Visual Analytics of Flight Trajectories for Uncovering Decision Making Strategies

Gennady & Natalia Andrienko, Georg Fuchs, Stefan Rüping, Jose Manuel Cordero Garcia, David Scarlatti, George A Vouros, Ricardo Herranz, Rodrigo Marcos

http://geoanalytics.net/and
Big Data (Vs) & Data Science in ATM & ATC (As)

Variety of data

• Trajectories
  • Actually flown
  • Flight plans
  • Regulated flight plans
• Events
  • Regulations
• Spatial time series
  • Weather: actual and predicted

❖ ... all Vs of big data

Variety of stakeholders

• ATM
• ATC
• Airports
• Airlines

❖ Restricted access to data

❖ Limited understanding of decision making criteria, strategies and procedures
Origins of this work

• Informal collaboration with C.Hurter / ENAC 2010 –
• Basic research projects with Univ Constance 2008 –
• A Big Data Research project datAcron 2016 – 2018
• SESAR projects DART, INTUIT and BigData4ATM 2016 – 2018

We are grateful to funding agencies for enabling this research and to all or project and cooperation partners for great collaboration
Who we are?

• A multidisciplinary team:

• Computer science researchers (Fraunhofer IAIS, City Univ London, Univ Piraeus)
  • KD & ML
  • VA
  • DB management
  • Data Science

• Data Science researchers and practitioners (Nommon)

• ATM and ATC researchers and practitioners (CRIDA, Boeing Research)
Who we are? Visual Analytics researchers

Visual Analytics is the science of analytical reasoning* facilitated by interactive visual interfaces

* Analytical reasoning = data → information → knowledge → solution, decision, ...

Visual Analytics of Movement
1. Introduction
2. Conceptual framework
3. Transformations of movement data
4. Visual analytics infrastructure
5. Visual analytics focusing on movers
6. Visual analytics focusing on spatial events
7. Visual analytics focusing on space
8. Visual analytics focusing on time
9. Discussion and outlook
Aircraft trajectories … include altitudes!
Altitude changes

Up  Down
Up and down together
Why Visual Analytics?

What we got from visuals:

• Data is complex: 3D space + time
• Space is continuous
• Space is often discrete
  • Flight levels
  • Flight routes
• Flights have different stages (semantics)
• Data is not perfect
Before analysis starts:

• Identifying & fixing data problems

• Key ideas:
  1. Consider the data structure
  2. Support data transformations
  3. Take into account different types of problems: missing data, inconsistent sampling rates, precision errors, occasional and systematic errors in the data.

Gennady Andrienko, Natalia Andrienko, Georg Fuchs
Understanding Movement Data Quality
Journal of Location Based Services, 2016, vol. 10(1), pp.31-46
http://dx.doi.org/10.1080/17489725.2016.1169322
Identifying data problems

• Spatial coverage
Identifying data problems

• Varying temporal resolution
Identifying data problems

• Duplicate IDs
Understanding decision making of As

- Aircraft trajectories …

What else?

- Airports, departures, and arrivals
  - Impact of the environment
  - Impact on the environment

- Route choices
  - Criteria?
  - Deviations from the chosen routes

- Flight management
  - Airspace configurations
  - Flight regulations and delays
Airports, departures, and arrivals

• Impact of the environment: wind
• Impact on the environment: noise
Task: Extract the airport approach routes and observe the wind impact

Gennady Andrienko, Natalia Andrienko, Georg Fuchs, Jose Manuel Cordero Garcia

Clustering Trajectories by Relevant Parts for Air Traffic Analysis

The holding loops are not essential parts of the approach routes.
Interactive filtering

Workflow: **filter → cluster → summarize → analyse**
Visual support to interactive filtering

Workflow: filter → cluster → summarize → analyse

Filter-aware rendering
Filtering → Boolean attribute → visual encoding
Different level of detail for active and inactive parts
Clustering by relevant parts

Workflow: filter → cluster → summarize → analyse

- Clustering engine is separated from similarity assessment
  - Allows the use of different distance functions (implemented externally)
- Implementation of a distance function (e.g., ‘route similarity’)
  - Inputs:
    - Two trajectories to compare
    - Relevance masks of the trajectories (specify which segments are active)
  - Compares only the active segments of the trajectories
- Progressive clustering
  - Application of clustering with different distance functions or parameter settings to different data subsets
    - Particularly, subsets may be defined by previous clustering runs
    - Useful when clustering of the whole set produces clusters of differing quality
      - “Bad” clusters (with high internal variation) can be refined through further clustering and good clusters can be preserved
Resulting clusters by approach routes (loops disregarded)

Central trajectories of the clusters represent the routes.
Use of the routes over time

Workflow: filter → cluster → summarize → analyse
Understanding the wind impact

Workflow: filter → cluster → summarize → analyse

December 2016 Weather in London — Graph
Loop statistics by the routes

Workflow: filter → cluster → summarize → analyse

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CITY UNIVERSITY LONDON
Fraunhofer IAIS
Task: explore the impact on the environment

J. Buchmuller, H. Janetzko, G. Andrienko, N. Andrienko, G. Fuchs, and D. A. Keim

Visual Analytics for Exploring Local Impact of Air Traffic

*Computer Graphics Forum*  
(proceedings *EuroVis* 2015)  
2015, 34(3): 181-190

Air traffic routes for arrivals (red) and departures (blue) to Zurich airport and average distributions of flights amongst them. Note the Swiss-German border to the north.
Exploring the flights that violate rules

Part A denotes the management area. Part B contains a map view depicting all selected data and showing details on a flight violating a rule in a textbox-overlay. Black tracks denote flights that violate rules.
Exploration and predictive modelling

Predicted flight density distribution for the given weather conditions
Route choices

• Criteria?
• Deviations from the chosen routes
Task: Identify and compare the major flight routes from Paris to Istanbul

Gennady Andrienko, Natalia Andrienko, Georg Fuchs, Jose Manuel Cordero Garcia

Clustering Trajectories by Relevant Parts for Air Traffic Analysis

The movements around the airports are not parts of the routes
Routes extracted using the relevance-aware clustering of trajectories

The routes are represented by the central trajectories of the clusters.
Route popularity and navigation charges

![Map showing route popularity and navigation charges](image)

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- Sorting options: group by classes, sort by charges, median, ascending, condensed, table lens, condensed, attribute.
Route statistics

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Group by classes: | Sort by: | Ascending | ✓ | TableLens | Condensed | Attributes | ➤ |
Route choices

### Table 1: Route Charges

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</table>

### Notes
- Charges are listed in ascending order by operator group and then by median charge.
- The table includes all operators for a comprehensive view of route choices.

### Diagram
The diagram illustrates the route choices with color-coded lines indicating different operators and their respective charge structures. The map highlights various cities and routes, providing a visual representation of the data.
Task: compare the actual trajectories to the flight plans

Point matching
Detailed comparison for a single flight
Deviations from the planned routes: distances
Deviations from the planned routes: altitudes
Deviations from the planned routes: altitudes
Deviations from the planned routes: time

Comparison of trajectories: planned against actual

Representation method: Classified shading

Positions of compared trajectories: planned and actual

Time gap to match point

- 738: 2488 objects (0.8%)
- 3600: 8150 objects (2.8%)
- 2400: 25861 objects (8.8%); active: 23326 objects (77.9%)
- 1200: 71076 objects (24.2%); active: 51837 objects (72.0%)
- 60: 9903 objects (3.4%); active: 4930 objects (49.9%)
- -60: 71945 objects (24.1%); active: 19159 objects (27.0%)
- -1200: 25812 objects (8.8%); active: 530 objects (2.1%)
- -2400: 8146 objects (2.8%); active: 0 objects (0.0%)
- -3600: 2481 objects (0.8%); active: 0 objects (0.0%)

Total: 3434 objects; active: 1717

Actual flights Paris-Istanbul

Total: 1717 objects

Flight plans Paris-Istanbul

Total: 1717 objects
ATM* and ATC**

* ATM – air traffic management
** ATC – air traffic control

- Airspace configurations
- Flight regulations and delays
Airspace division (by example of Spain)

- The Spanish air space consists of 11 ACC (area control centres), of which 5 are terminal manoeuvring areas (TMA, left) around airports and 6 are control areas (CTA, right) covering the whole country.
Exploration of configuration structure
Periodicity of changes

• configuration changes over time in selected ACCs
Periodicity of changes

• Weekly patterns
Periodicity of changes

• Daily patterns
Transitions between configurations

- Configurations and transitions between them by intervals of time of the day:
  [02:00, 05:00), [05:00, 07:00), [07:00, 08:00),
  [08:00, 22:00), [22:00, 24:00), [00:00, 03:00)
Task: Explore temporal and spatial patterns of flight regulations*

Natalia Andrienko, Gennady Andrienko, Elena Camossi, Christophe Claramunt, Jose Manuel Cordero Garcia, Georg Fuchs, Melita Hadzagic, Anne-Laure Jousselme, Cyril Ray, David Scarlatti, George Vouros

Visual Exploration of Movement and Event Data with Interactive Time Masks


* Each airport and air traffic control sector has a published maximum capacity. When capacity is exceeded, measures are taken to reduce the traffic. This is termed regulation.

Wikipedia article “Air traffic flow management”
Flight regulations

<table>
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<th>Reason</th>
<th>Total N delayed flights</th>
<th>CTOT - ETOT (minutes), sum</th>
<th>ATOT - ETOT (minutes), sum</th>
<th>Mean assigned delay per flight</th>
<th>Mean actual delay per flight</th>
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C – ATC capacity deficit;
P – special event, including implementation of ATM systems;
I – ATC industrial action, including strikes;
W – bad weather conditions;
S – ATC staff deficit;
G – aerodrome capacity deficit;
O – other

The distribution of the flight departures delayed for the reason C (ATC capacity) by the days (rows of the matrix) and day hours (columns).
Unregulated and regulated flights

Aggregated unregulated flights

Aggregated flights delayed due to ATC capacity deficits
Transformations of spatio-temporal data

Spatial events
- integrate
- aggregate
- extract

Trajectories
- disintegrate, extract
- divide

Spatial time series (place-based)

Spatial time series (link-based)

Local time series

perspectives (views)

Spatial situations
Conclusion

• To analyse and understand air traffic, it is not sufficient to look at flight trajectories only.

• Visual analytics has the potential to make intricate interrelationships understandable.
  • Impact of weather on flight planning and management
  • Flight planning ↔ choosing airspace configurations ↔ demand-capacity imbalances ↔ flight regulations ↔ deviations from the plans

• Visual analytics applied to real data helped us to gain some understanding of the aviation domain. Now we are prepared to addressing more complex analysis and modelling tasks.

• A long way still lies ahead … we are looking forward to new opportunities to continue.

New projects are welcome!