UNITED NATIONS
Office for Outer Space Affairs

United Nations/Finland Workshop on the Applications of Global Navigation Satellite Systems
Helsinki, Finland,
23rd - 27th October, 2023

Airplane Trajectory Reconstruction and Analysis Using GNSS-Based ADS-B Data: What to Do with the Open Access Data Using Open-Source Software

Renato FILJAR[1,2], Robert Spudić[2]

[1]Faculty of Engineering, University of Rijeka, Rijeka, CROATIA
[2]Laboratory for Spatial Intelligence,
Hrvatsko Zagorje Krapina University of Applied Sciences,
Krapina, CROATIA

VELEUČILIŠTE HRVATSKO ZAGORJE KRAPINA

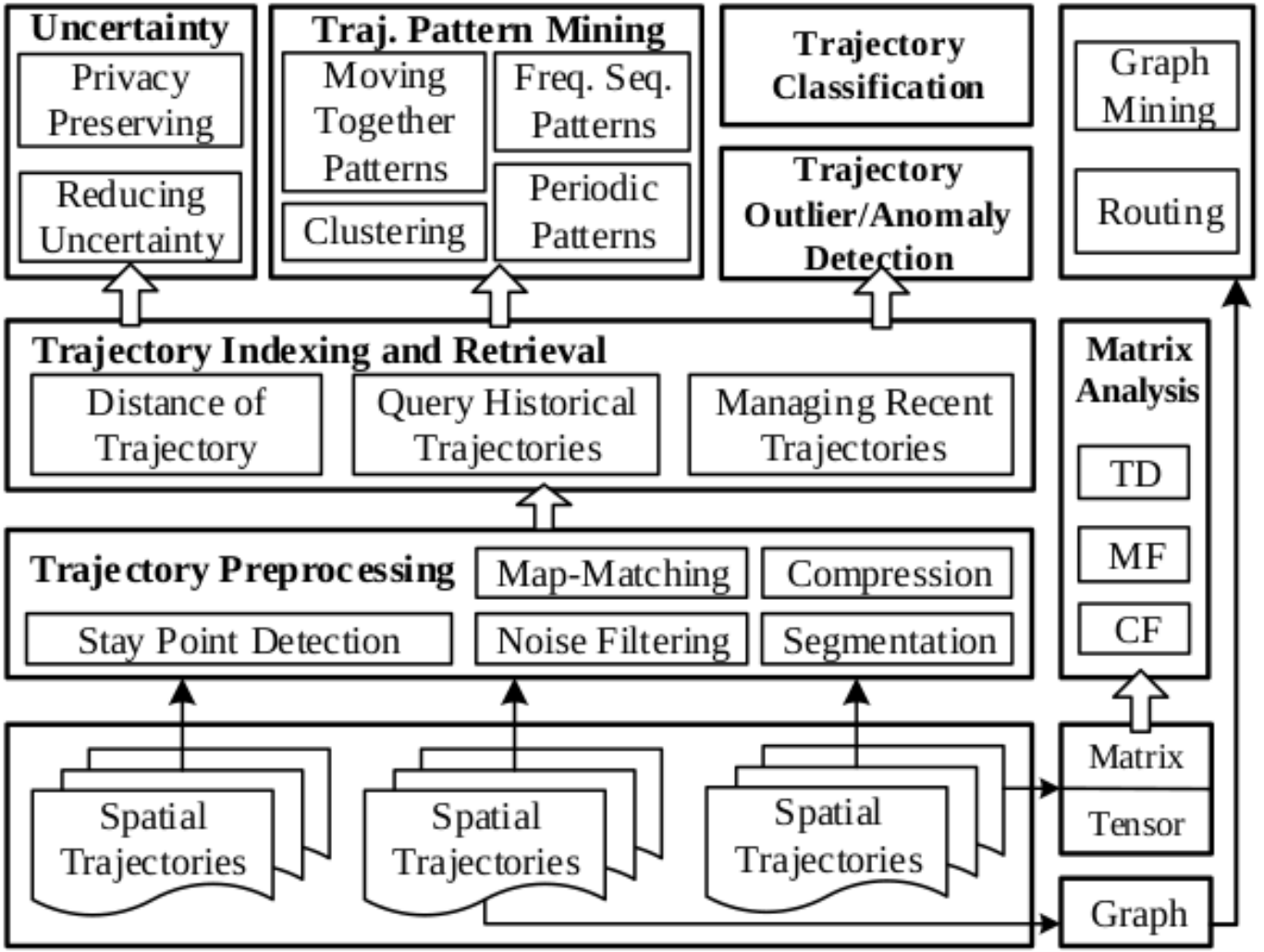
Sveučilište u Rijeci
TEHNIČKI FAKULTET

- Definition of a trajectory
- A set of chronologically collected observations about the current positions of an object in motion
- Formal vector representation of a trajectory:

$$\boldsymbol{P_i} = (t_i, x_i, y_i, z_i)$$

- According to the above notation, a trajectory is the observation matrix, which in the rows contains individual observation vectors, while in the columns are the time-instants of observation t_i and the observed coordinates of the position in the reference coordinate system x_i, y_i, and z_i,

Deep trajectory data analysis and its applications (Zheng, 2015)



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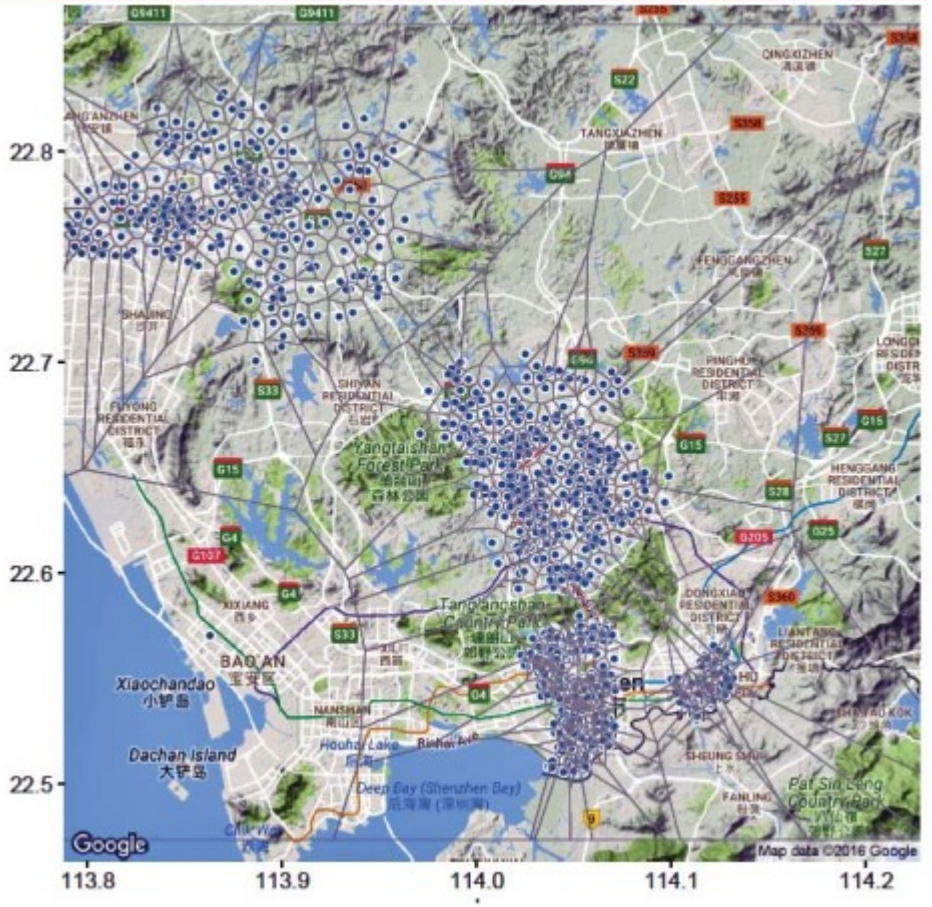
- Trajectory data collection
- Trajectory of an individual → individual and group mobility research
- Routes/trajectories of public transport vehicles
- Paths of animals in their natural habitat
- Paths of natural phenomena (tornadoes, weather changes, ocean currents, etc.)



Filjar, R, Filić, M, Lučić, A, Vidović, K, Šarić, D. (2016). Anatomy of Origin-Destination Matrix derived from GNSS alternatives. Coordinates, 12(10), 8-10.

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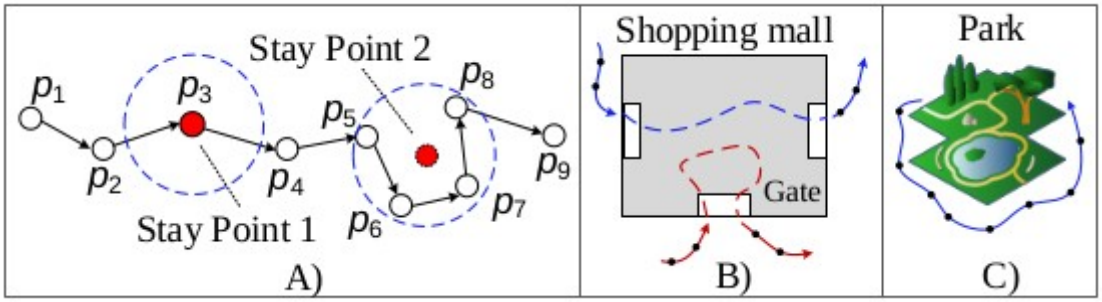
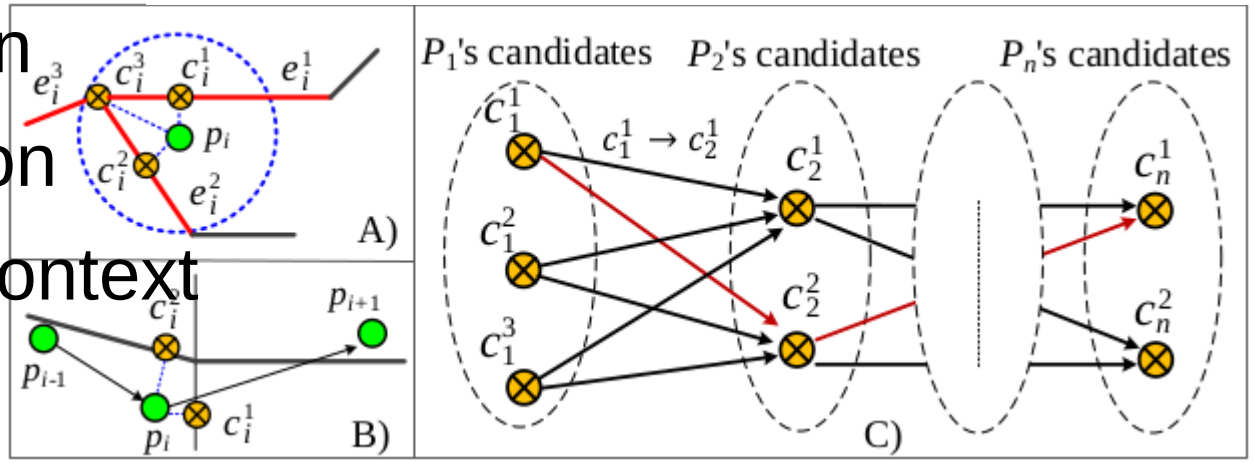
- Exploratory trajectory analysis
- Filtering noise from trajectories (averaging, Kalman and particle filtering, heuristic extraction of outliers)
- Stopping point detection
- Data transforms
- Fractal dimension
- Hovering intervals
- Path compression
- Path segmentation
- Adapting to the context (Map-Matching)

Source: Zheng, 2015





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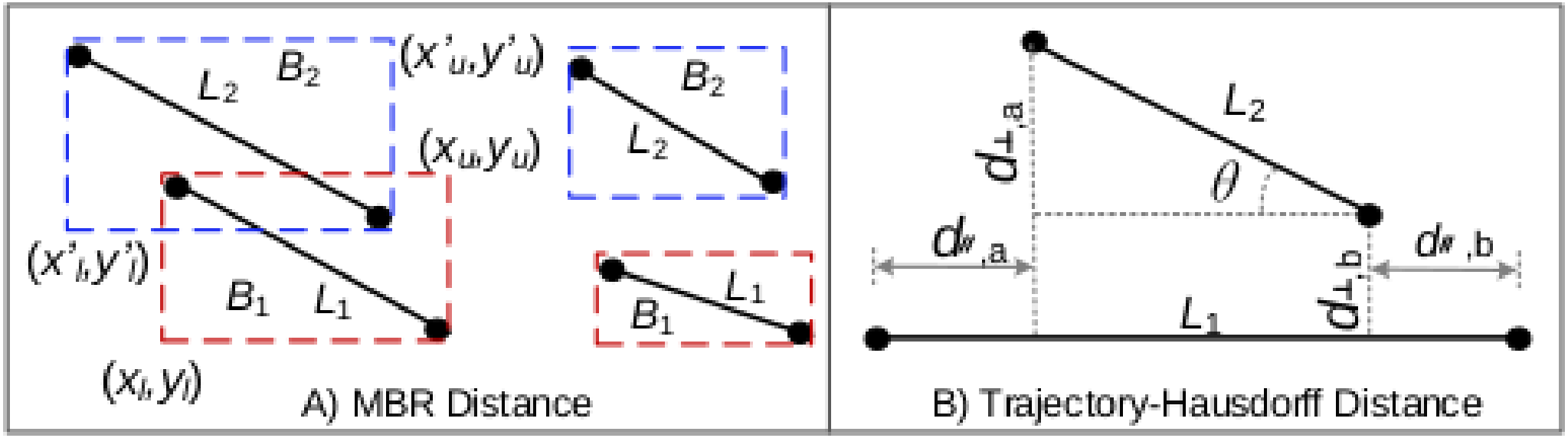
- Exploratory trajectory analysis
- Indexing and retrieving path-related observations
- Mutual distance and path similarity measures

Source: Zheng, 2015



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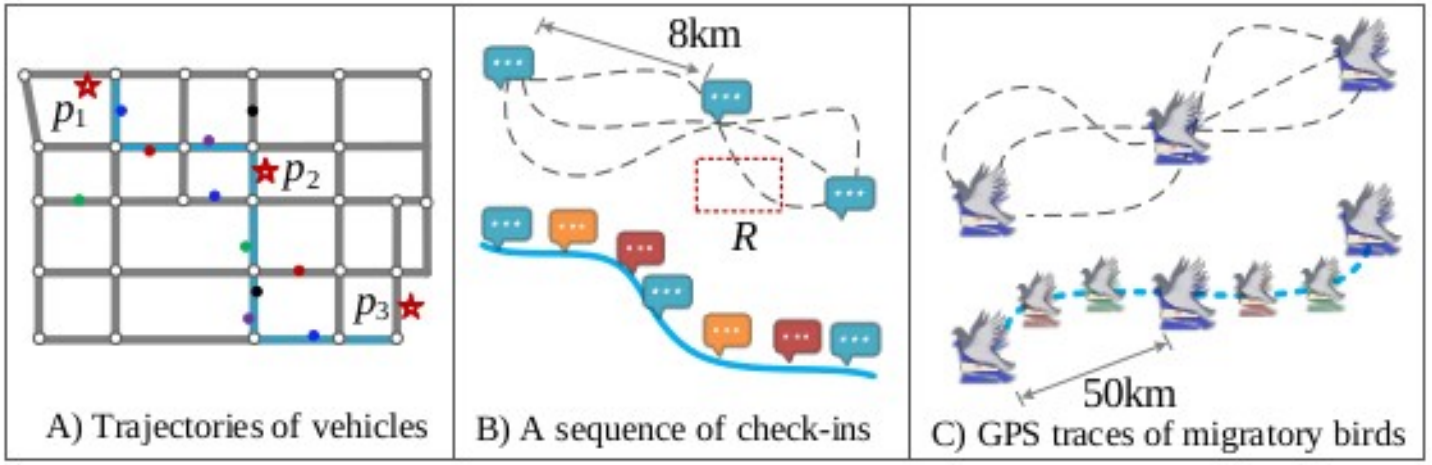
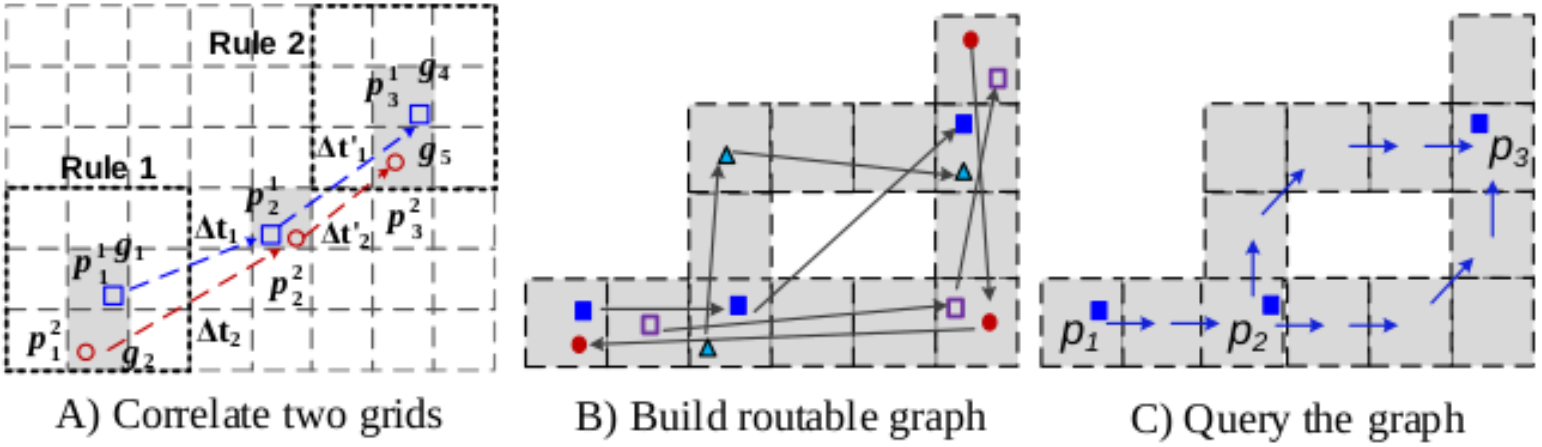
- Uncertainty of trajectory
- Detection and identification of errors in positioning and trajectory determination & reconstruction



Source: Zheng, 2015



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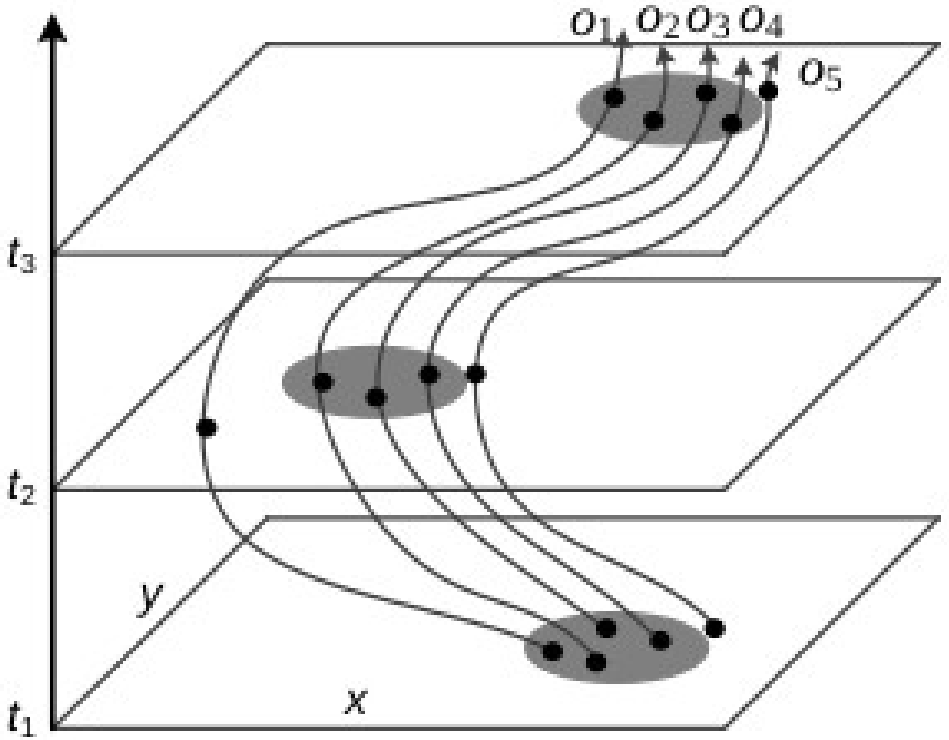
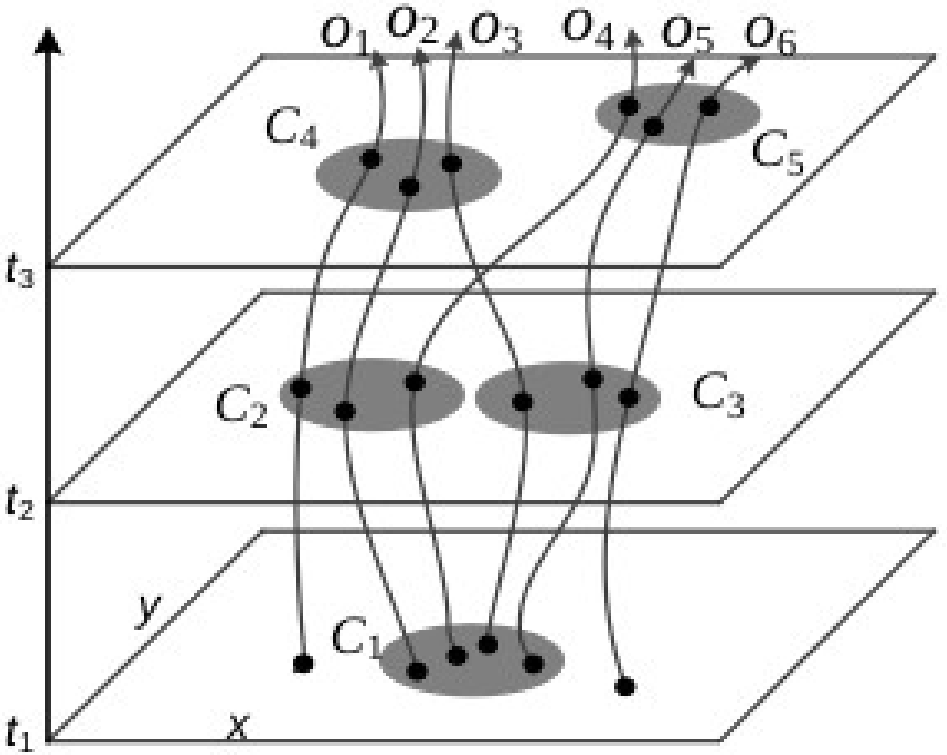
- Deep analysis of trajectory
- Group movement

Source: Zheng, 2015



A) Flock, convoy and swarm



B) Gathering

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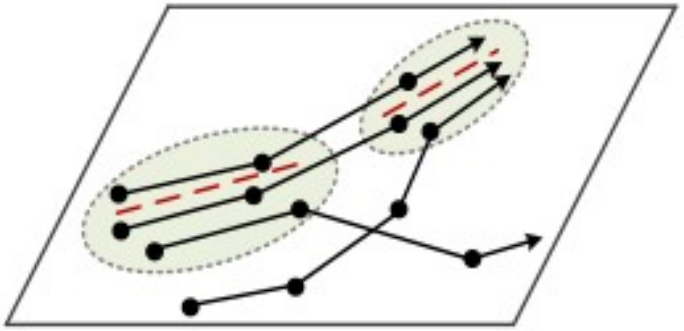
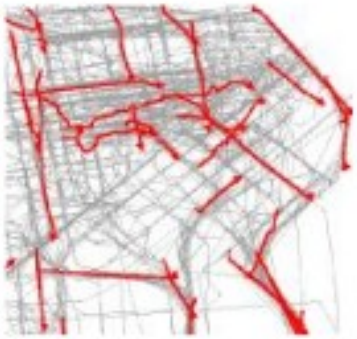
- Deep analysis of trajectory
- Trajectory clustering

Source: Zheng, 2015



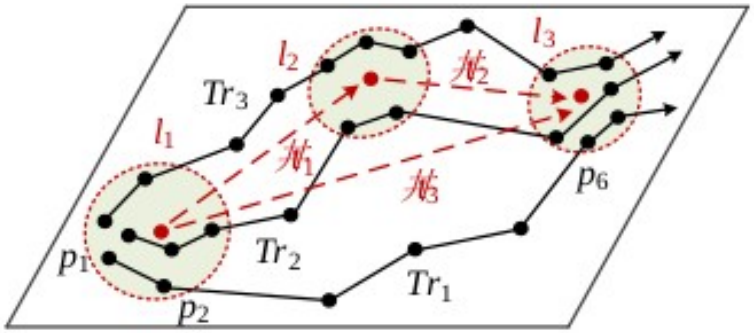
A) Clusters of segments

B) Micro-clusters

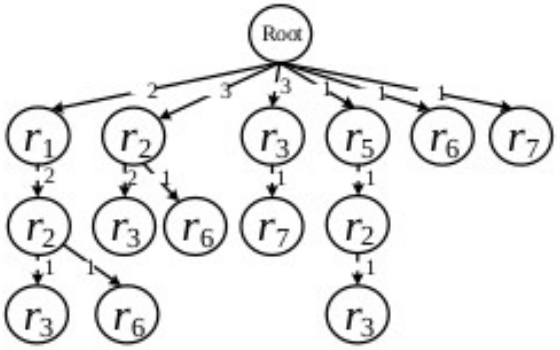


C) Macro-clusters

- Recognising sequential patterns in trajectories



A) Sequential trajectory patterns



B) Suffix Tree-based sequential pattern mining

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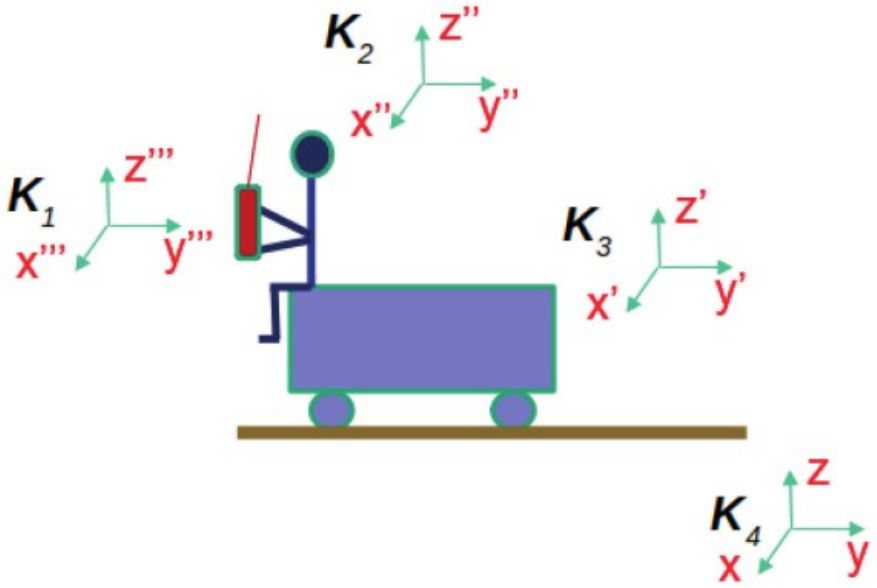
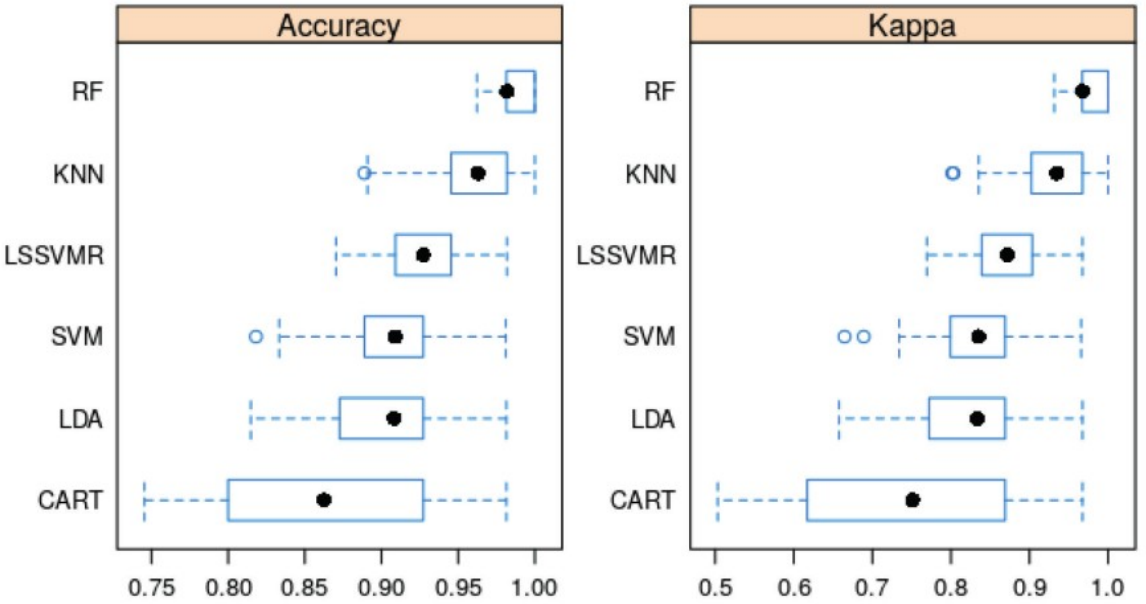
- Trajectory classification
- Detection of mobility means

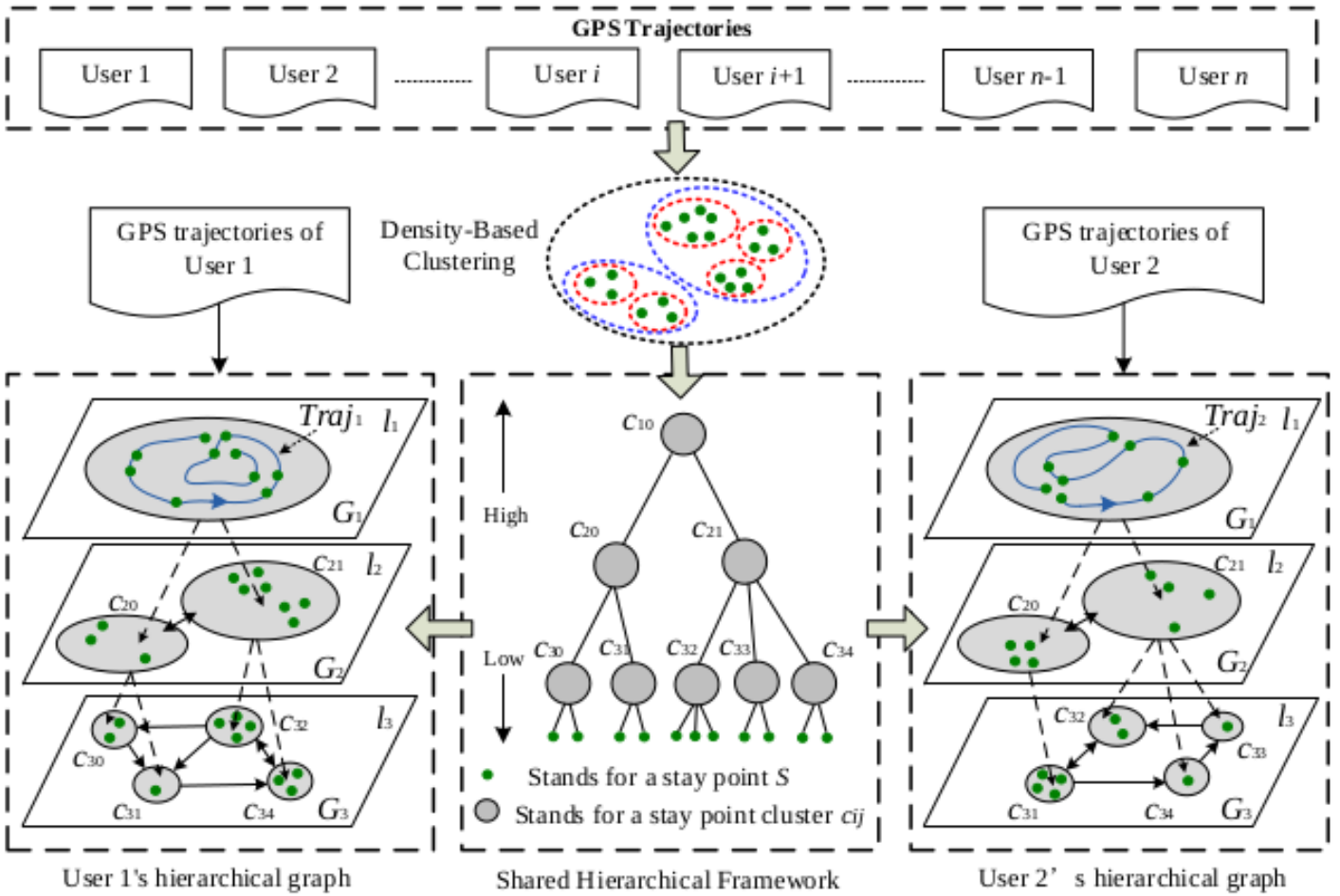




Filjar, R, Sklebar, I, and Horvat, M. (2020). A Comparison of Machine Learning-Based Individual Mobility Classification Models Developed on Sensor Readings from Loosely Attached Smartphones. Communications - Scientific Letters of the University of Zilina, 22(4), 153-162. doi: https://doi.org/10.26552/com.C.2020.4.153-162

- Outlier detection
- Hierarchical diagram of trajectory similarity

Source: Zheng, 2015



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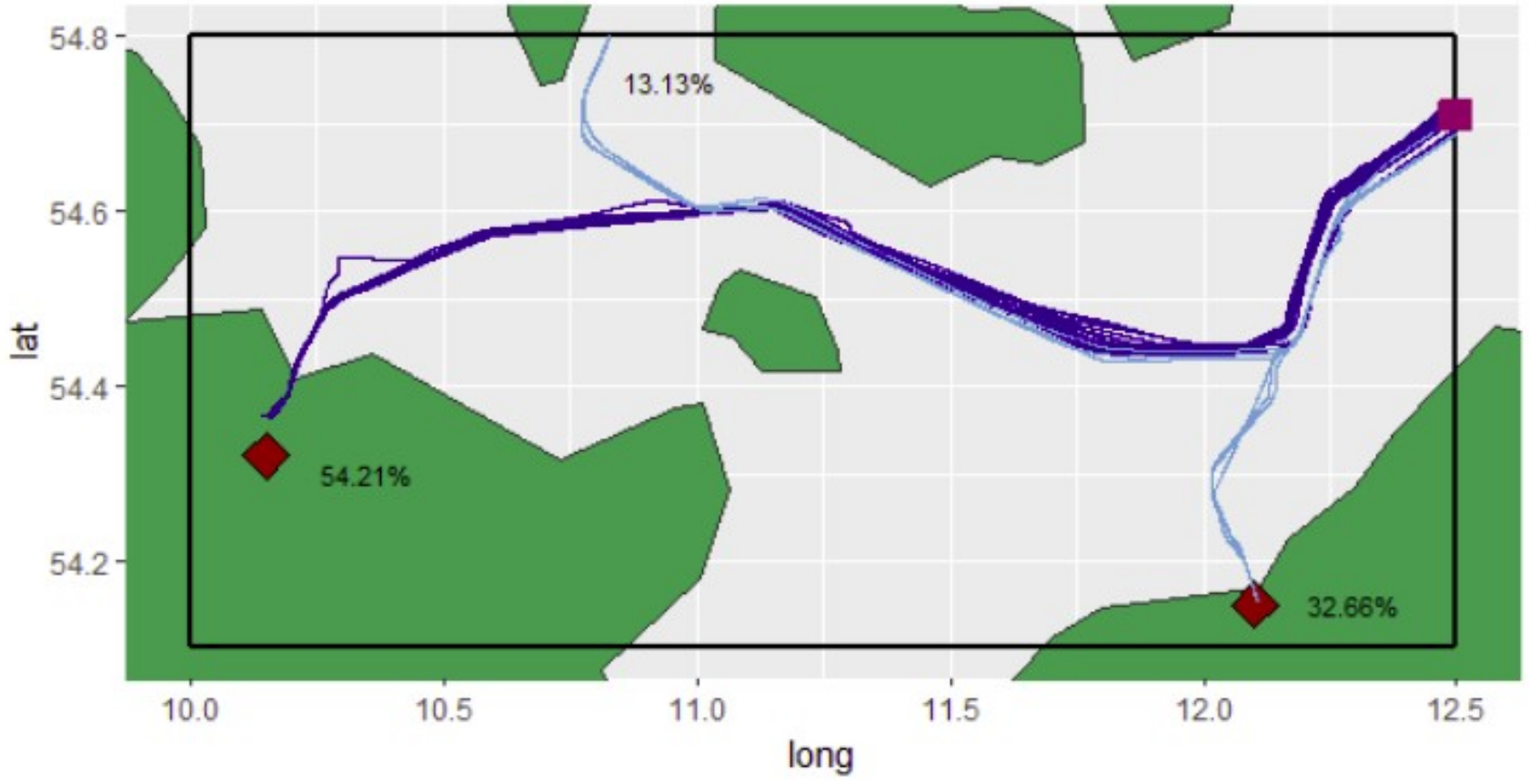
- Bayesian (probabilistic) trajectory predictive model
- AIS data (vessels) (Gamulin, 2020)



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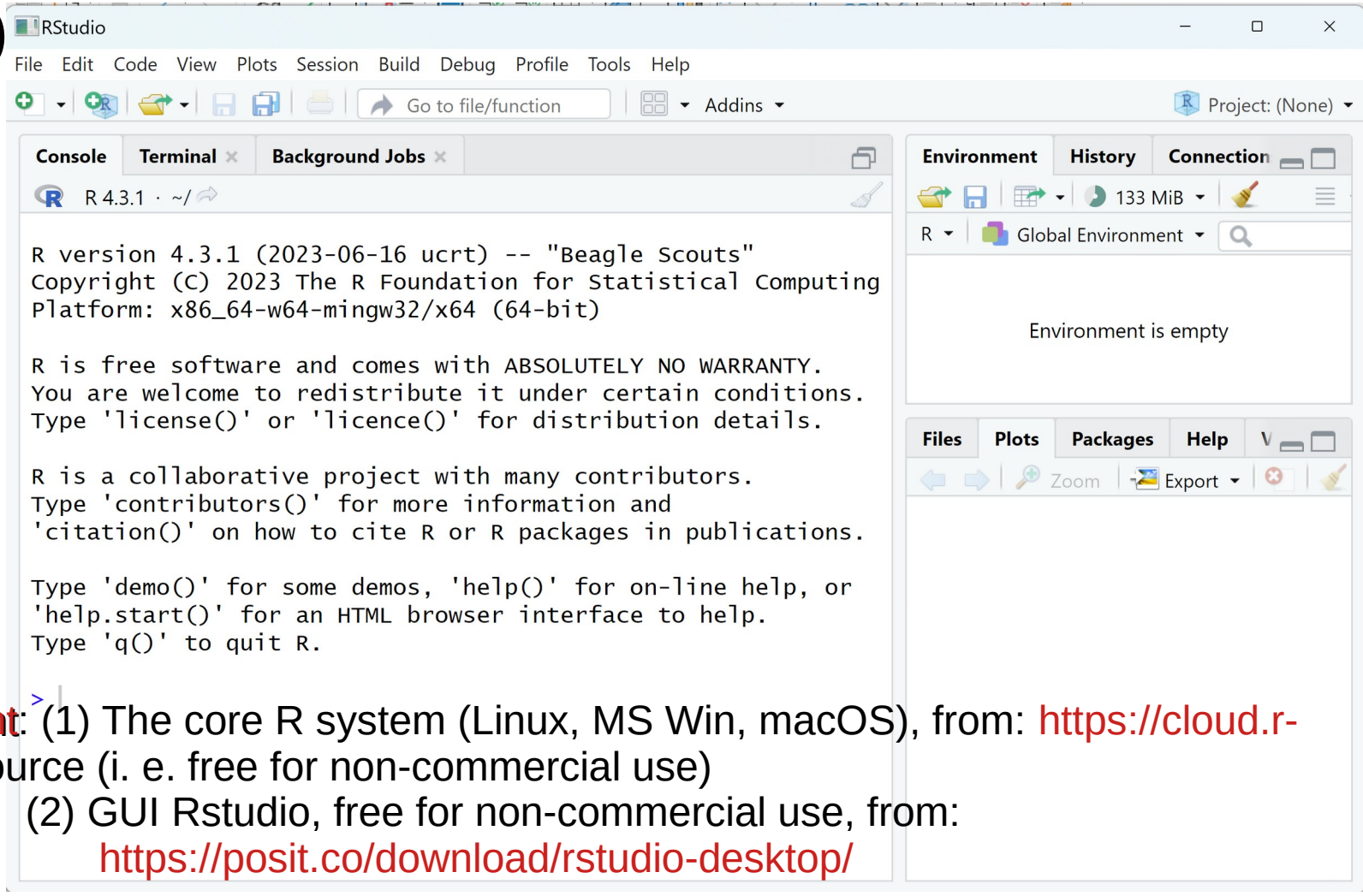
- Research environment
- The R environment for statistical computing (open source)



R Core Team (2023). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: http://www.R-project.org

Working environment: (1) The core R system (Linux, MS Win, macOS), from: https://cloud.r-project.org/, 0pen source (i. e. free for non-commercial use)
(2) GUI Rstudio, free for non-commercial use, from:
https://posit.co/download/rstudio-desktop/

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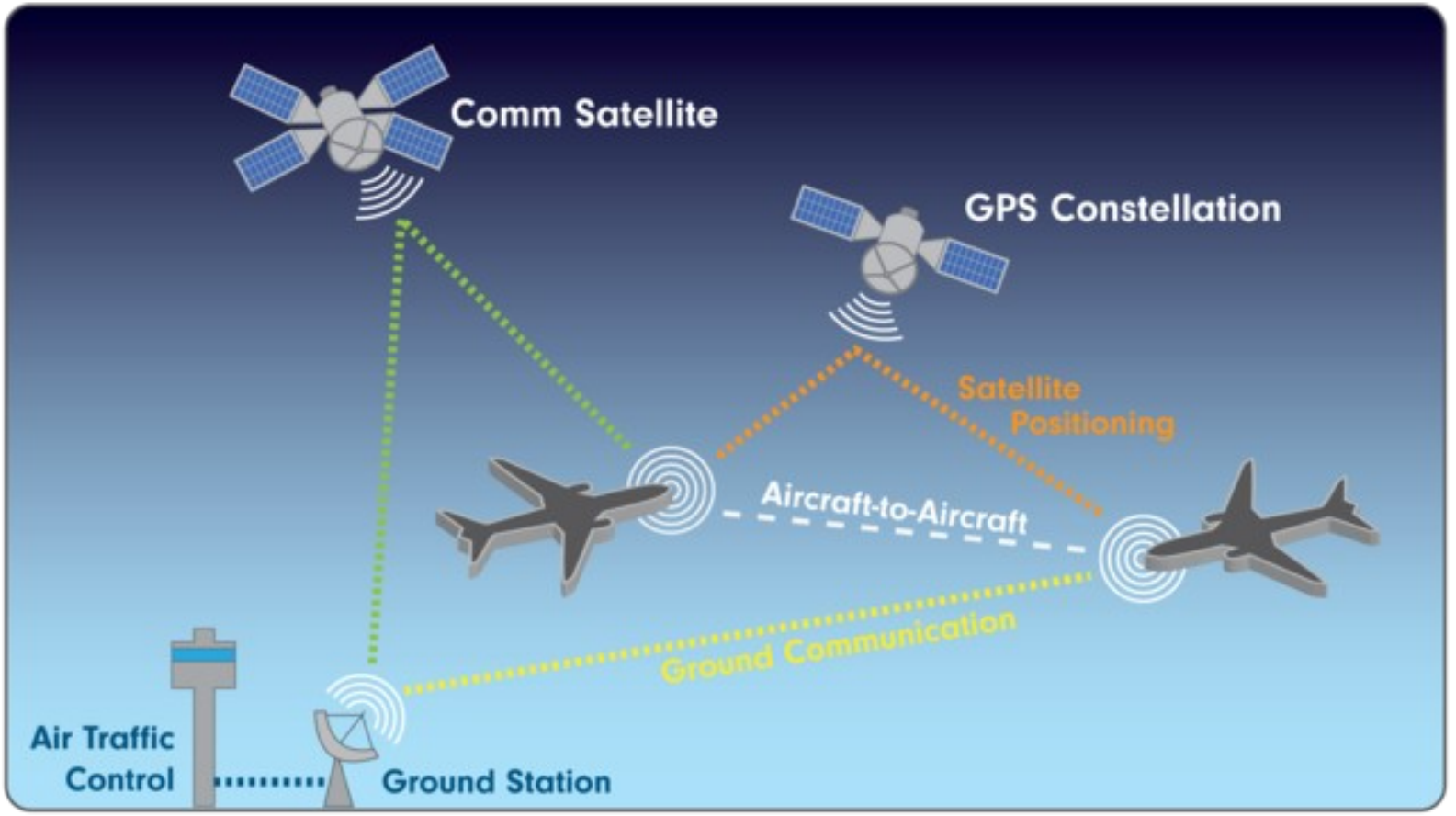
- Data sources
- Automatic Dependent Surveillance – Broadcast (ADS-B) Software-Defined Radio (SDR) Receiver



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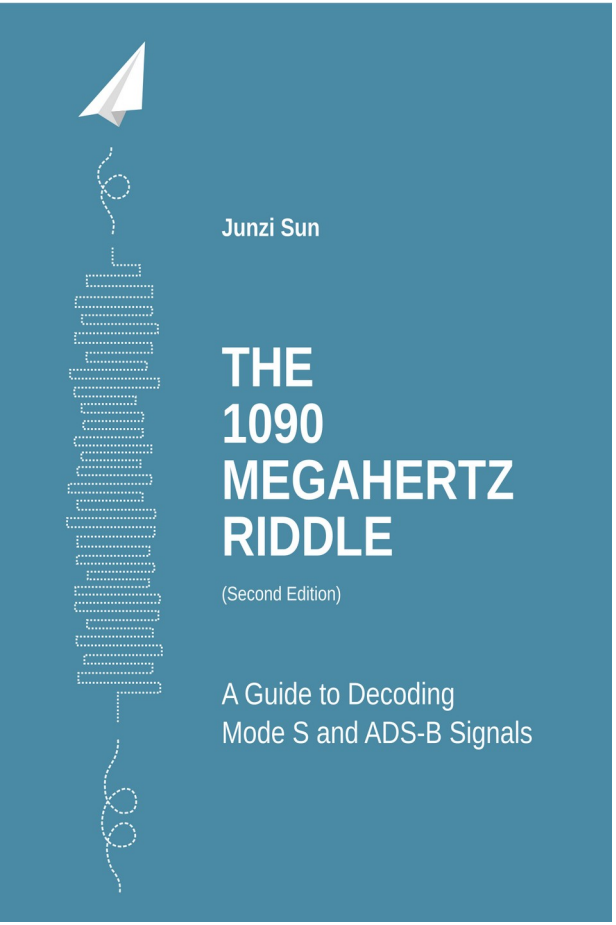
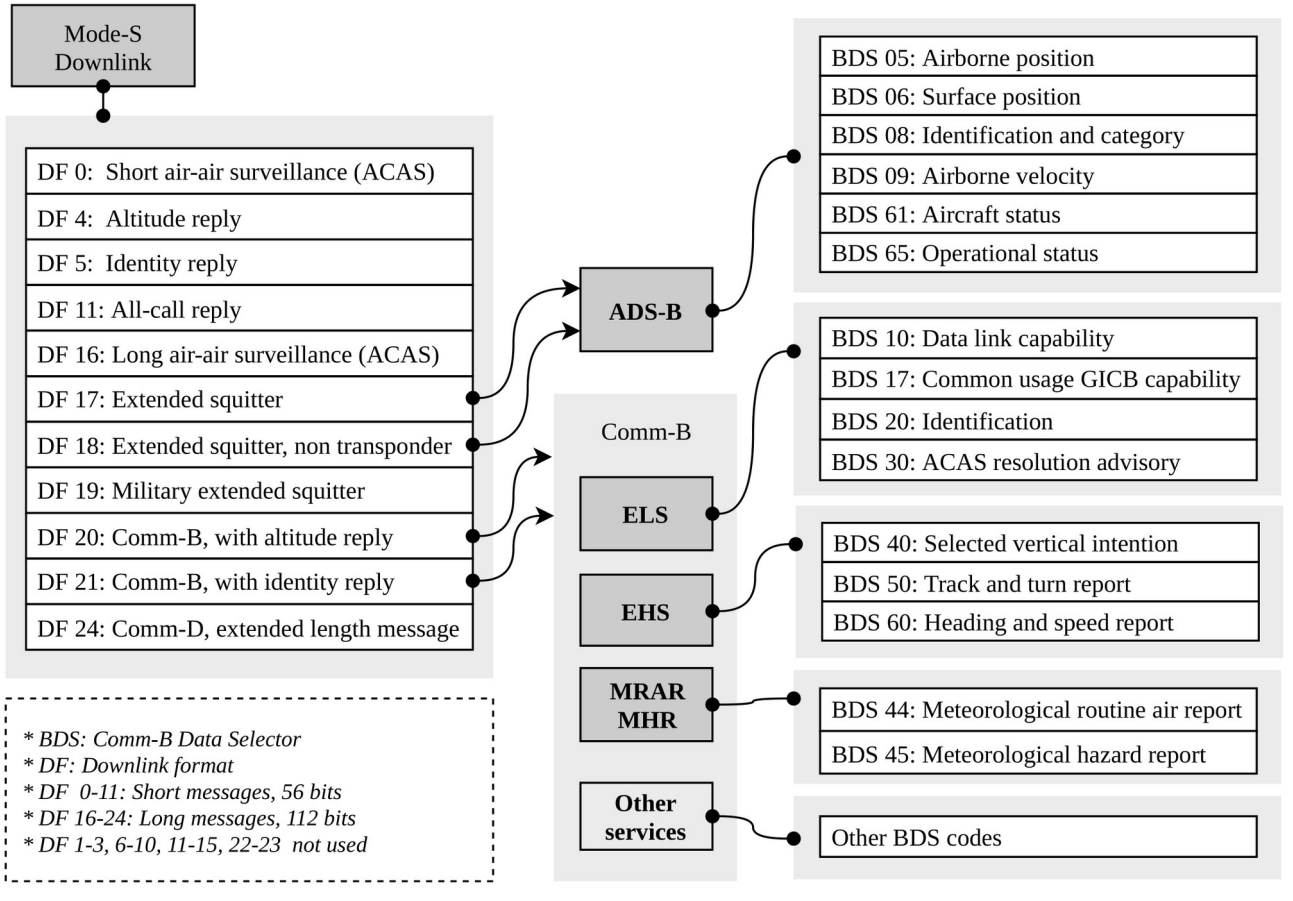
- Data sources
- ADS-B Software-Defined Radio (SDR) Receiver
- Data transfer protocol





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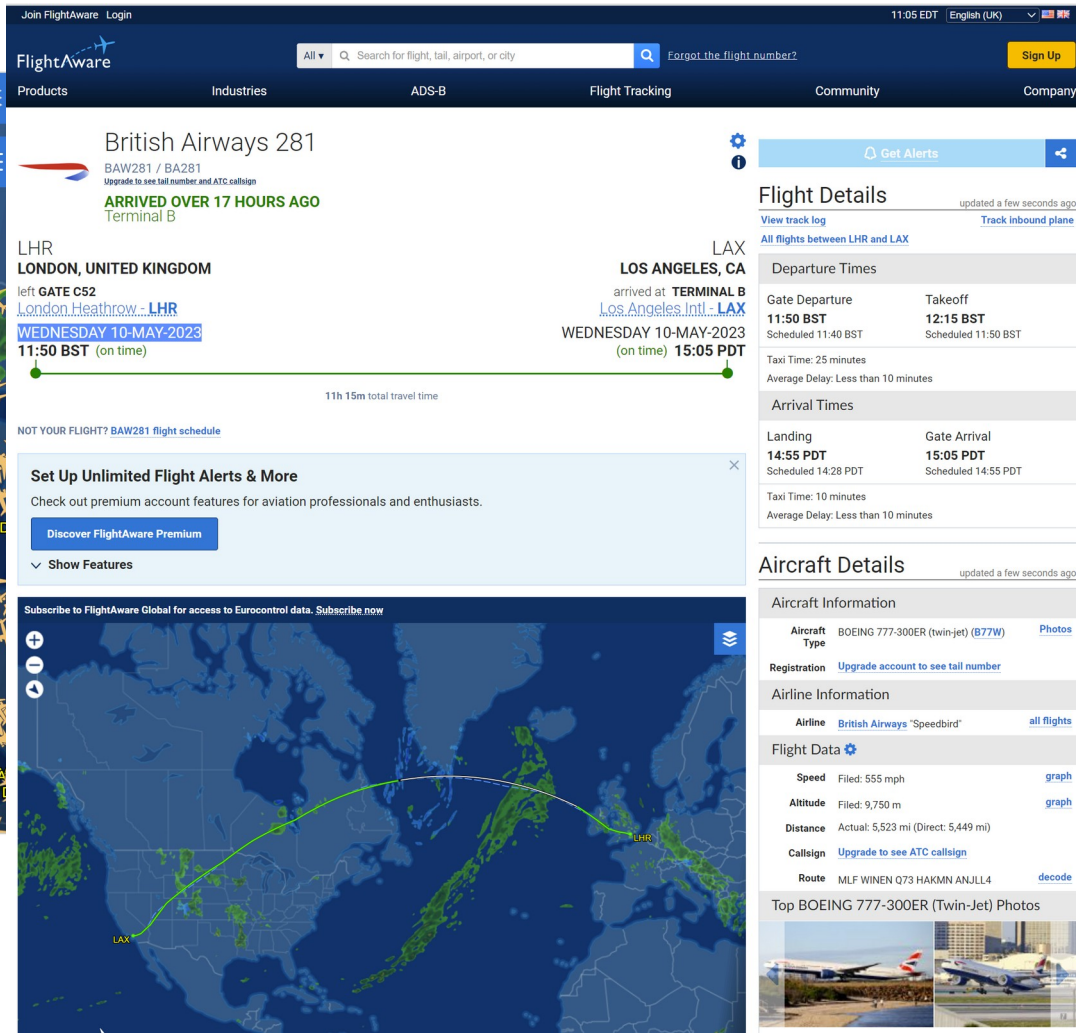
- Data sources - FlightAware
- Crowdsourcing data with ADS-B SDR Receiver



Source: https://flightaware.com/

- Data sources – ADS-B Exchange

Izvor: https://adsbexchange.com/

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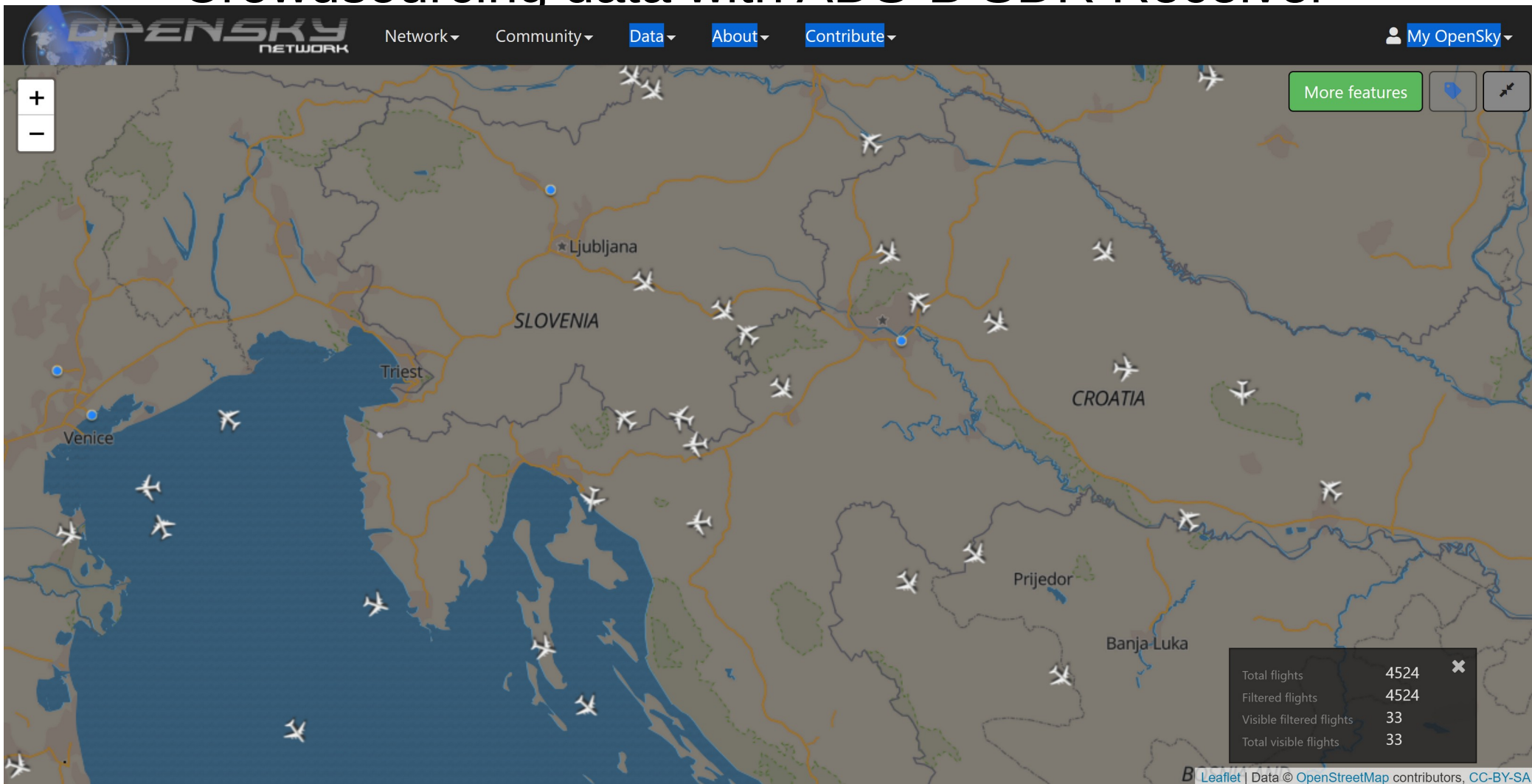
- Data sources – OpenSky Network
- Crowdsourcing data with ADS-B SDR Receiver



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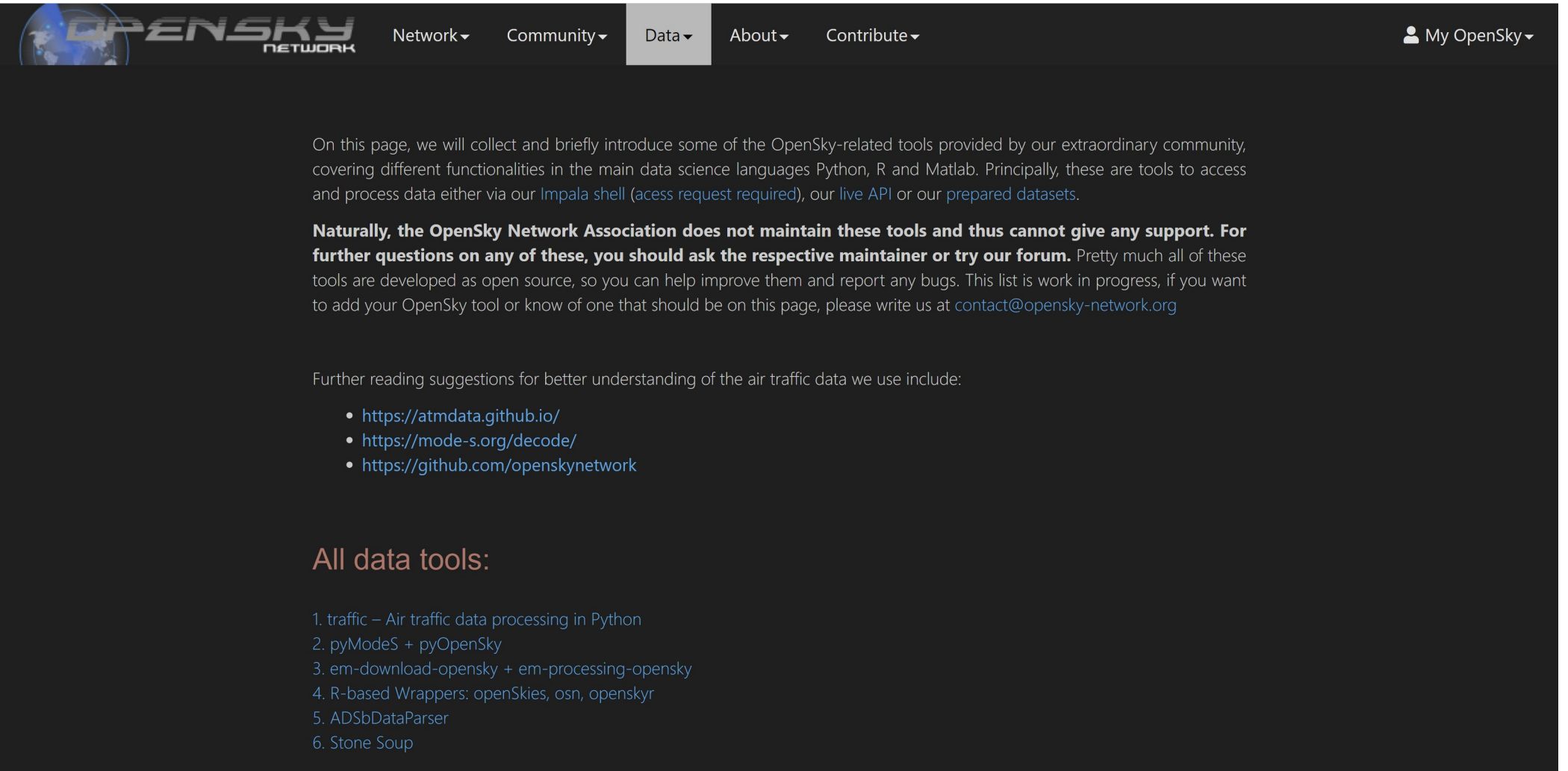

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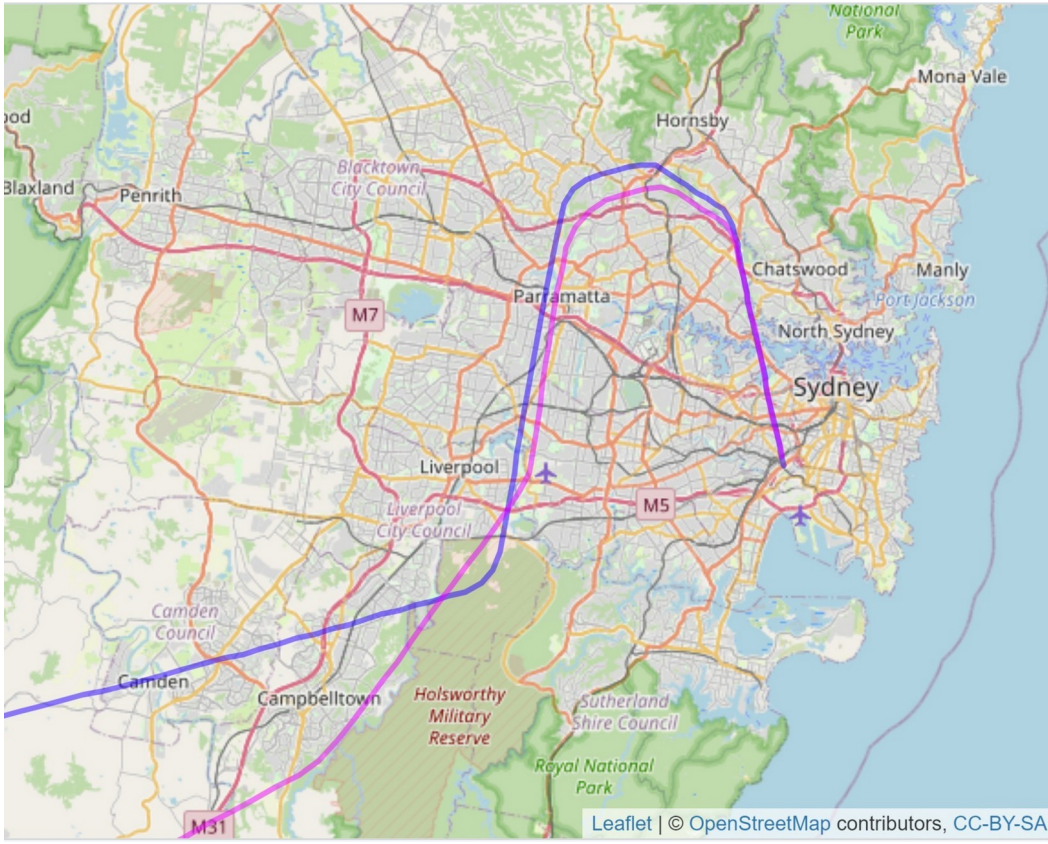
- <u>ADS-B airplane trajectory analysis and estimation</u>
- Estimation methods and uncertainty quantification of PNT
- Statistical learning-based spatial predictive models
- Outlier detection
- Trajectory planning and estimation uncertainty (errors) in targeted environment conditions
- Ambient-based trajectory convergence towards corridors



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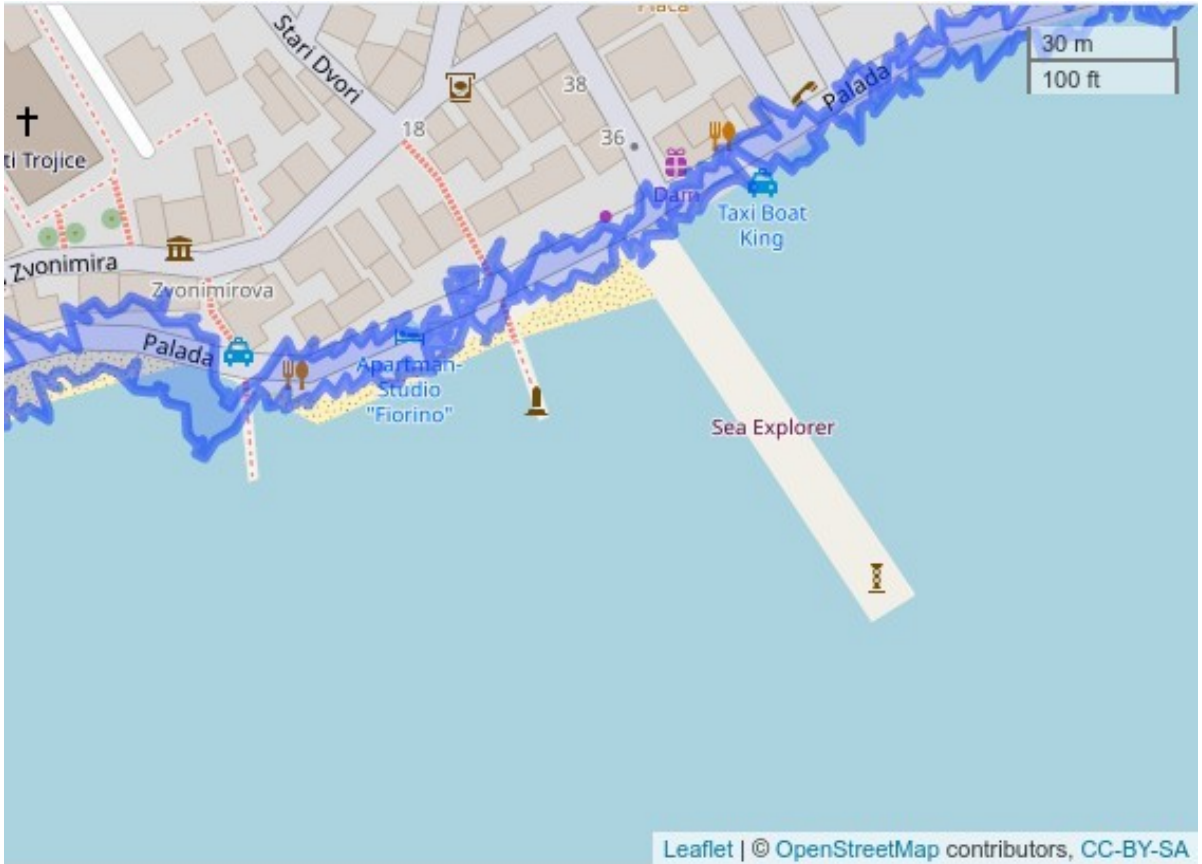
- Spatial & PNT uncertainty quantification
- Estimation and quantification of positioning, navigation, spatial predictive models, trajectory planning and estimation uncertainty (errors)



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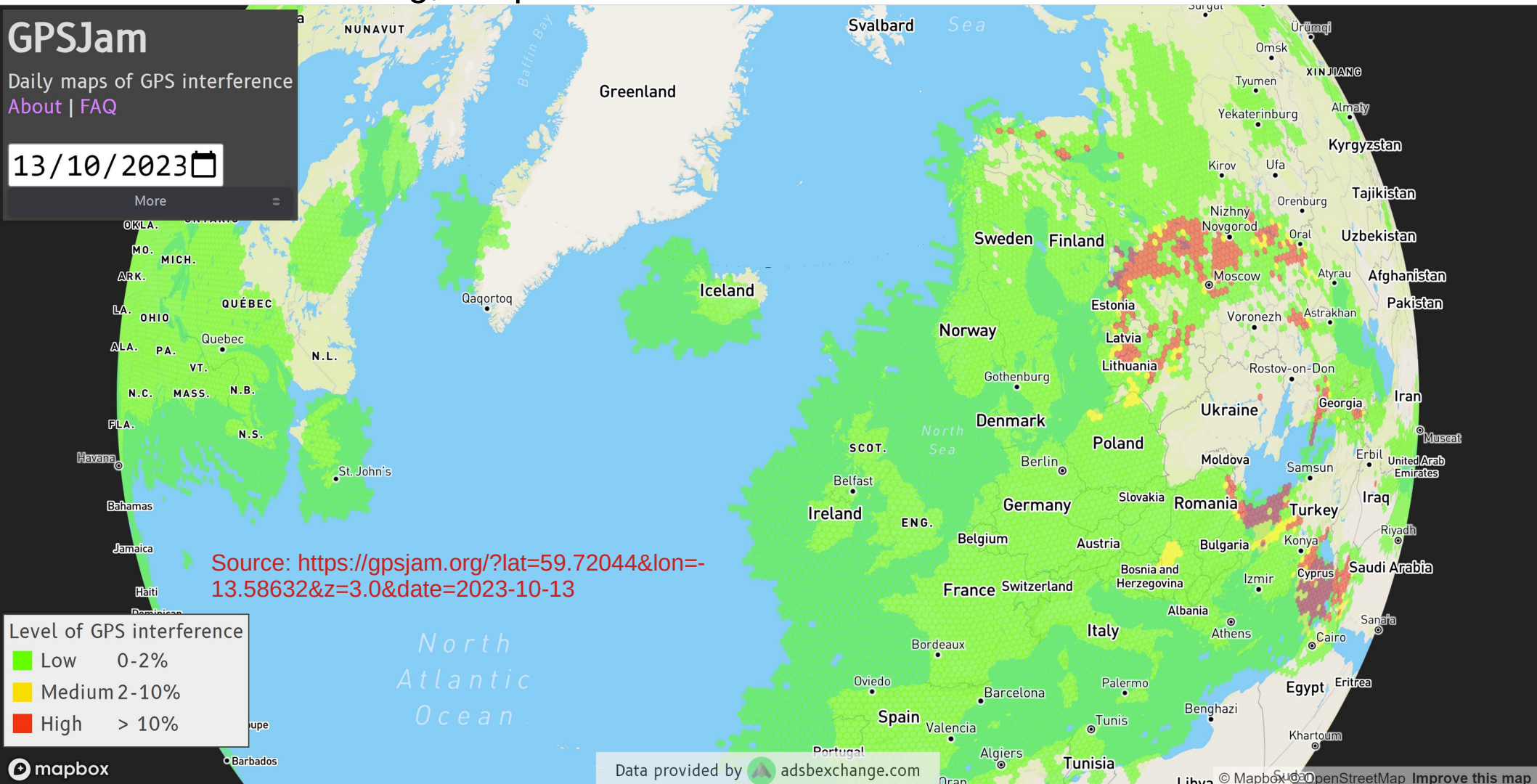
- Spatial analysis of GNSS positioning uncertainty
- GPSJam.org, snapshot taken on 15OCT23 at 0941 CEST



- Evidence and recommendations
- Formal ontology is established for trajectory description → statistical and machine learning analysis → programming frameworks available (R)
- Data collection through SDR receivers → large data bases of ADS-B observations are available in open access manner
- Stage is set → (1) encourage international co-ordinated and collaborative framework for statistical methods development and trajectory analyses, inference and modelling

→ (2) facilitate international co-operation network on data exchange, analysis for targeted applications, and academic education in the field

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- Laboratory for Spatial Intelligence,
  Hrvatsko Zagorje Krapina University of Applied Sciences,
  Krapina, Croatia

- Research, advisory, and academic education concerning:
  - Positioning, Navigation, and Timing (PNT) estimation methods, techniques, correction models, and algorithms
  - Spatial and PNT uncertainty quantification
  - Trajectory analysis, estimation/prediction, and convergence towards corridors
  - Spatial occupancy detection and modelling
  - Statistical learning-based spatial data modelling and predictions
- Research activities based on tailored software developed in the open source R environment for statistical computing

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Happy 50th Birthday, GPS!

Source: ION, https://www.ion.org/

Thank you for your attention!

With an invitation to
Baška SIF (Spatial Information Fusion) Forum
to be held in Baška, Krk Island, Croatia
22nd - 26th September, 2024

Professor Dr **Renato Filjar**, FRIN
Faculty of Engneering, University of Rijeka, Croatia, and
Laboratory for Spatial Intelligence,
Hrvatsko Zagorje Krapina University of Applied Sciences, Croatia
E-mail: renato.filjar@gmail.com