Holistic trajectory management in the maritime scenario

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Informatics & Telematics

MASTER
Multiple Aspect Trajectory Management and Analysis

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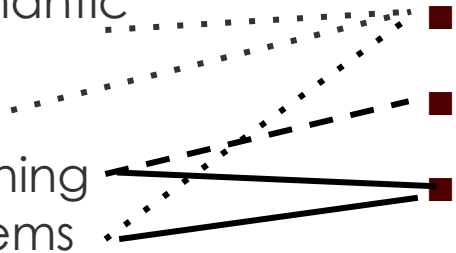
About me

- Position: Associate Professor in the Department of Informatics and Telematics at Harokopio University of Athens
- Domain: Data management
- Interests: Data mining & Information Retrieval
- Topics
  - Text Mining and Semantic Similarity
  - Graph mining
  - Trajectory (data) mining
  - Recommender Systems
- Applications
  - Social Networks
  - Maritime surveillance
  - Daily life



The maritime scenario

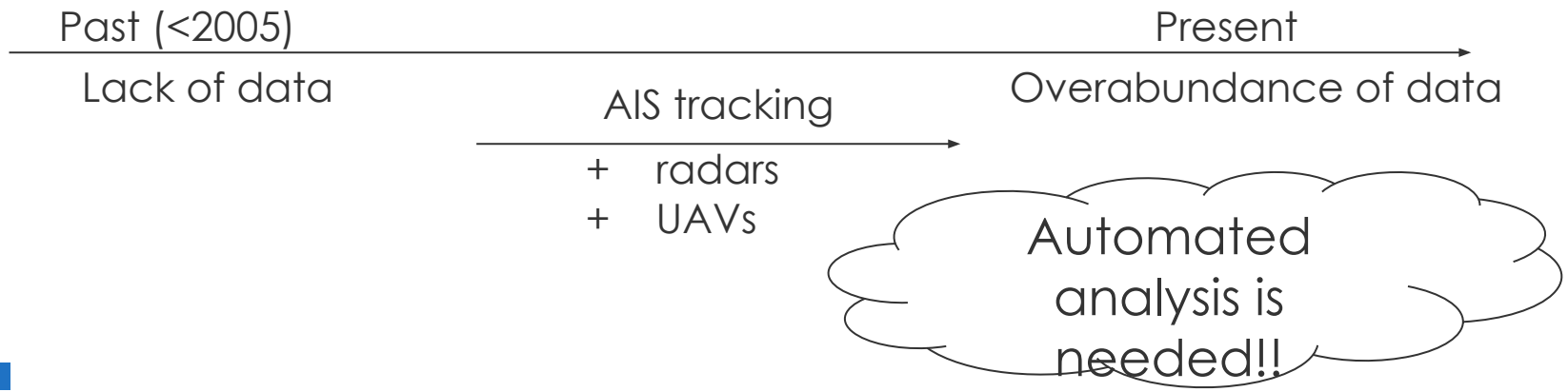
- The requirement
  - ***Maritime Domain Awareness***: Effective understanding of anything associated with the maritime domain that could impact the security, safety, economy, or environment ()
- The opportunity
  - ***Automatic Identification System (AIS)***: vessels report their position
  - Designed for collision avoidance
- Highlights
  - Lots of trajectory data (from sailing and fishing boats to cargo)
  - Data are public/open
  - Collecting and processing AIS data is a challenge by itself

Contents

- Maritime Domain Awareness market
  - Single vessel tracking
  - Multiple vessel tracking
- Automatic Identification System
- Solutions developed far
  - Search and Rescue Missions
  - Abstraction of multiple trajectory data
  - Anomaly detection in single and multiple trajectory data

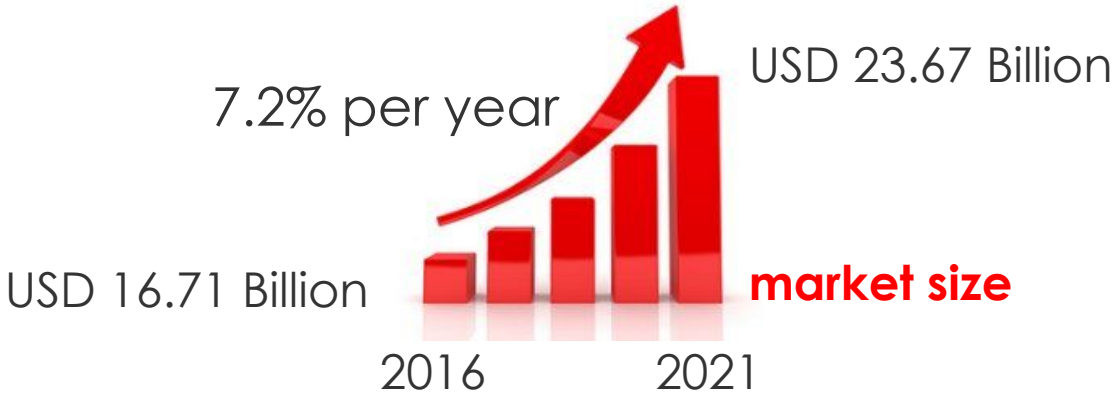
Maritime Domain Awareness

- MDA: Collect the maximum information about any vessel
- Maritime surveillance: Monitor water areas
  - Purpose: Military, Naval Law enforcement, Economic, Coast defence, Rescue, ***Safety & Security***



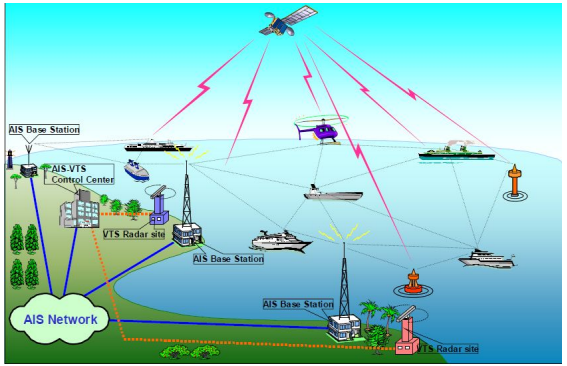
Maritime safety market

- Surveillance & Tracking, Detectors, GIS, Communication, SCADA (Supervisory Control and Data Acquisition), Screening & Scanning, Access Control, and Weather Monitoring



Definitions

- AIS: Automatic Identification System
  - Static and dynamic vessel information, broadcasted (VHF) by vessels (using an AIS transponder) and electronically exchanged between AIS-receiving stations (onboard, ashore or satellite)



Static data (every 6 minutes)	Dynamic data (every 2-10 seconds)
Vessel: International Maritime Organization (IMO) number (vessel's lifetime ID), Name, Type (or cargo type), Dimensions, Location of the positioning system's antenna on board the vessel, Type of positioning system (GPS, DGPS, Loran-C) **Voyage**: Draught, Destination, ETA (estimated time of arrival)	Maritime Mobile Service Identity (MMSI) number (vessel's communication ID), Vessel's Navigational Status, Rate of Turn (degrees per minute), Speed over Ground, Position Coordinates, Course over Ground, Heading, Bearing at own position, timestamp (in UTC seconds)

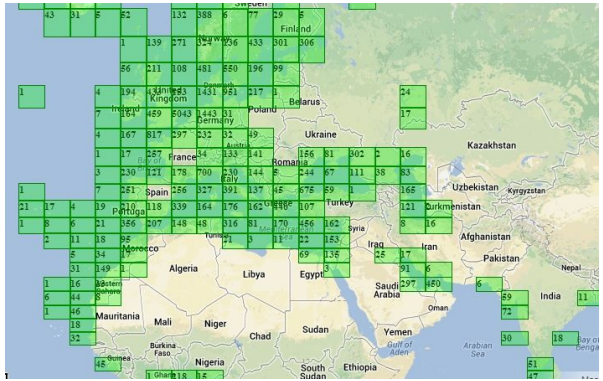
How big are AIS data?

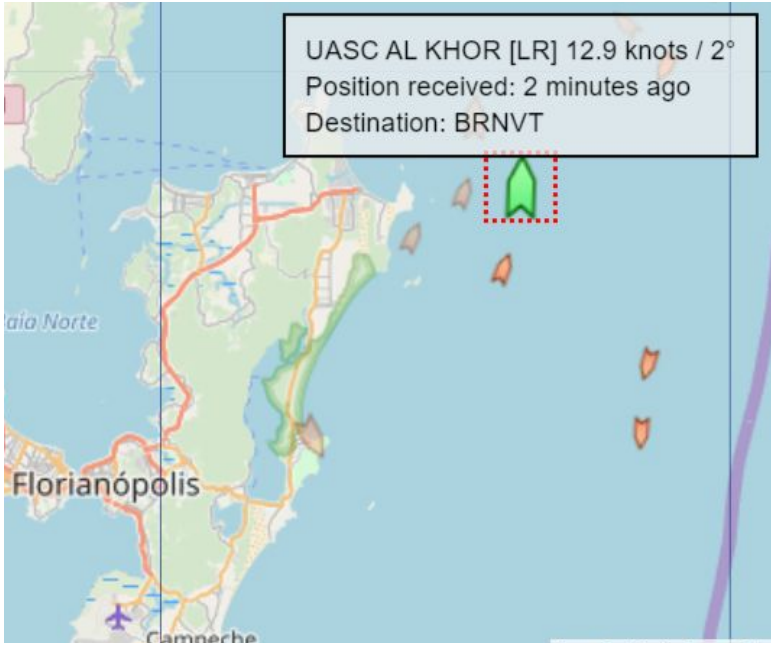
www.marinetraffic.com

- Marine-Traffic, records monthly
  - at least 800 million vessel positions
  - 18 million vessel and port-related events
- offers information about
  - 650000 marine assets such as vessels, ports, and lights etc.
- operates
  - more than 2, 000 AIS stations
  - located in over 165 countries
- has
  - over 600, 000 registered users
  - around 20 million visits to its website every month

Single vessel tracking

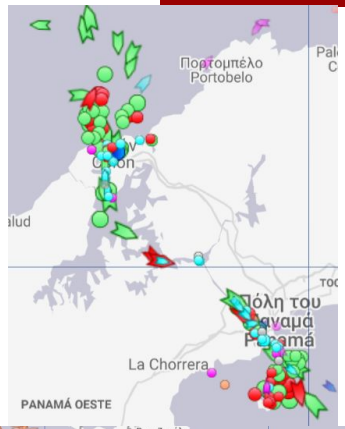
- Fleet monitoring services
  - Real-Time Tracking & Updates
  - Route Optimization
  - Advanced Analytics

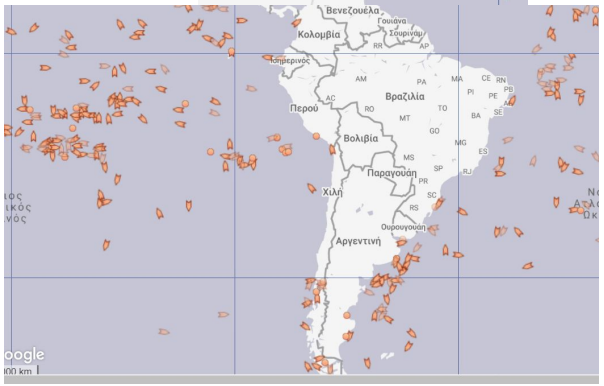




Multiple vessel tracking

- Area monitoring
  - ports
  - canals
  - protected areas (Natura) of restricted access
  - emission control areas
  - borders
- Fishing boats monitoring
- Cargo vessel monitoring
- Search and rescue missions monitoring





Open challenges

- Data sampling
- Data compression
- Distributed data processing
- Data fusion (AIS, satellite etc)
- Knowledge extraction
- Validation

who will count the plant leaves?

Our work in MASTER

- Search and Rescue (SAR) missions detection
- SAR maneuver classification
- Multi-trajectory abstraction and summarization
- Anomaly detection

Search and Rescue missions

Search and Rescue missions

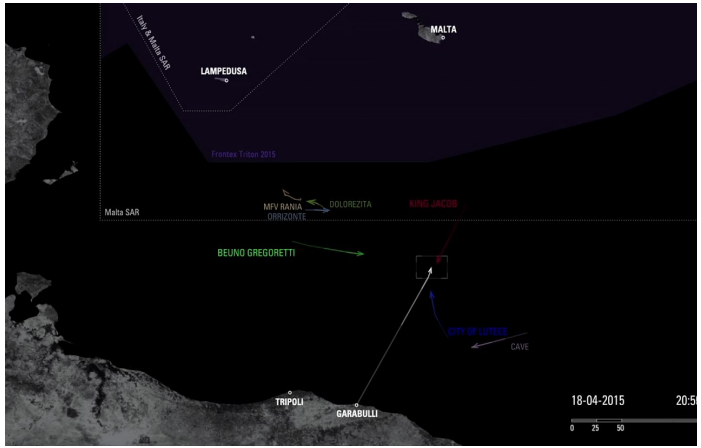
- SAR or ASR (Air-sea rescue missions): Aircraft and vessels, search for and recover survivors or bats in distress
- SAR missions from National Coastguards and NGOs to retrieve refugees' boats in the Mediterranean
  - Italy's 'Mare Nostrum' until 2015,
  - Medecines Sans Frontiers in southern Italy,
  - Refugee Rescue in the Aegean Sea (Greece)

http://searchandrescue.msf.org/

http://www.refugeerescue.co.uk/

What happens in an emergency

- A vessel's or coastguard's radar detect a boat in distress and notifies nearby vessels
- One vessel is in command and the others perform SAR maneuvers one after the other for many hours/days
- There is a long story on **when** the 'nearby' vessels have been engaged on the SAR mission and **where** they were before the mission.



https://vimeo.com/219739614 @ 8:56

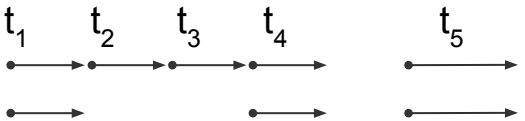
So.... →

The challenge

- Automated surveillance: Detect a SAR mission using only AIS data
- Break down to smaller tasks
  1. monitor all vessels in the region (big data management)
  2. ***detect when vessels perform SAR maneuvers*** (clustering/classification)
  3. ***combine information from multiple vessels at time period*** (knowledge abstraction)

1 Big data management

- Scalability
  - >3,000 vessels in the Mediterranean per day
  - AIS data every few seconds
- Data selection: only position, speed, heading and timestamp
- Data compression and noise reduction: only representative points when position/speed/heading does not change much (data every few minutes)
- Incremental processing: Data streams require incremental algorithms



2 Detect SAR maneuvers

- The approach we followed

For a single vessel

- Trajectory simplification
- Turn detection
- Maneuver detection and annotation

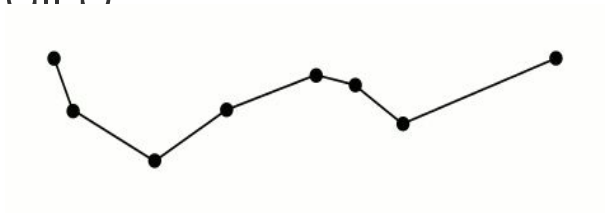
For multiple vessels

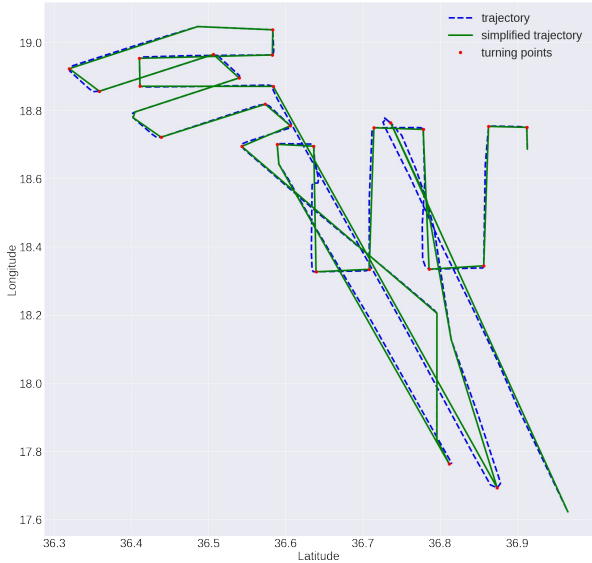
- Detection of multi-vessel maneuvers co-occurrence

Varlamis, I., Tserpes, K., & Sardianos, C. (2018, April). Detecting Search and Rescue missions from AIS data. In *2018 IEEE 34th International Conference on Data Engineering (ICDE) Workshops* (pp. 60-65). IEEE.

Trajectory Simplification

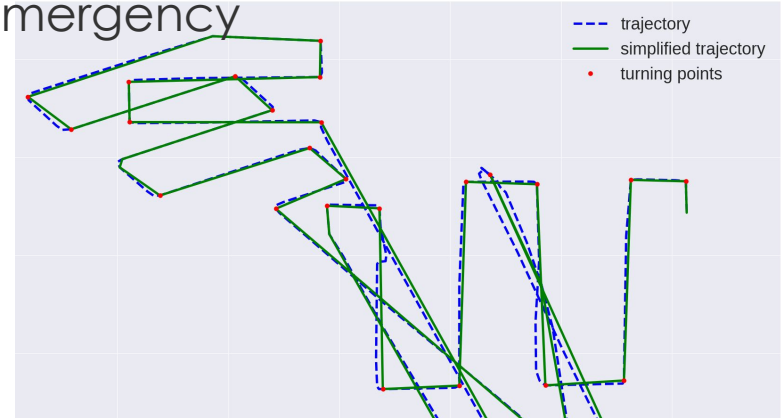
- Noise removal: Simplify trajectory information by removing records that do not provide much information about the vessel trajectory
- Ramer–Douglas–Peucker (RDP) algorithm:
  if max($dist_{perpendicular}$ (p_i,ε)) <e then ignore all p





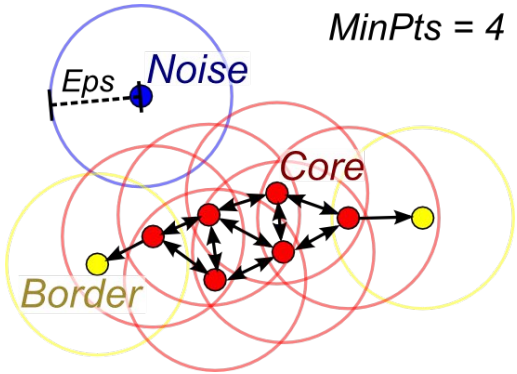
Not only Stops and Moves

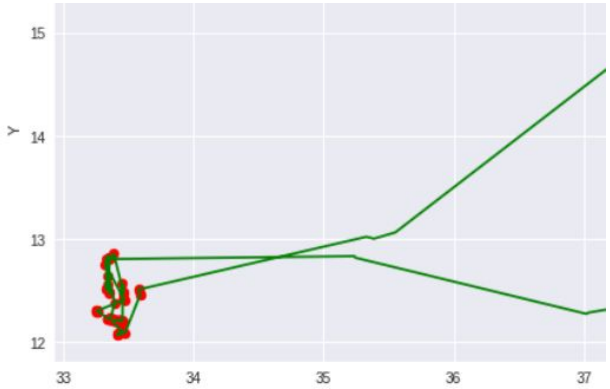
- **Turns**: the heading changes more than a threshold (e.g. 30deg)
  - Near ports
  - Capes
  - Dangerous or protected areas
  - In an emergency



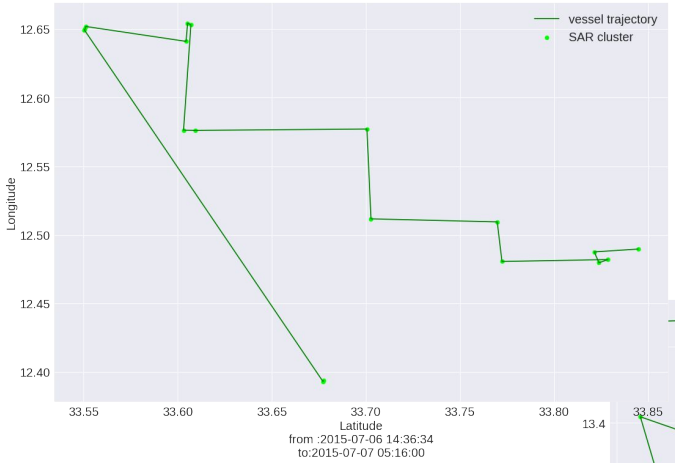
Not only Stops and Moves

- **Maneuvers**: Many turns in a small area (high density)
- Density based clustering of turning points
  - Incremental DB-Scan on the turns only (while they are detected)
  - Eps=40, MinPts=8 : 8 or more turns within a range of 40 Km

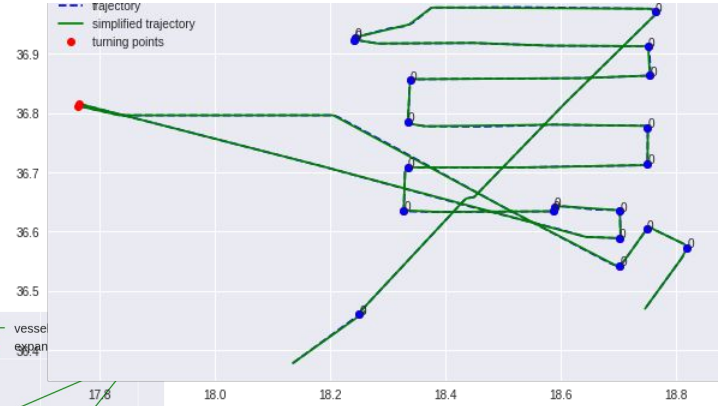


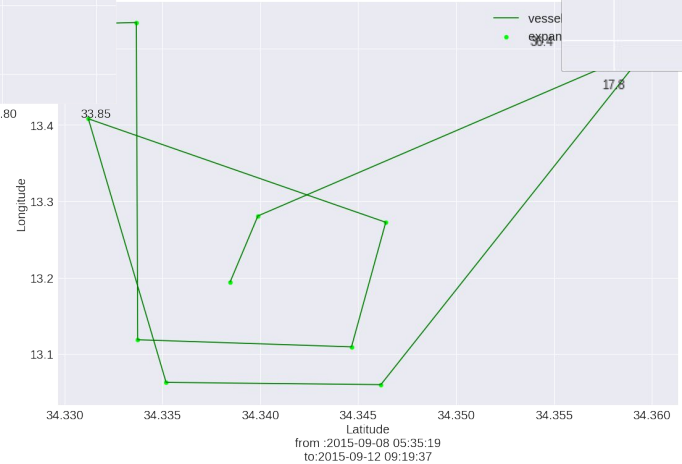


Maneuvers detected



There exist similarities among patterns





but:

Composite movements
Differences in scale
Differences in orientation

3 Search and Rescue missions

- engage multiple vessels
  - More than one vessel are performing maneuvers in the same region
- are long-lasting
  - A SAR mission lasts from a few hours to a few days

Detecting potential SAR missions

- Machine (unsupervised) learning approach
  - Cluster the detected maneuvers
  - Label clusters as SAR maneuvers or not
  - Detect the features that characterise SAR maneuvers

3a

- Supervised learning approach using Shapelets
  - Create synthetic maneuver trajectories
  - Train a shapelet classifier

3b

- Information retrieval approach
  - Spatio-temporal retrieval of maneuver clusters
  - Get maneuver clusters from 3 or more vessels in the same wider area during a specific time window (i.e. vessels operating in the same area within a few hours)

3c

Empirical evaluation

- Dataset:
  - AIS data for 3 months (Jul-Sept, 2015) for
  - 5 SAR vessels (supply vessels hired by NGO's)
  - 20 random vessels in the same area and period

1. Simplify trajectory
2. Detect turns
3. Cluster turns to get maneuvers (333)
4. Extract maneuvers features (avg speed, duration, distance covered, area covered, avg/max radius, num turns, stops)
5. Cluster maneuvers

3a

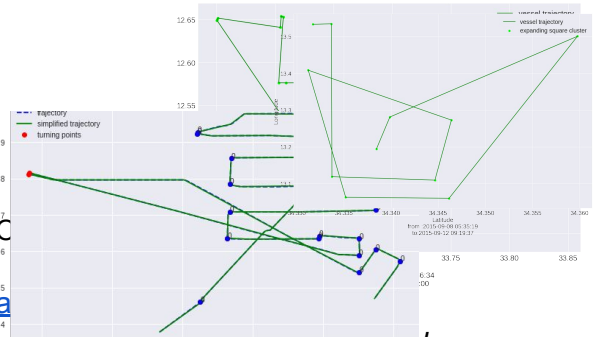
scanning
operating
sailing
operating

cluster	avgsp	difhead	turns	tot_dist	stops
0	64.148257	75.428571	20.095238	76.468132	1.809524
1	12.952170	76.201258	60.440252	37.727155	32.679245
2	109.711685	33.000000	15.666667	50.164467	0.555556
3	32.408262	52.536585	25.715447	56.888629	8.788618

Retrieve SAR events

- Define the bounding box of a detected cluster
- Retrieve overlapping bounding boxes (in space) that also overlap in time
- Result:
  - 2015-09-02 06:50:07:::2015-09-02 18:20:07 PHOENIX & DIGNITY I
  - 2015-09-02 12:22:07:::2015-09-02 18:14:55 PHOENIX & BOURBON ARGO

3c



http://www.msf.org/en/article/mediterranean-migration-1658-people-rescued-busiest-da

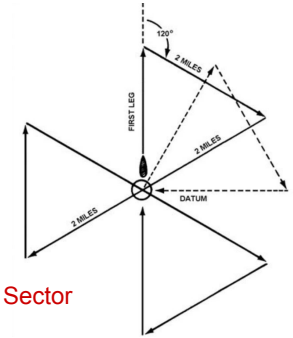
02/09/2015: "*...Beginning at 7am, when the Bourbon Argos rescued 353 people from a wooden boat in the international waters north of Zuwara, the day continued with the Dignity I rescuing three inflatable boats with a total of 323 people onboard. Then the Bourbon Argos rescued another wooden boat bringing a further 650 people on board, and finally the MY Phoenix rescued 332 Eritreans from a wooden boat in the early afternoon...*"

Supervised SAR maneuver detection

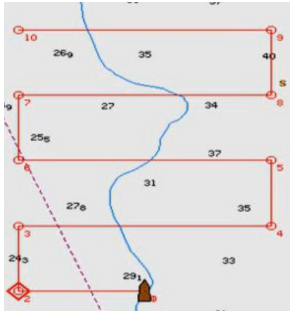
3b

Search

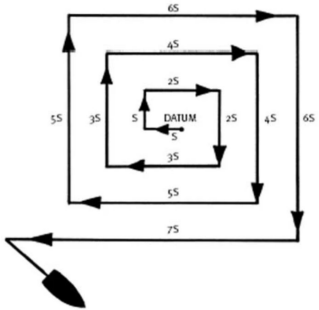
Sector



Parallel track

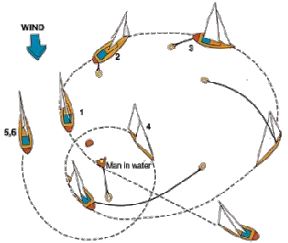


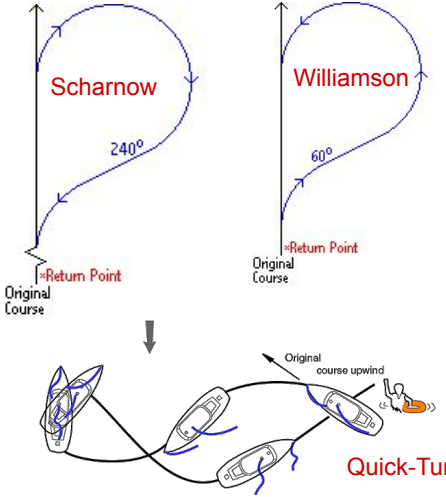
Expanding rectangle



Rescue

Man overboard (MOB)

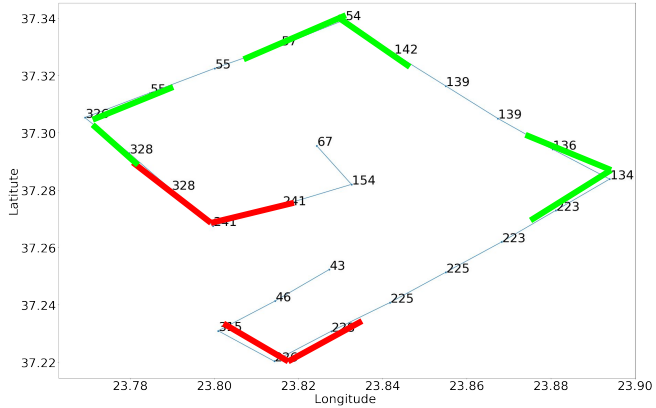


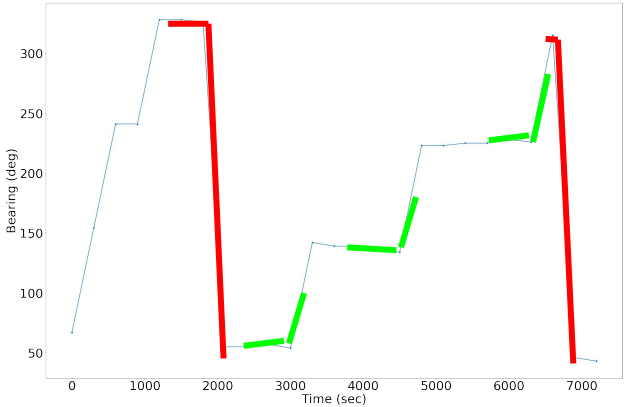


Kapadais, K., Varlamis, I., Sardianos, C., & Tserpes, K. (2019). A Framework for the Detection of Search and Rescue Patterns Using Shapelet Classification. *Future Internet*, *11*(9), 192.

Synthetic maneuver generator

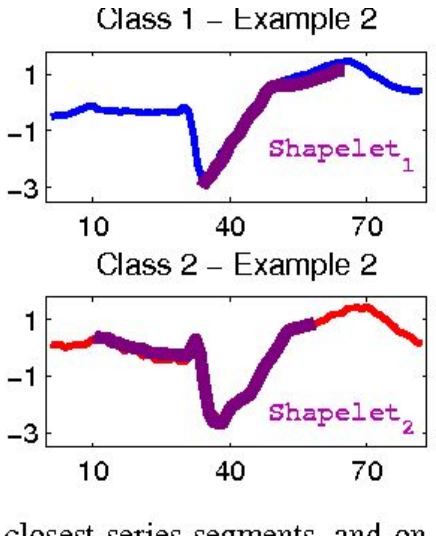
- SAR maneuvers have specific patterns
- The generator creates synthetic trajectories following these patterns
- Randomness is introduced in the number of turns or the length of straights
- The speed and bearing time-series of trajectories are used for training
- Shapelet-based features are extracted





Shapelet-based classification

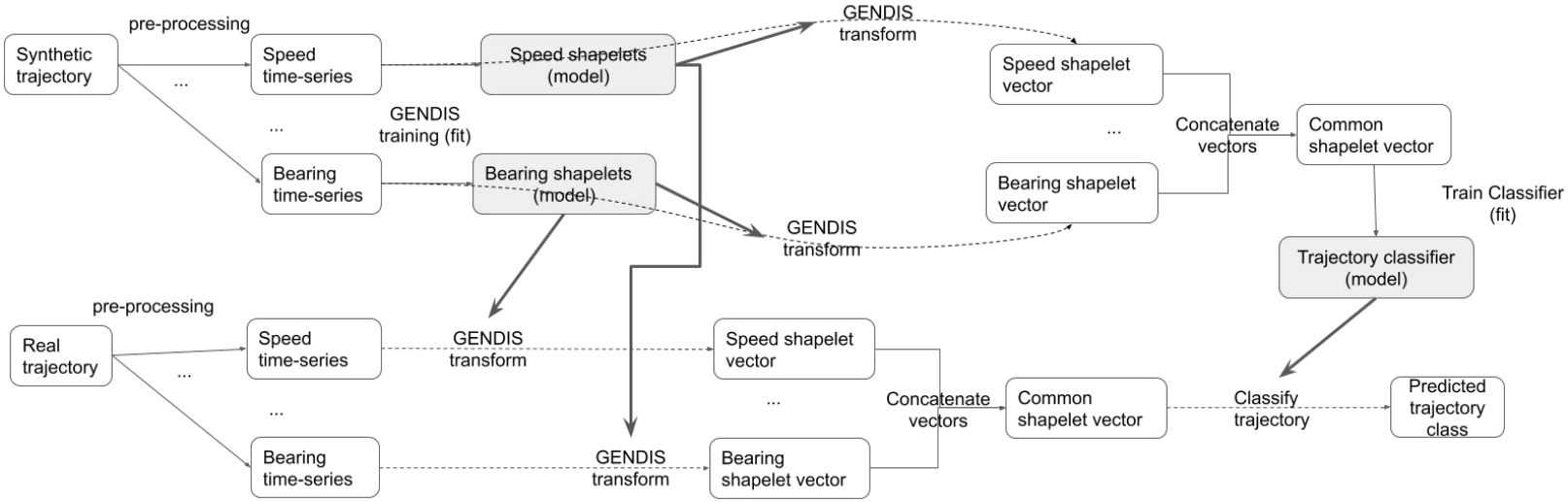
- Shapelet = time-series subsequence
- A shapelet in a SAR maneuver can be the clockwise (or anti-clockwise) turn of 90 (or 45) degrees, or a combination of turns
- The amount/frequency etc of such turns (shapelets) is a feature in the maneuver
- Shapelet-based classification involves measuring the similarity between a shapelet and each series, then using this similarity as a discriminatory feature for classification.



Ye, L and Keogh, E., Time series shapelets: a new primitive for data mining Proceedings of the 15th ACM SIGKDD international conference on Knowledge discovery and data mining, 2009.

GENDIS shapelet classifier

https://github.com/IBCNServices/GENDIS
https://github.com/gustrip/hua-thesis/

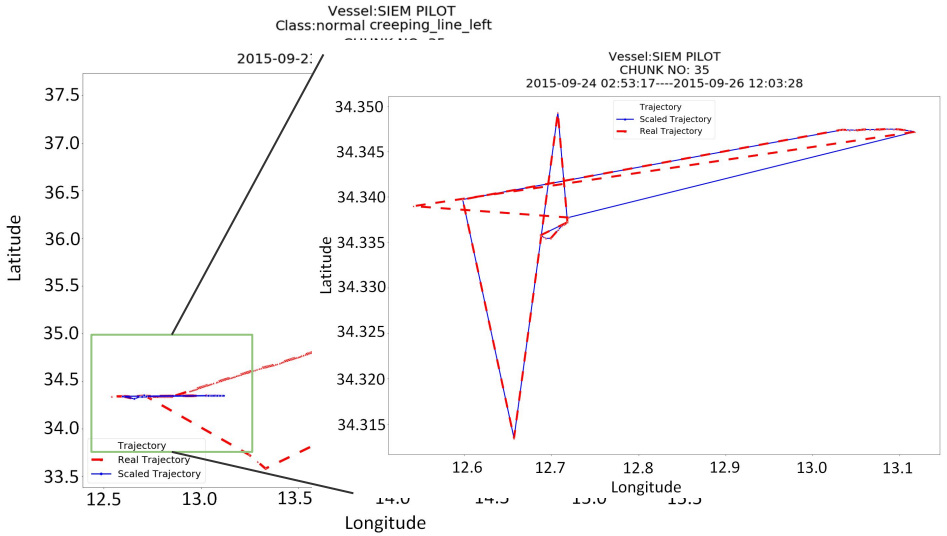


Classification performance

- Binary classification on synthetic data

Scenario	Class A	Class B	Average Accuracy
9	Spiral	Random	99.38 ± 0.25
10	Expanding square	Random	97.38 ± 0.62
11	Creeping line	Random	91.62 ± 2.08
12	Sector	Random	92.25 ± 1.2
13	Spiral	Steps	99.63 ± 0.2
14	Expanding square	Steps	99.38 ± 0.26
15	Creeping line	Steps	96.5 ± 0.69
16	Sector	Steps	95.5 ± 0.67

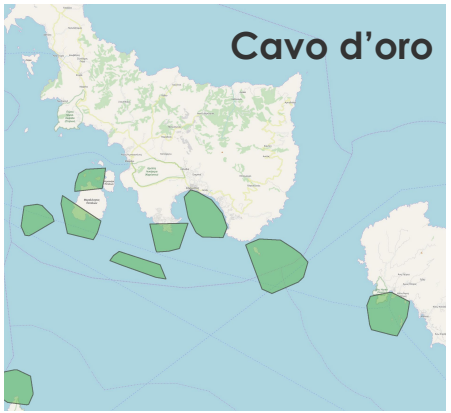
- On real data



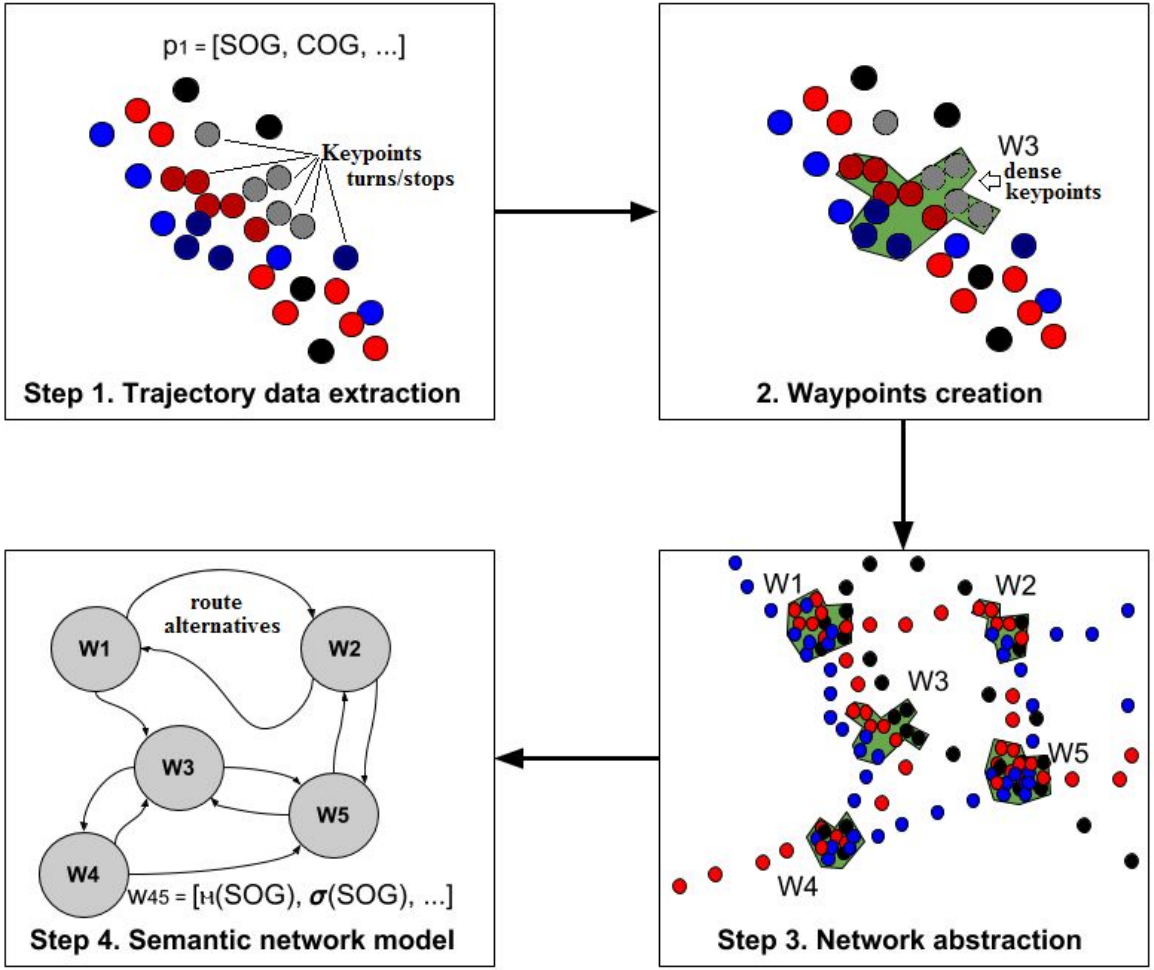
A network abstraction of multi-vessel trajectory data

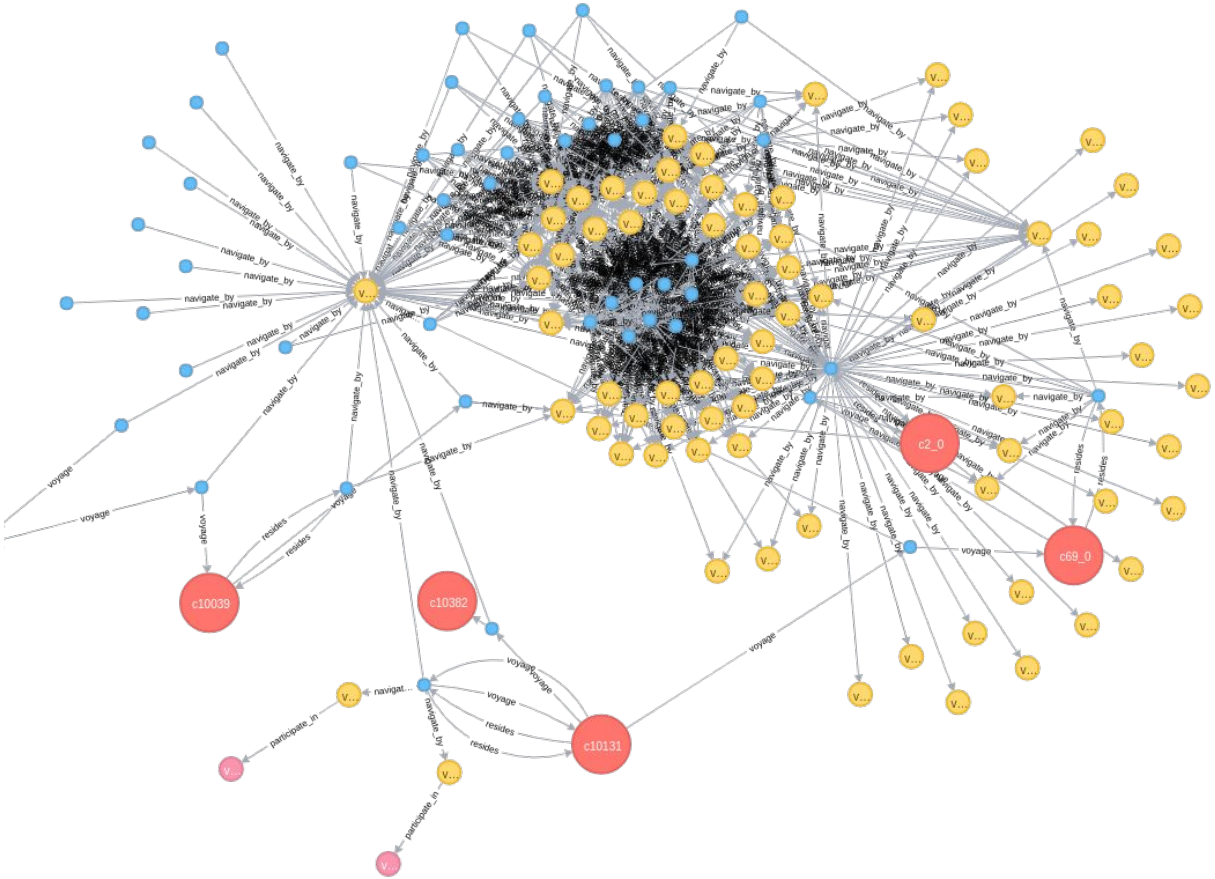
Abstraction steps

1. Detect ***stops*** and ***turns*** in each vessel trajectory
2. Cluster stops and turns from multiple vessels ⇒ ***waypoints***
3. Create a network with waypoints as vertices. Edges are drawn based on the available trajectories
4. Extract information about vertices (e.g. convex, number of vessels) and edges (e.g. mean speed or average course)



At a glance


p1 = [SOG, COG, ...]
Keypoints
turns/stops
Step 1. Trajectory data extraction
W3
dense
keypoints
2. Waypoints creation
W1
W2
W3
W5
W4
Step 3. Network abstraction
route
alternatives
W1
W2
W3
W5
W4
W45 = [μ(SOG), σ(SOG), ...]
Step 4. Semantic network model



Varlamis, I., Tserpes, K., Etemad, M., Soares A., & Matwin, S. (2019). A Network Abstraction of Multi-vessel Trajectory Data for Detecting Anomalies. In *EDBT/ICDT Workshops*.

Network value

- Identify route anomalies/outliers

  Kontopoulos, I., Varlamis, I., & Tserpes, K. (2019). Uncovering hidden concepts from AIS data: A network abstraction of maritime traffic for anomaly detection. !st MASTER Workshop @ ECML-PKDD, Wurzburg, Germany.

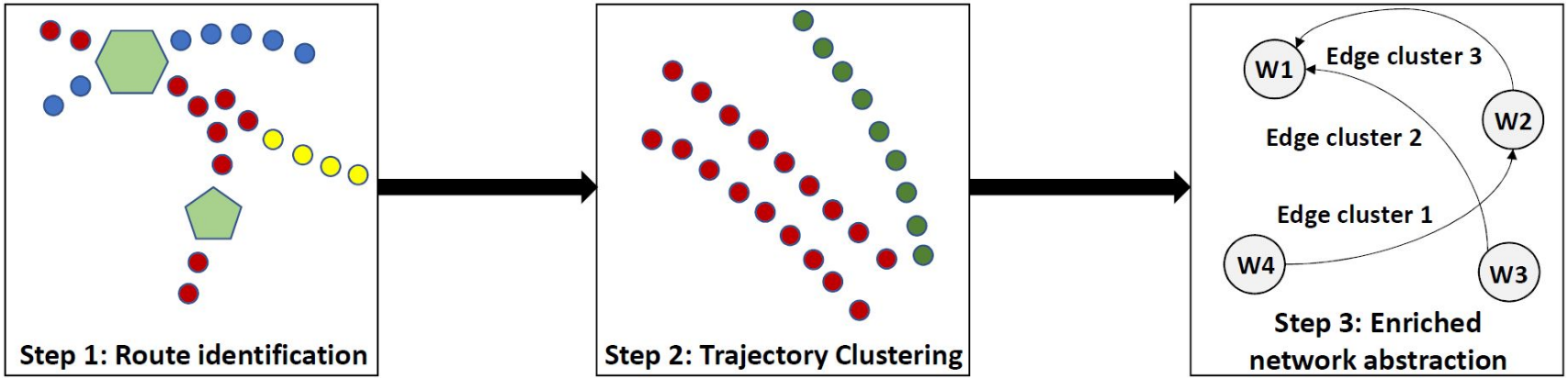
- Identify naval paths and restricted areas

  Varlamis, I., Kontopoulos, I., Tserpes, K., Etemad, M., Soares A. & Matwin, S. Constructing navigation networks from multi-vessel trajectory data. Submitted to Geoinformatica Journal.

- Compose route alternatives / optimize route

Extract route semantics

- Segment trajectories into port-to-port voyages
- Group sub-trajectories with similar characteristics together
- Create edges of a traffic network from the clusters

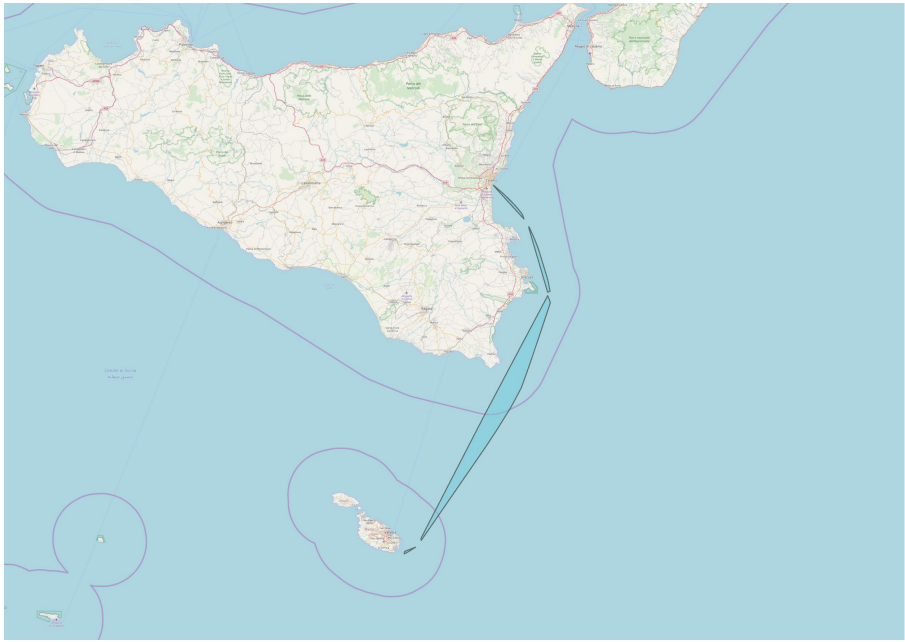


1 Route Identification

- Split the data for a vessel to trips from origin to destination port

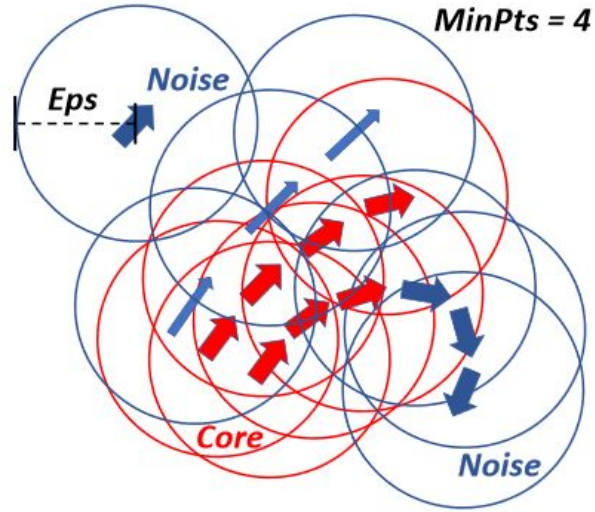
  e.g. Catania → Malta

- Use all vessel trajectories for this trip
- Use waypoints to segment vessel trajectories into sub-trajectories



2 Multi-trajectory segmentation

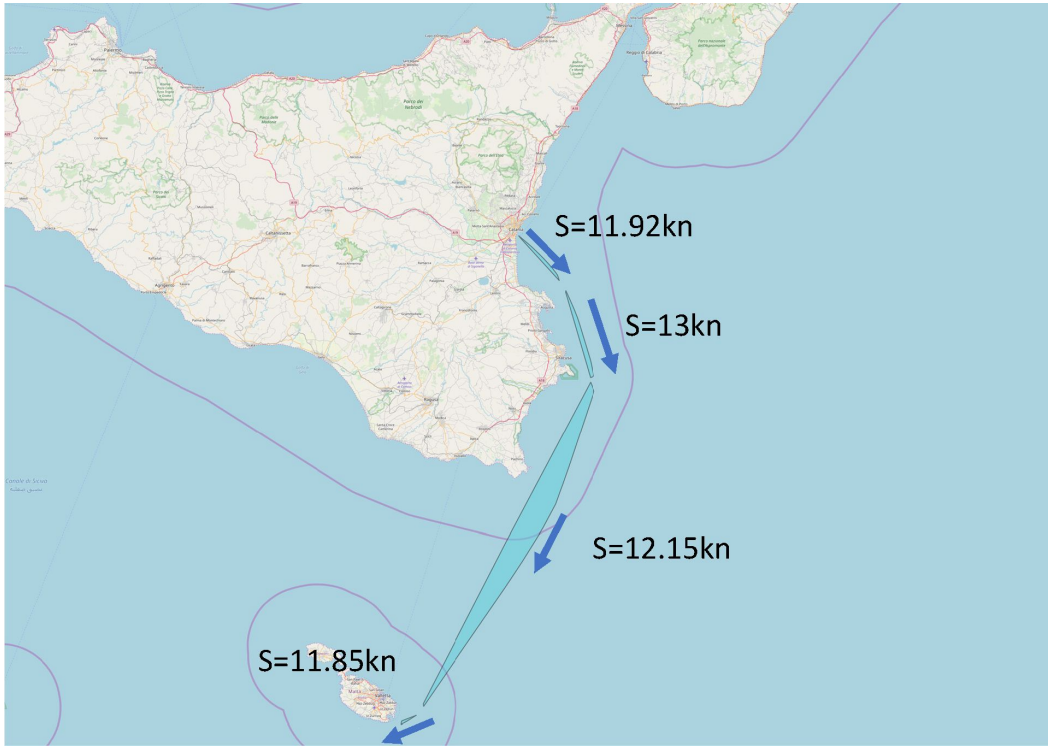
- Modified DB-Scan
- Use 3 different metrics to calculate whether two vessel positions are neighboring
  - Similar speed: absolute difference of the speed between two consecutive AIS messages
  - Similar heading: absolute difference of the course over ground between two consecutive positions
  - Spatially close: harvesine distance between the two positions



(b) Modified DB-Scan.

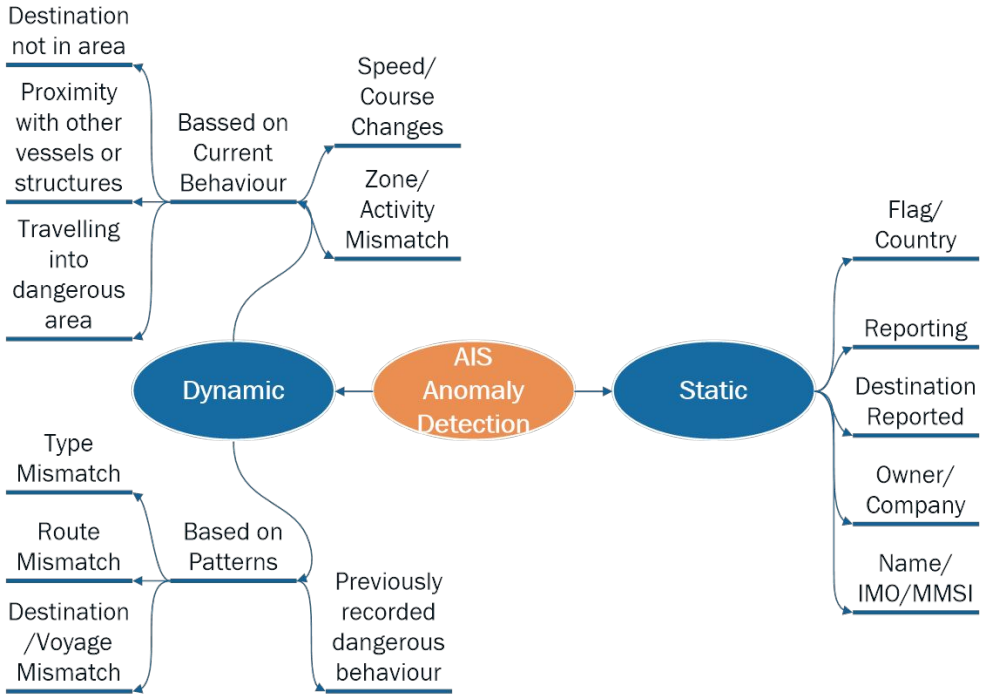
3 Extract edge information

- Mean speed
- Distance covered
- Average heading

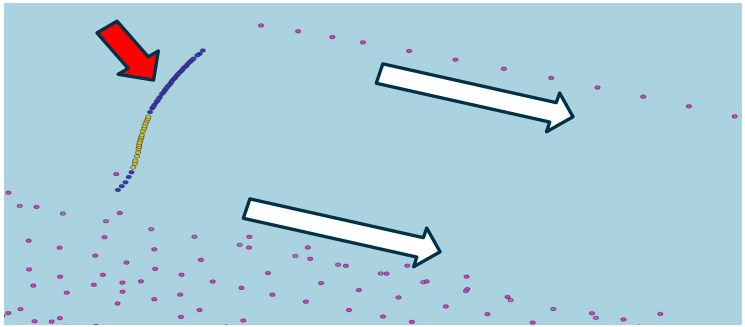


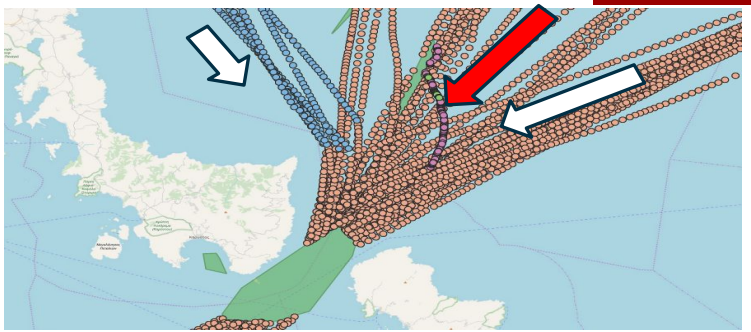
Anomaly detection

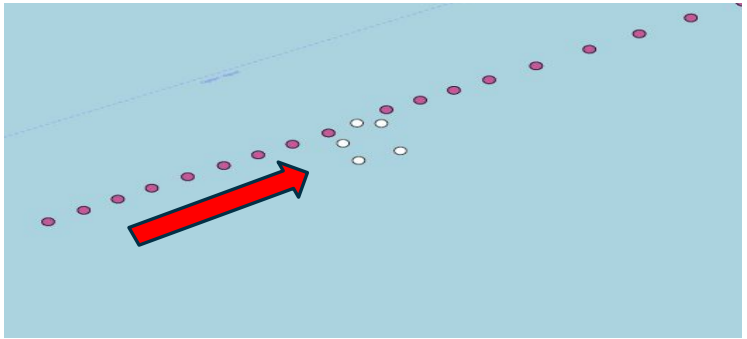
- Several types of vessel trajectory anomalies
- Based on
  - current status
  - previous patterns
  - metadata



Outliers

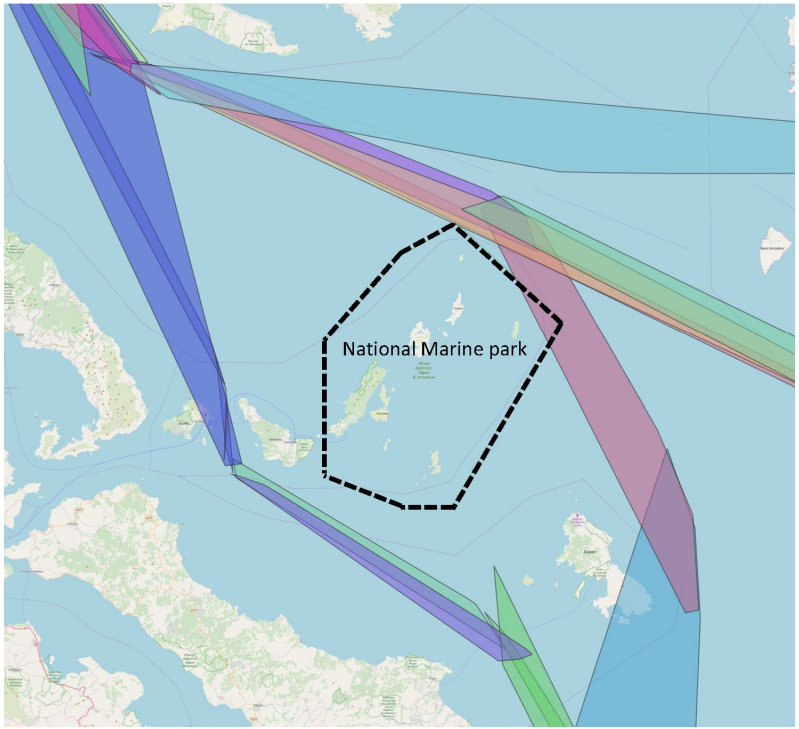






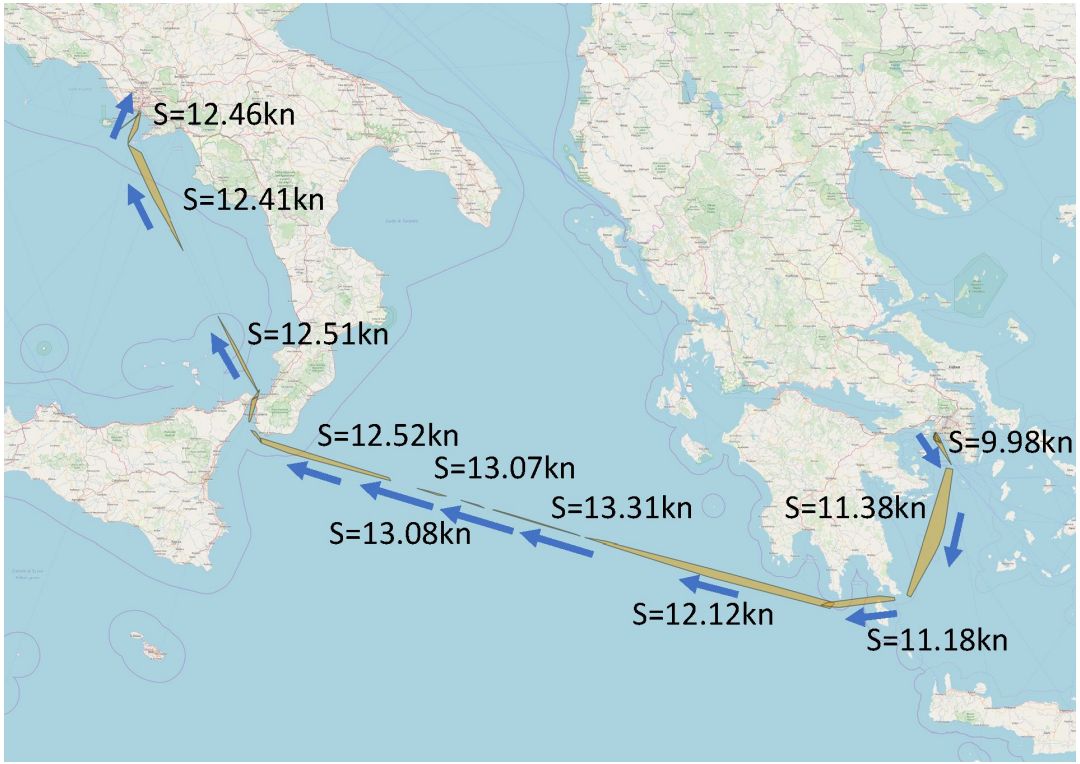
Naval paths and restricted areas

- Alonisos Natura Park
- Aegean Sea Naval Paths



Route planning

- Sail from Athens to Napoli
- Ideal path (based on past vessel behavior) and estimated speed per segment



Questions?

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