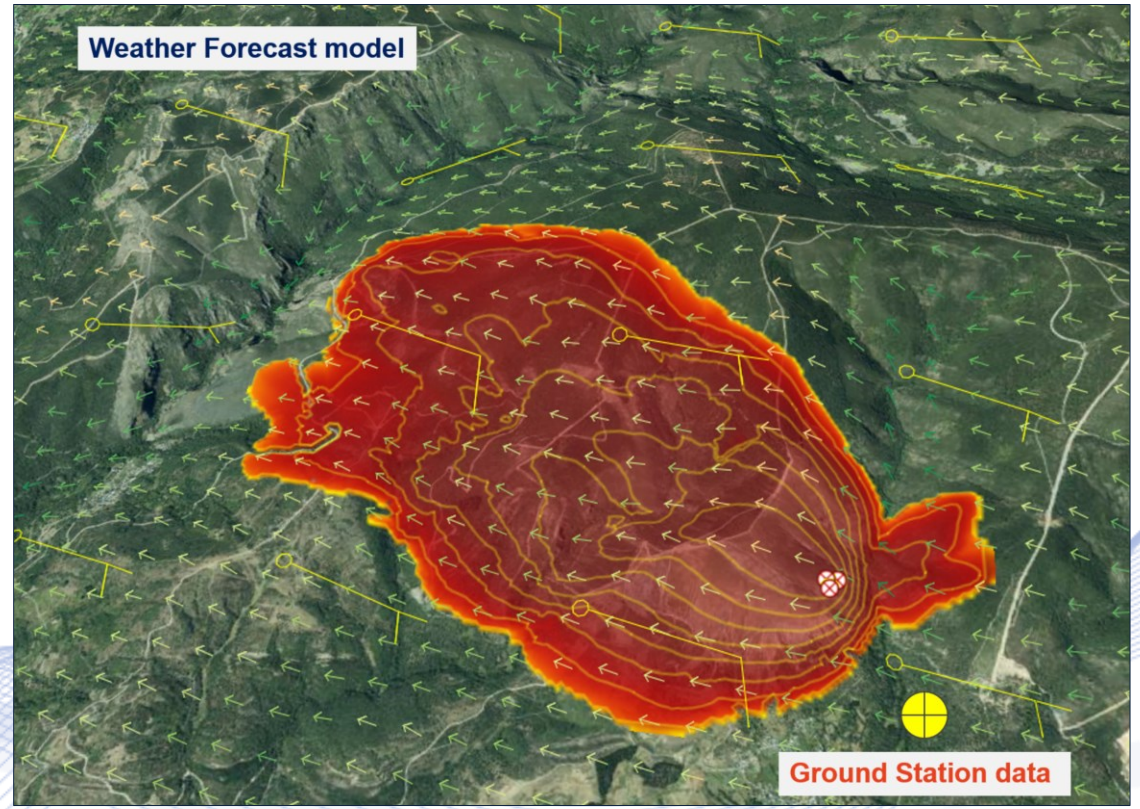


Wildfire Analyst® FireSim.

Forest Fire Modeling

Weather Data Model

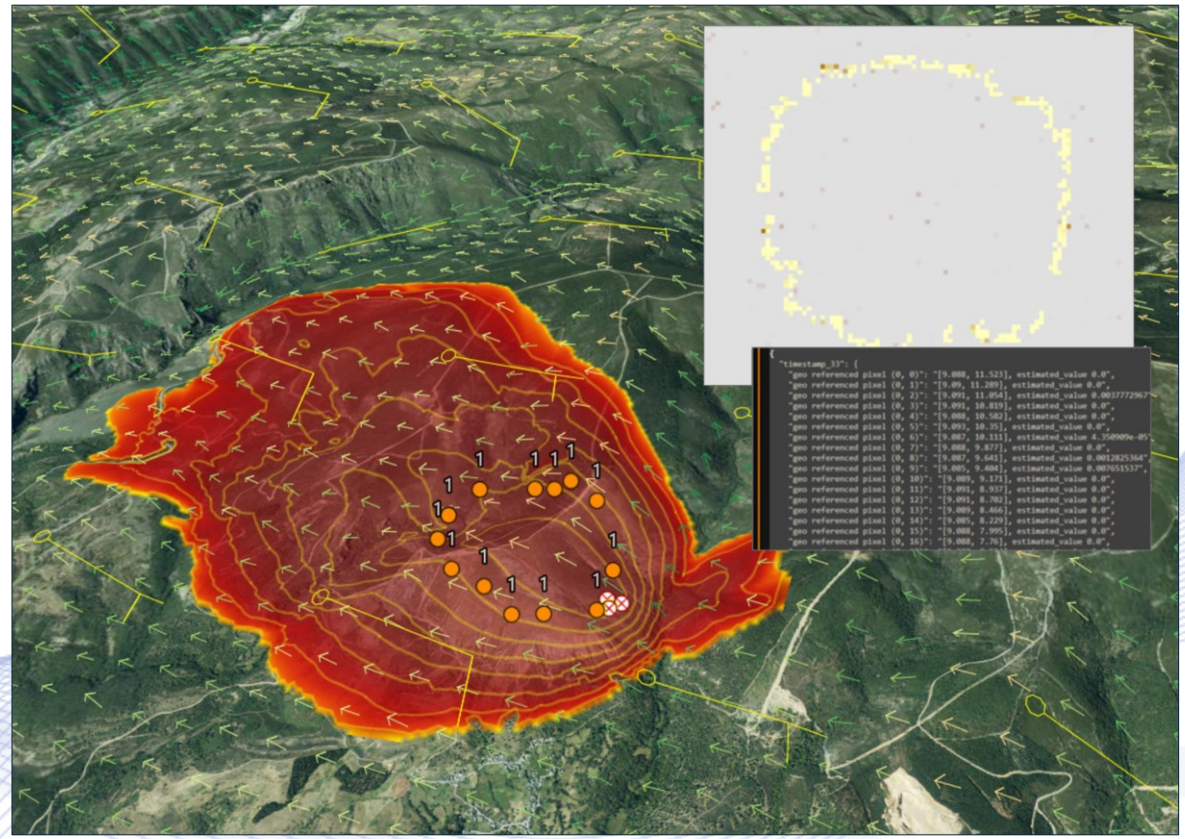
- Weather forecast data: HARMONIE-AROME, GFS.
- Real-time weather data from in-situ sensors.
- Spatio-temporal interpolation (IDW).
- Enhanced weather data model.



Forest Fire Modeling

Simulation Calibration

- Probability maps from Information Fusion.
- Set a probability threshold.
- GeoJSON ingestion for adjustment points.
- Adjustment parameters calculation.
- Run adjustment simulation every time new information is received.



Flood Segmentation

FloodSeg Dataset



FloodSeg training dataset images.

Flood Segmentation

CNN-i2i flood region segmentation on Ahrtal flash flood images (Germany).

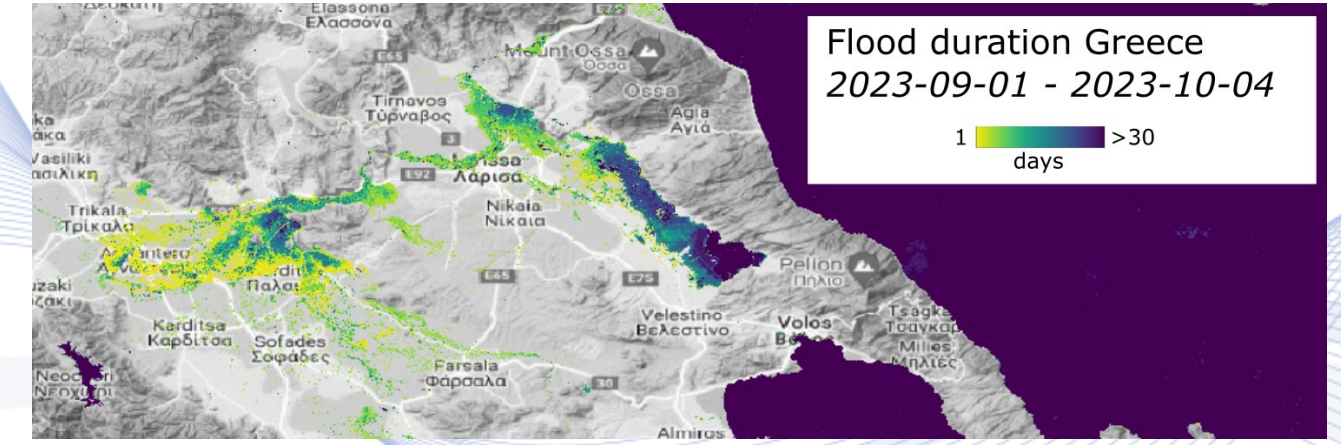
Object Detection and Tracking in Floods

DNN models, pretrained on COCO dataset were used to detect classes of interest (***cars, persons***) that may be in danger.

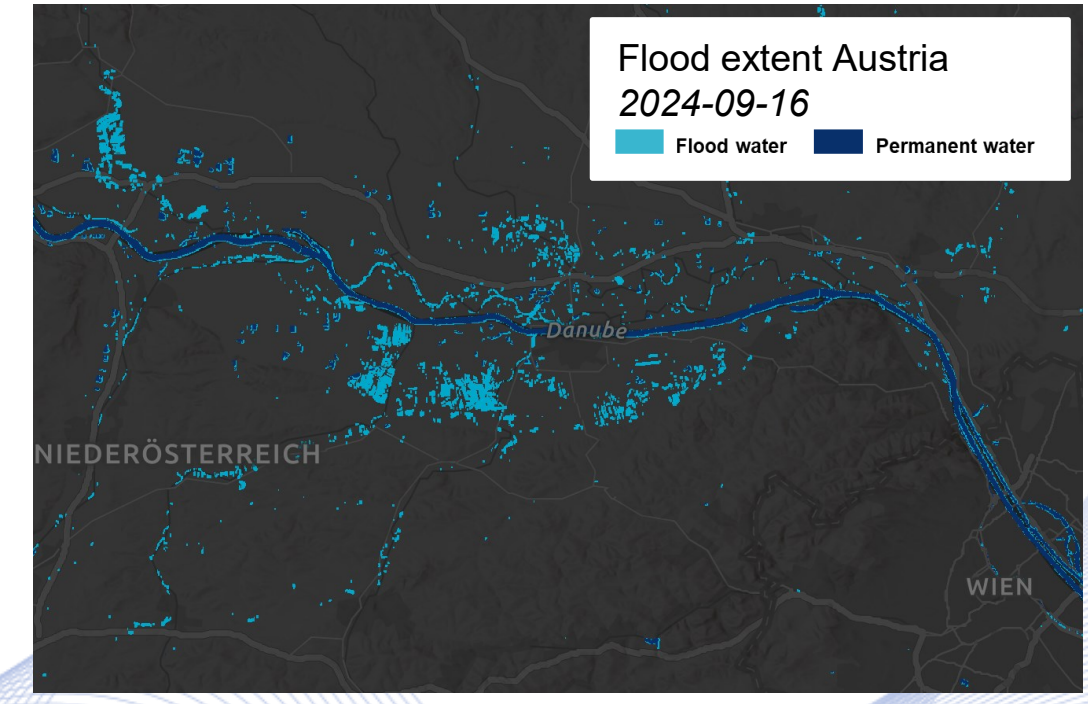
YOLOv6s 4.0 person and car detection in Thessaly floods, Greece (September 2023).

Satellite-based Flood Detection

- **Real-time AI-based flood extent mapping** (DLR-DFD)
- Continuous flood monitoring with Copernicus Sentinel-1/-2 satellite imagery
- Detection of flooded areas, permanent water bodies and flood duration
- Object detection in very high-resolution satellite and aerial images



Flood duration in Greece, September/October 2023, analyzed from Sentinel-1 and Sentinel-2 satellite images



Flood situation, Austria, September 2024

Detected Vehicles
2024-06-04
DLR 3K aerial images

Satellite Flood Image Analysis

Buildings Vehicles

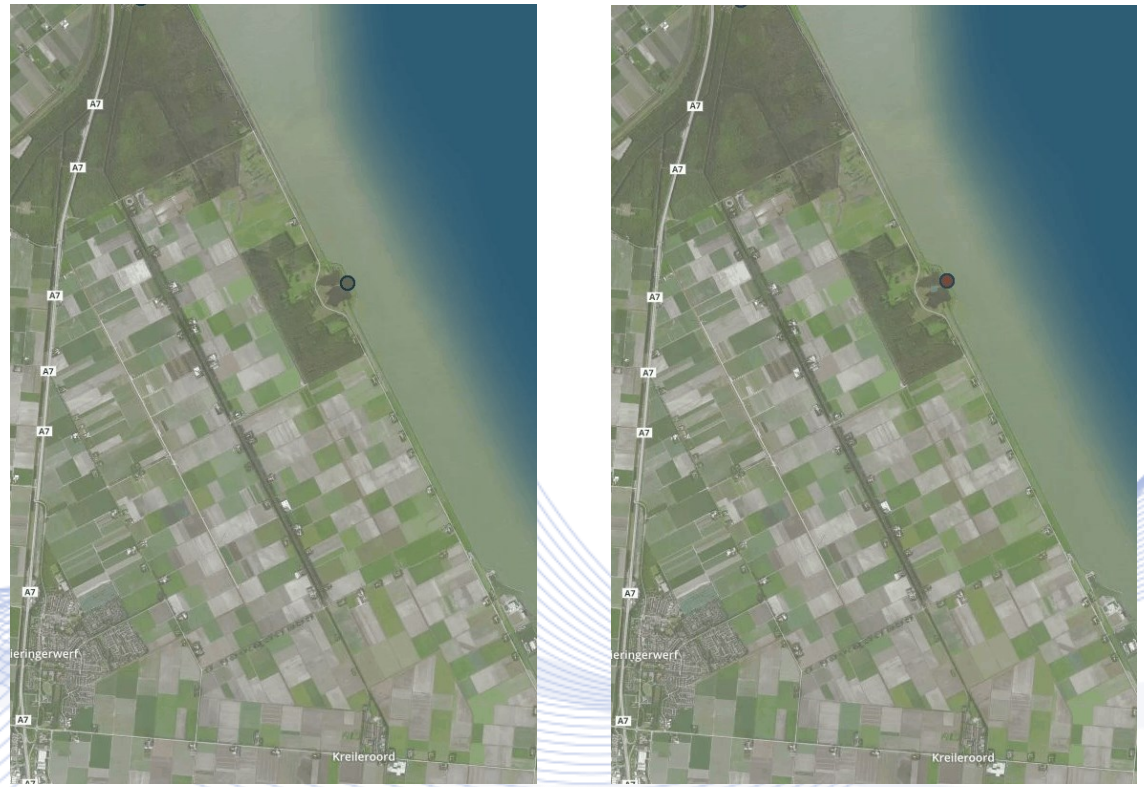
Flood mapping using satellite and aerial images.

Flood Modeling

Hydrodynamic simulation software

(Nelen & Schuurmans)

- Flood modelling in urban-suburban areas.
- Projection of results in a 2D map.



https://3diwatermanagement.com/learn/publications/

Digital Twin

Figure 22. Screenshot of the 3D model of a flood in the Larissa region using state-of-the-art algorithms.

Figure 23. Screenshot of the 3D model of a flood in the Larissa region (Greece) generated using our optimized processes.

Digital Twin

Visualization Tools

*Smart desk (*KAMK*)*

- The SmartDesk is an application running on a custom-built touchscreen computer
- The application is a mission management tool for civil protection
- It unifies the information and functionalities of TEMA in a single place
- It can be installed on any Windows PC
- Touch input, mouse, and keyboard are supported

AR visualization

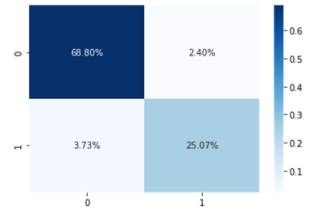
Geosocial Media Analytics

Natural Language Processing (NLP) for Semantic Topic Extraction (U Salzburg)

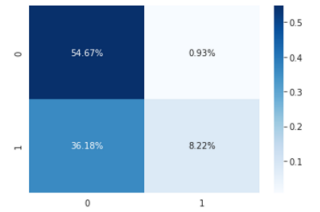
Understanding what posts talk about:

- Text pre-processing.
- Identification of semantic topics in social media text
- Semantic filtering (relevance).
- Currently testing GPT-3 and GPT neo

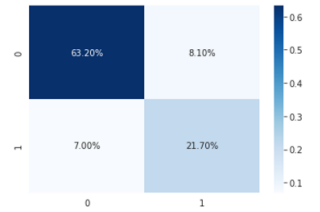
Vergleich von semantischen ML-Algorithmen



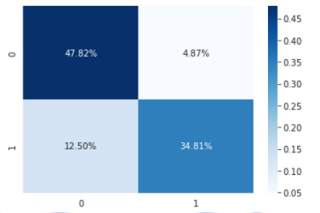
BERT: Accuracy (F1 Score): 97.3%, Training Accuracy: 99.2%



BERTopic: Accuracy (Current Best - F1 Score): 63%



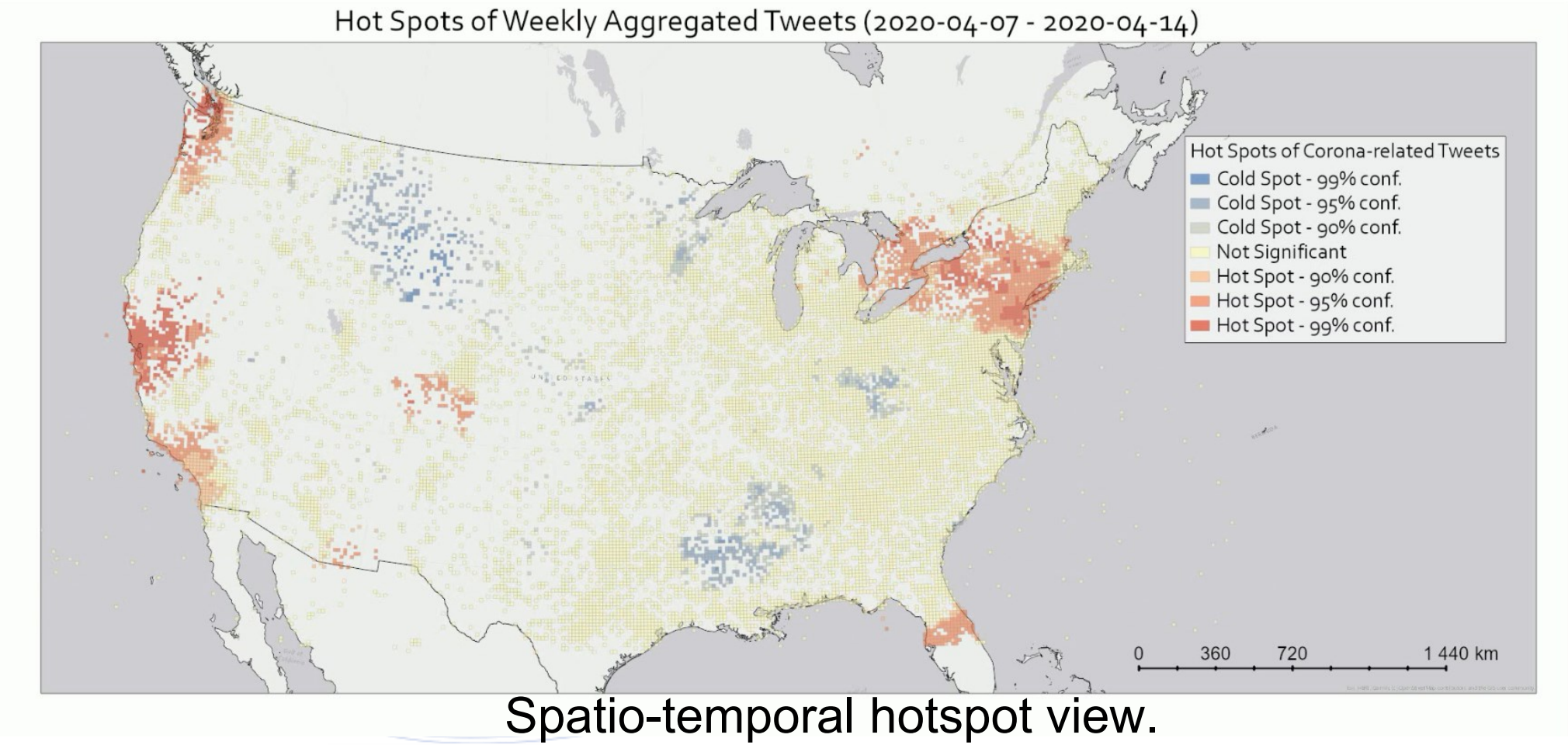
GuidedLDA: Accuracy (F1 Score): 85%



LDA: Accuracy (F1 Score): 83%

Geosocial Media Analytics

Georeferenced tweet analysis.

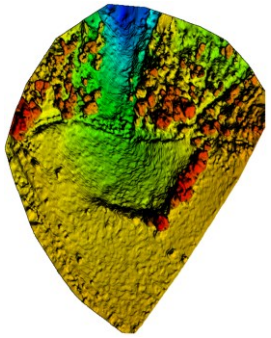


Spatio-temporal hotspot view.

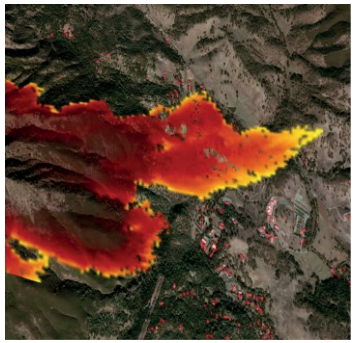
Information Fusion

Input data

Digital Elevation maps
Satellite imagery

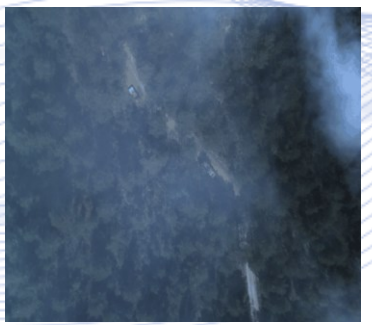


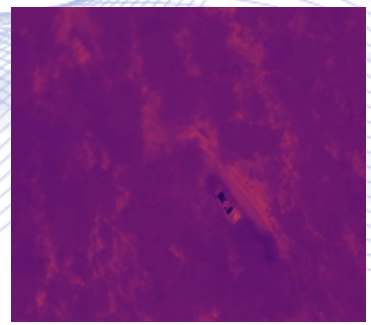
Fire simulators



Non-visual sensing (chemical + wind)

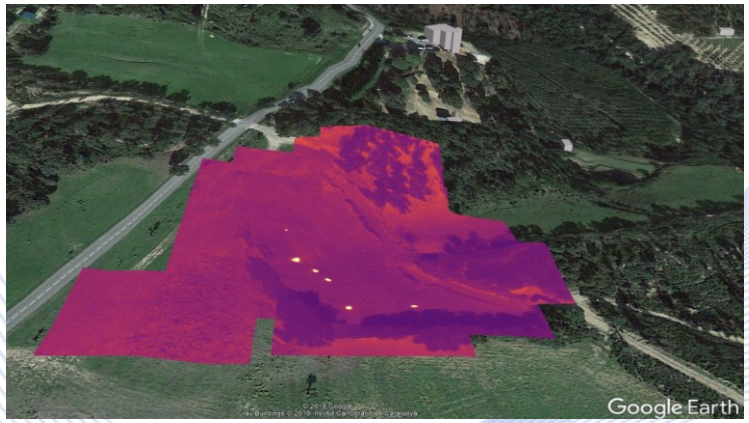
RGB and Thermal Infrared



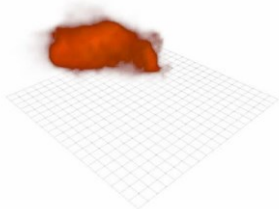


Fused information (U Seville)

Geo-Referenced Thermal Pictures/ improved situation awareness



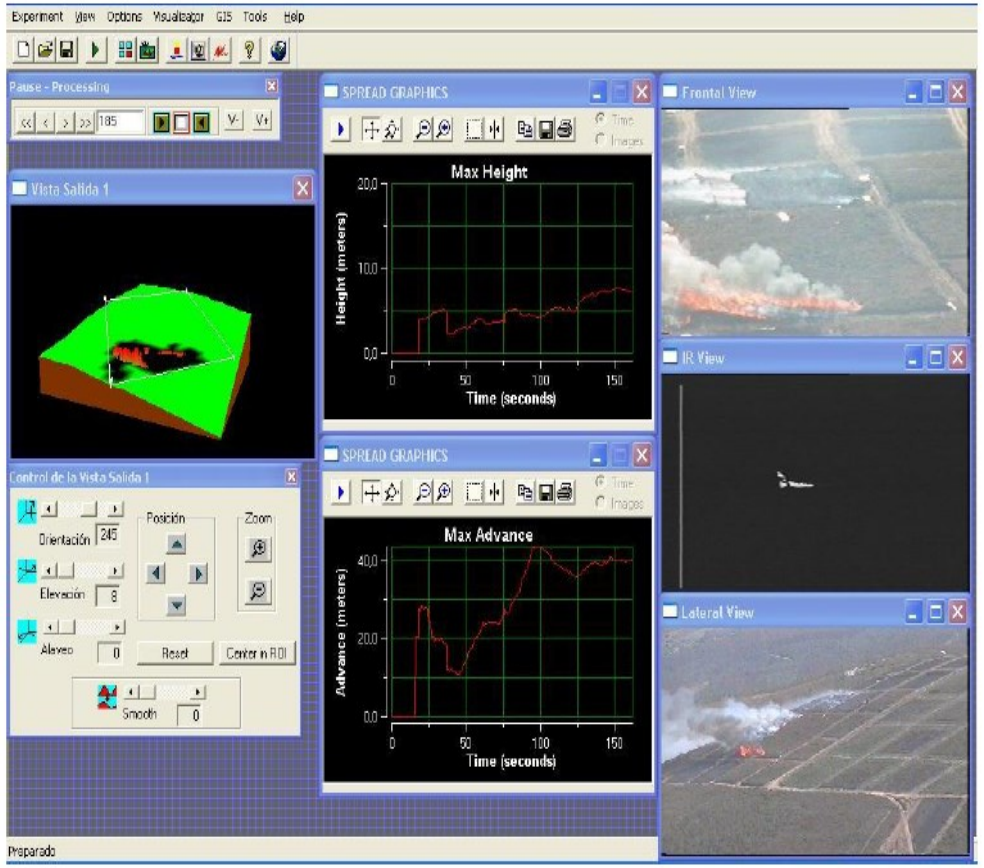
Geo-Referenced Digital models of wind and smoke

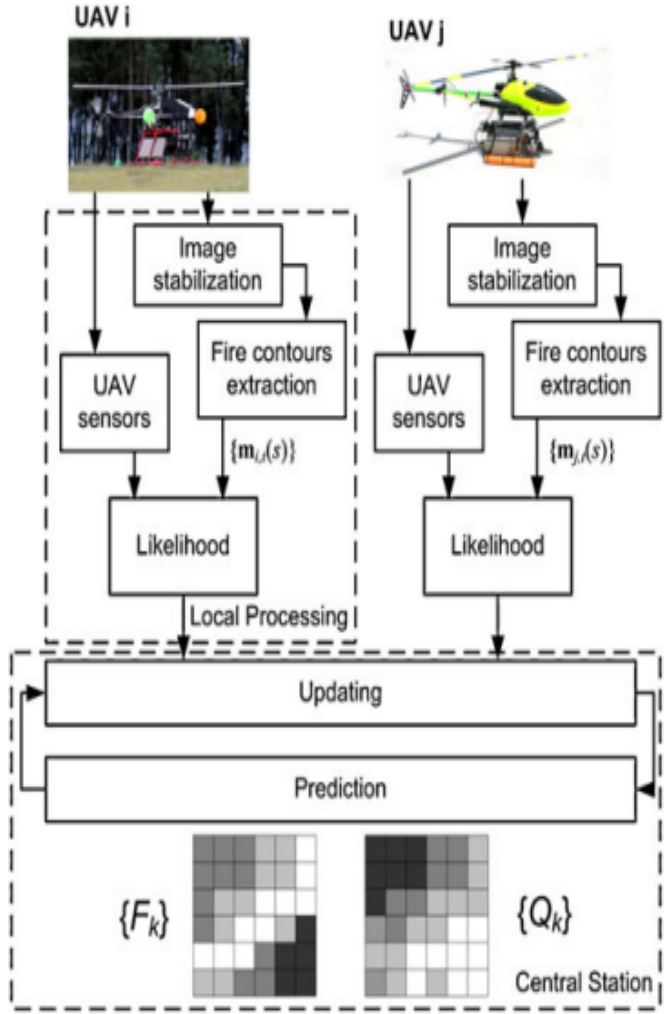


Information Fusion

Georeferenced Probabilistic Occupancy Grids

- Enables heterogeneity in observations temporal and spatial resolutions.
- Robust to occasional lack of observations.
- Robust to inconsistencies between observations.
- Enables multi-resolution observations.
- Provides georeferenced augmented maps (semantics).

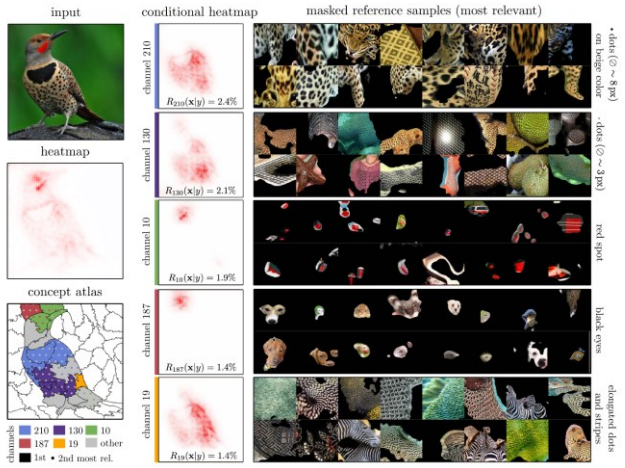


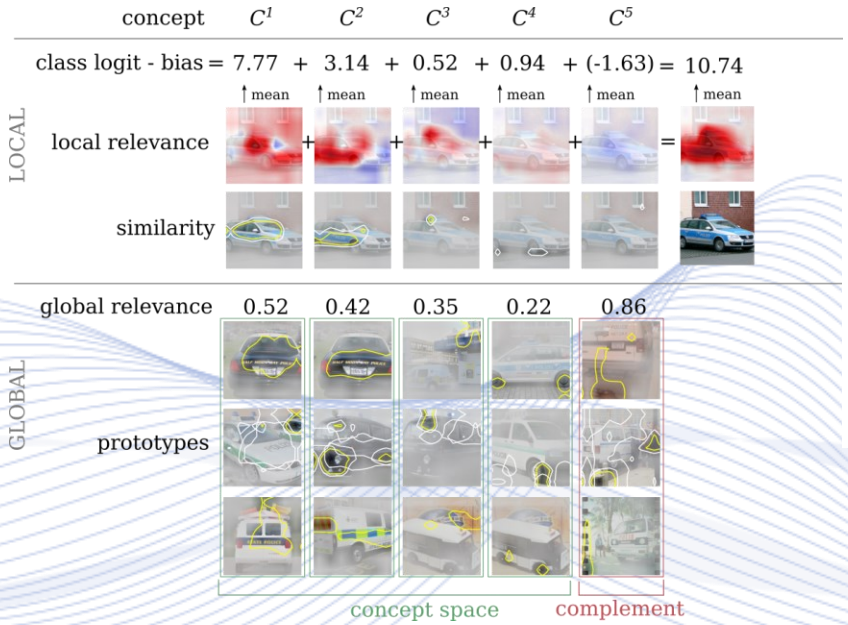


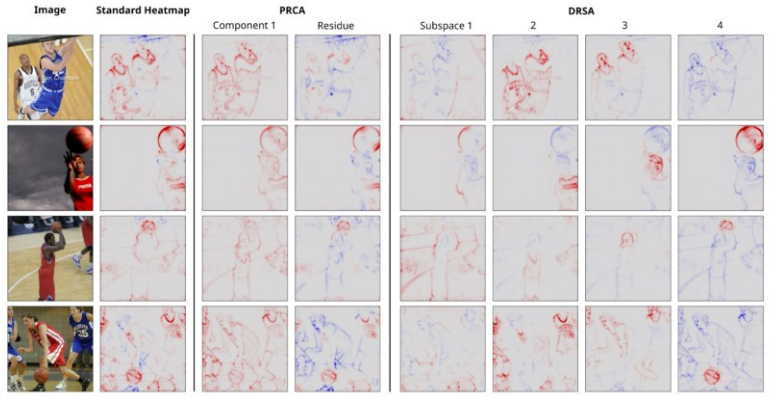
DNN Explainability

Concept-based explainability (Fraunhoffer HHI)

- Interpretability of explanations by decomposition into concepts with prototypes for context.







Relevant concept subspaces leveraging LRP

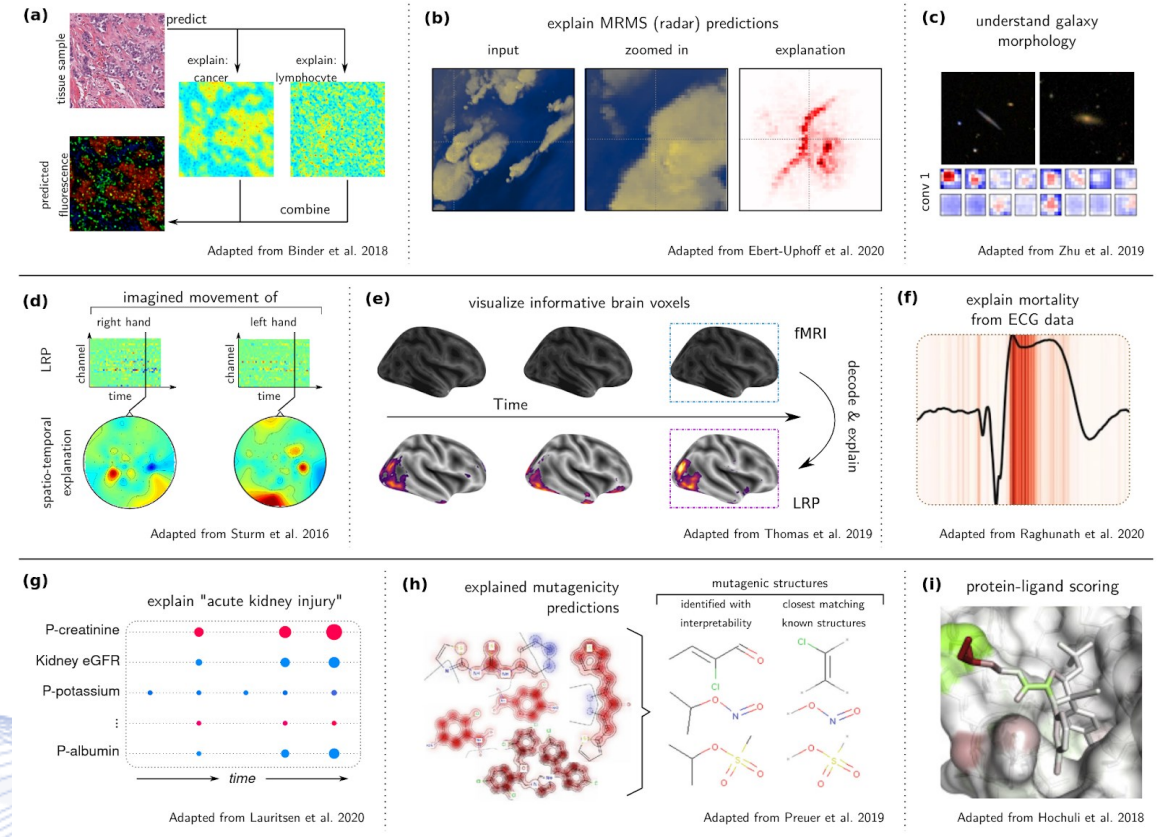
CRP: extension of LRP for glocal explanations.

MCD: dissecting feature space into concept subspaces

DNN Explainability

Layerwise relevance propagation

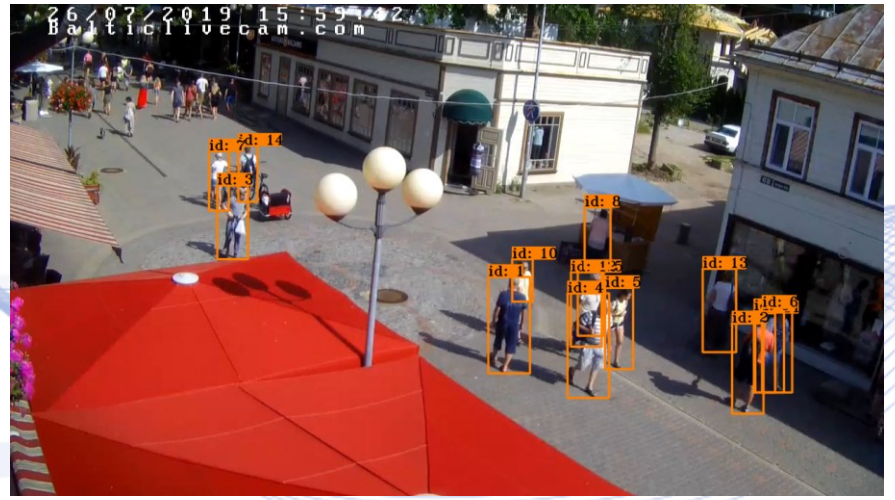
- Use the structure of the neural network to compute ***relevance scores*** for the input features.
- Tasks: DNN classification and regression.
- Data modalities: NLP, sensor data, audio, images, tabular, ...

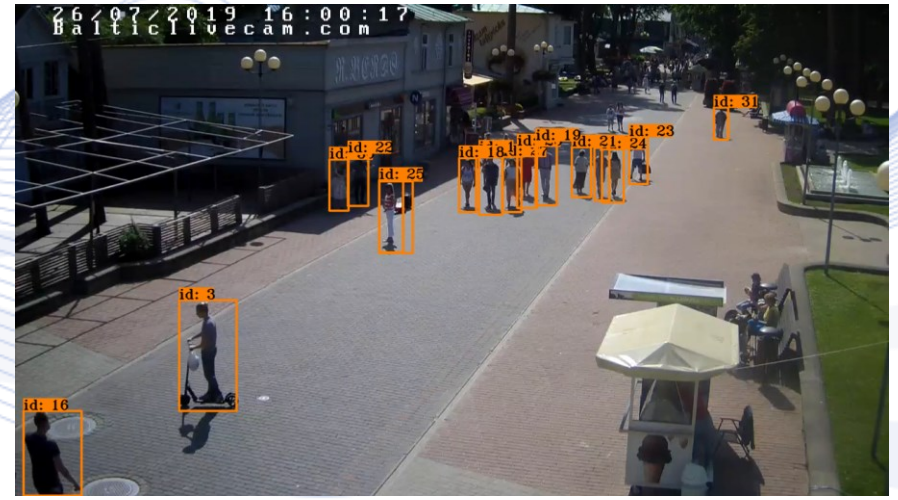


Person Re-identification

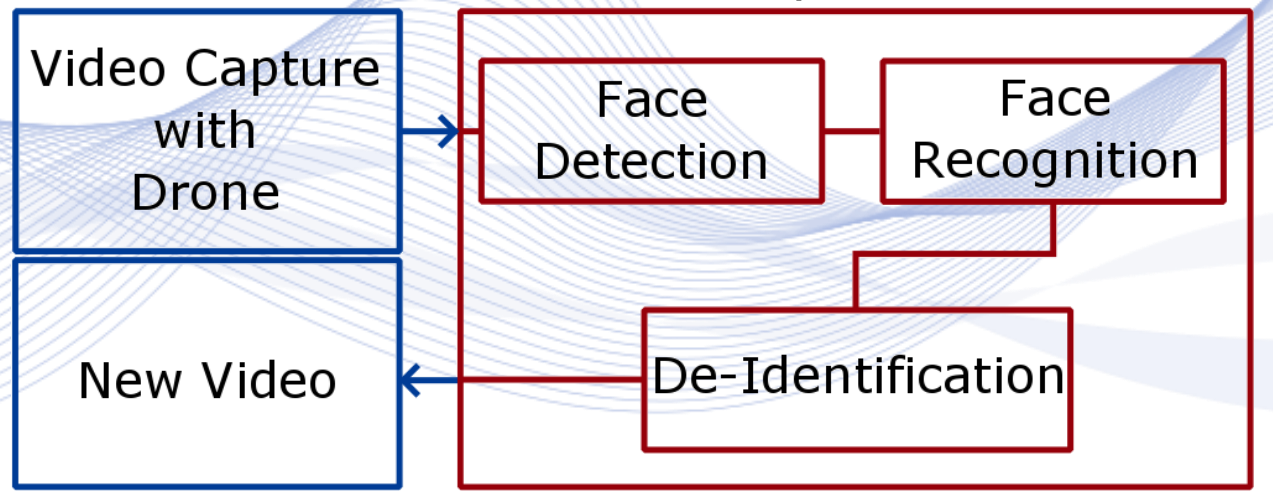
Person Re-identification (ATOS)

- YoloV8 performs person detection.
- DeepOCSORT tracker provides a unique person ROI id.
- Persons are re-identified on the same video stream further in time or in another stream.





Privacy Protection



Face de-identification on drone videos.

Privacy Protection

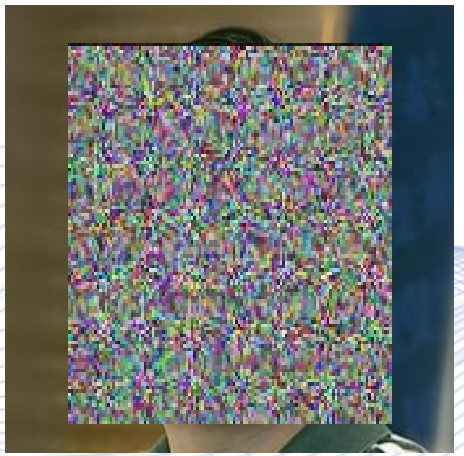
Adversarial attacks for privacy protection against automated classification systems.

- Generate unperceivable perturbations to fool DNN classifiers.
- Theoretical privacy guarantees.

Privacy Protection

Privacy Protection via Adversarial Reprogramming.

- Reprogramming the target DNN model (e.g., the face classifier), thereby effectively concealing sensitive information while maintaining model functionality



Big Data Analytics for Natural Disaster Management

- Natural Disaster Management
- NDM Concept and Objectives
- NDM Sensing
- Big NDM Data Analytics
- **Horizon Europe R&D project TEMA**

TEMA Consortium

- 19 Partners all over Europe
- AUTH is the coordinator

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Q & A

Thank you very much for your attention!

More material in
http://icarus.csd.auth.gr/cvml-web-lecture-series/

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