

# Conflict Management for Large Scale Scenarios

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Knowledge for Tomorrow



# Motivation: Trajectory-Based Operations

- Transition Sectors → Gate-to-Gate
- 4D-Trajectory driver for future concepts
- $\begin{pmatrix} x \\ y \\ z \\ t \end{pmatrix}$  for whole route

Trajectory is enabler for

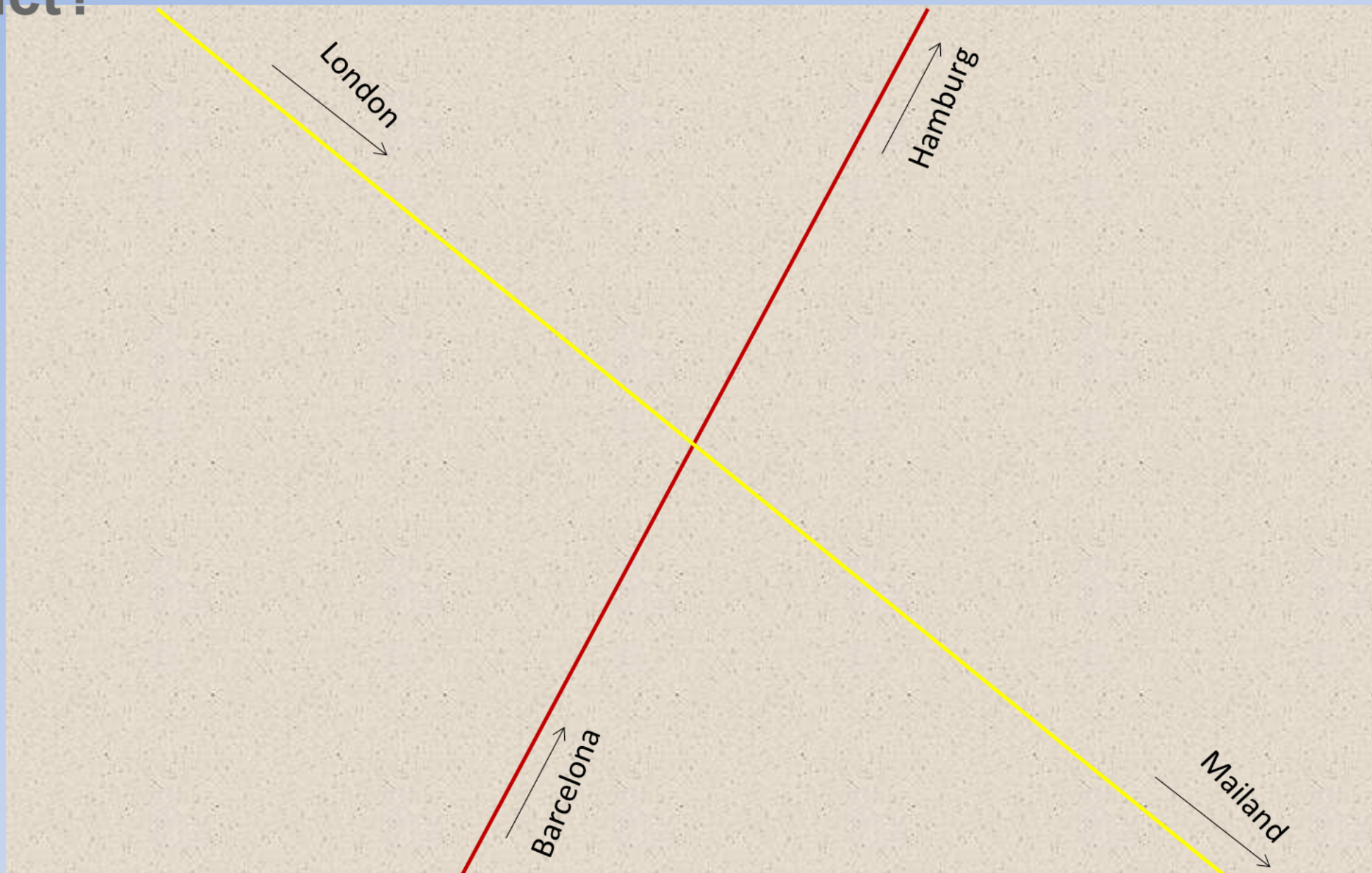
- Early conflict detection
- Efficient conflict resolution
- Global optimization
- Planing horizon increases Safety

But: complex system with real-time requirements!

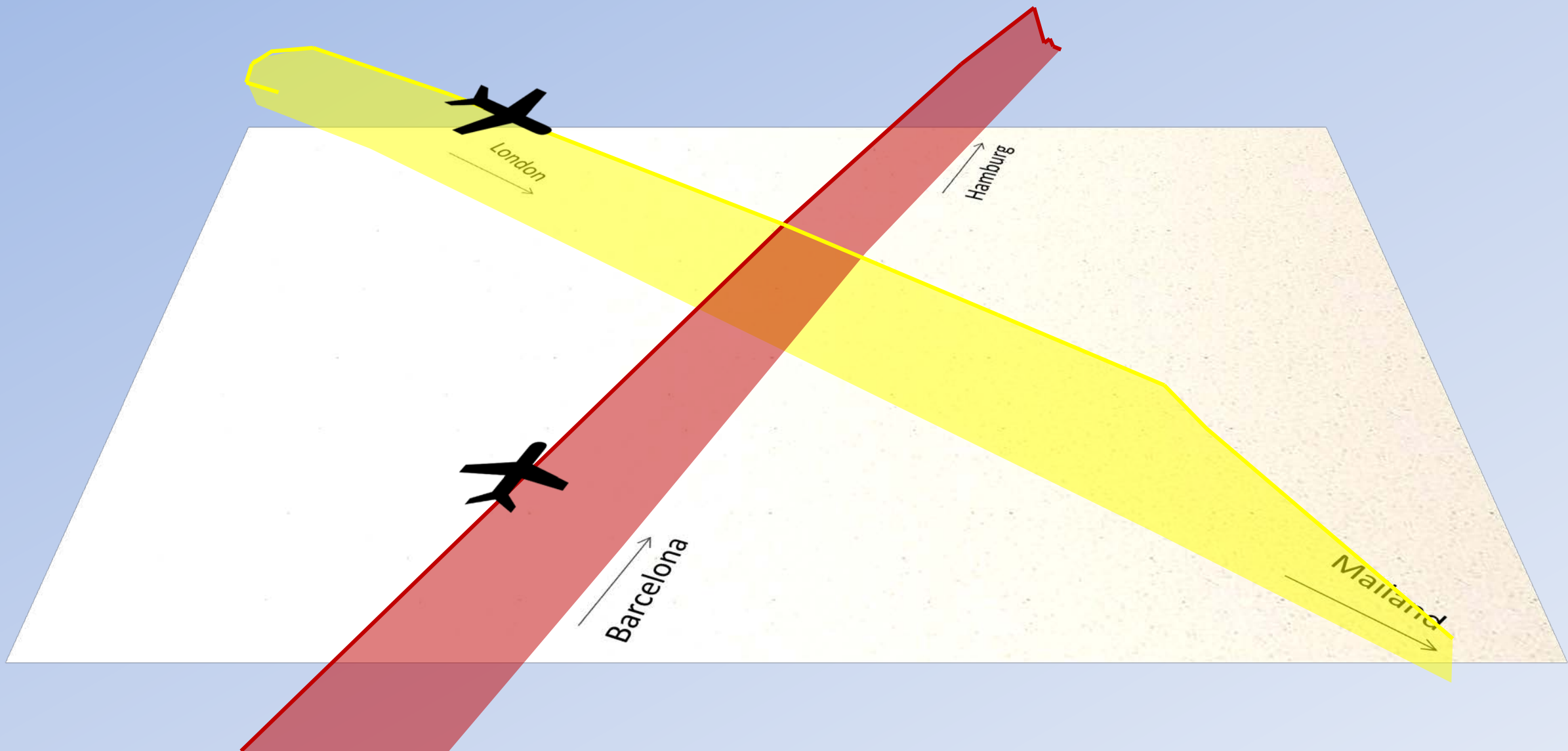




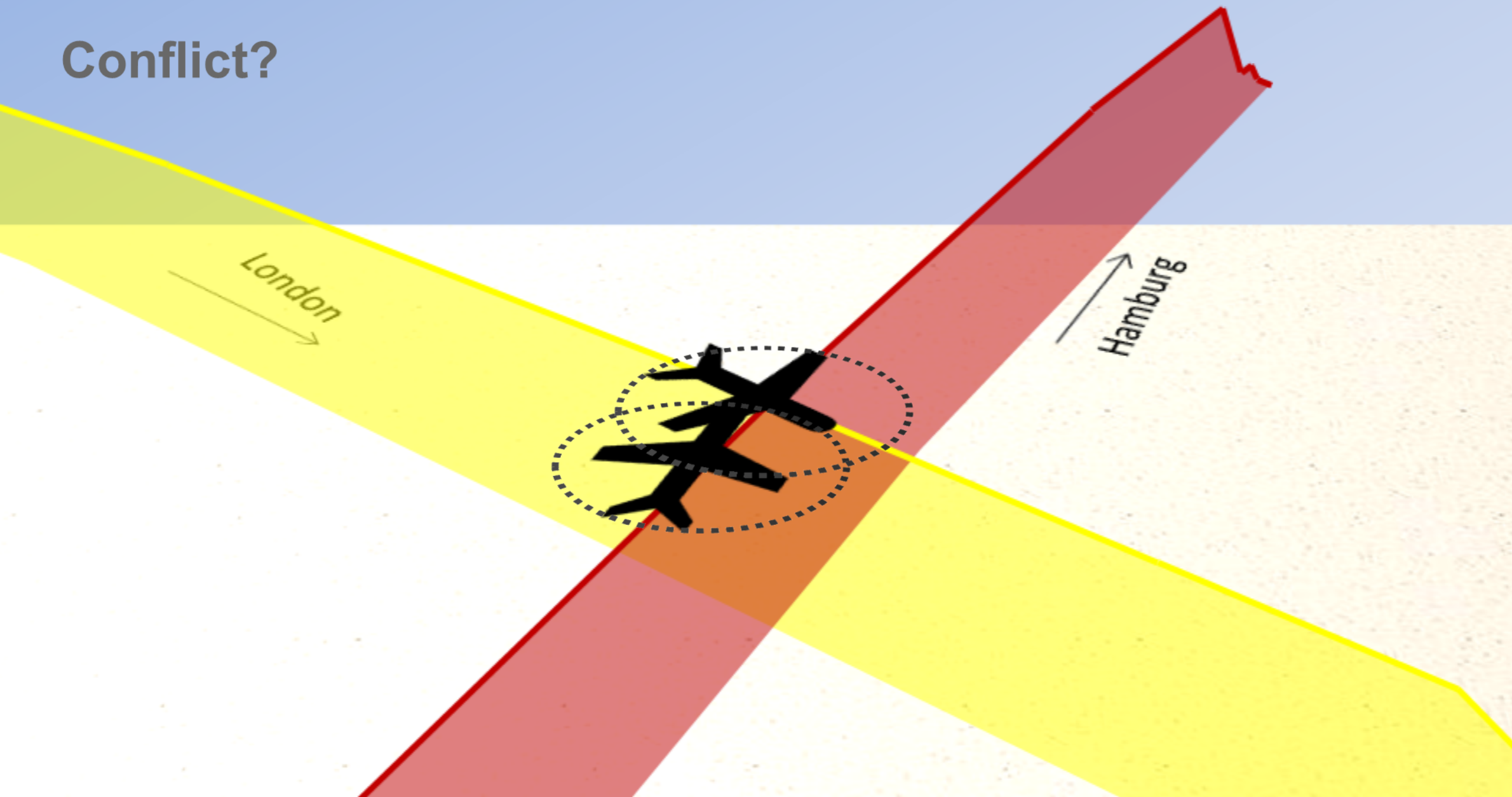
# Conflict?



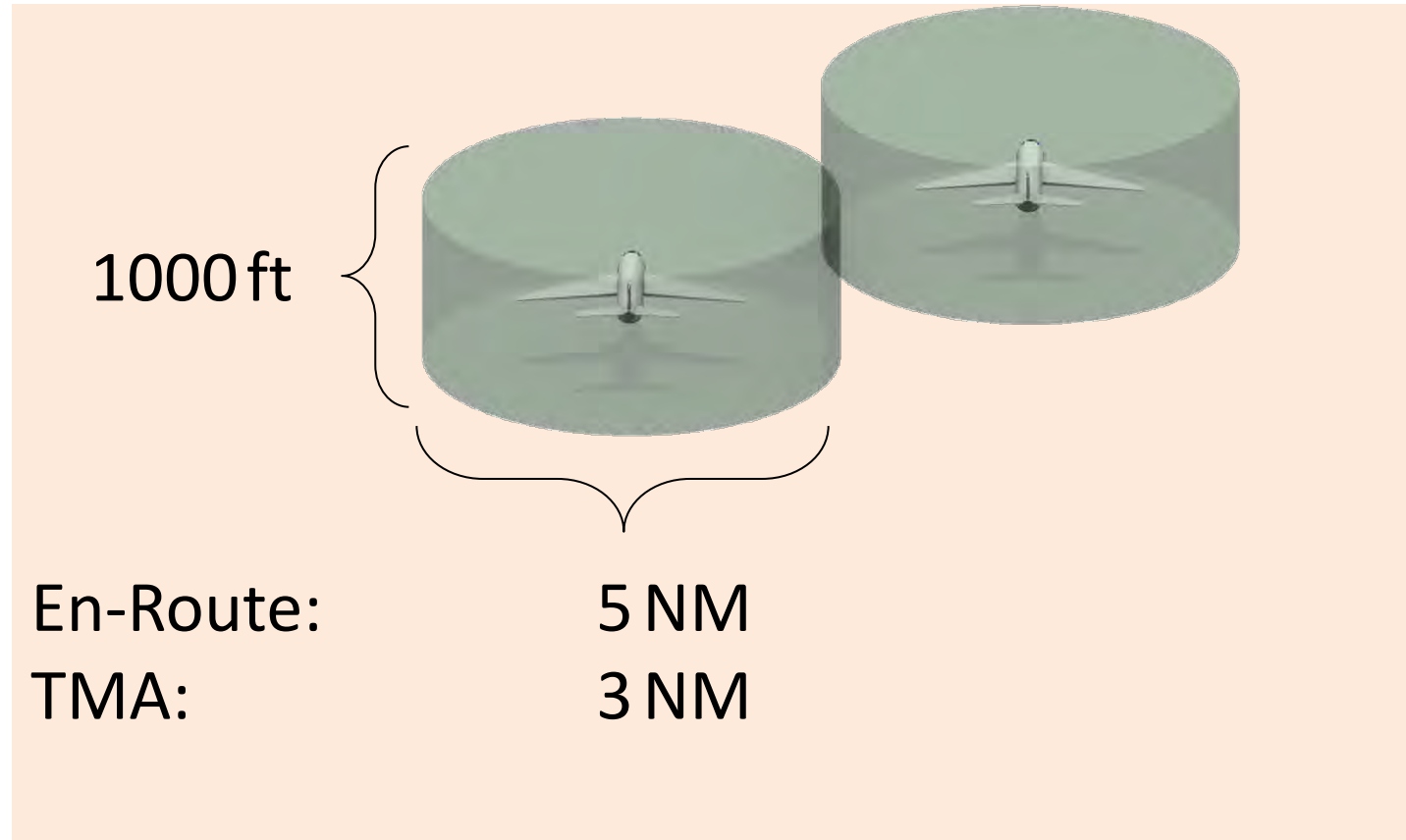
# Conflict?



Conflict?



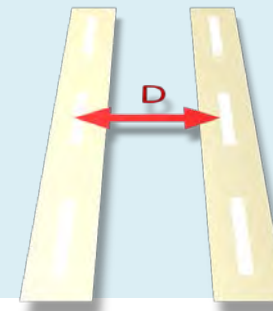
# Conflict Metrics (ICAO)



## In-trail aircraft

		Preceding aircraft		
		Heavy	Medium	Light
Succeeding aircraft	Heavy	4	3	3
	Medium	5	3	3
	Light	6	5	3

## Parallel and nearly parallel arrivals



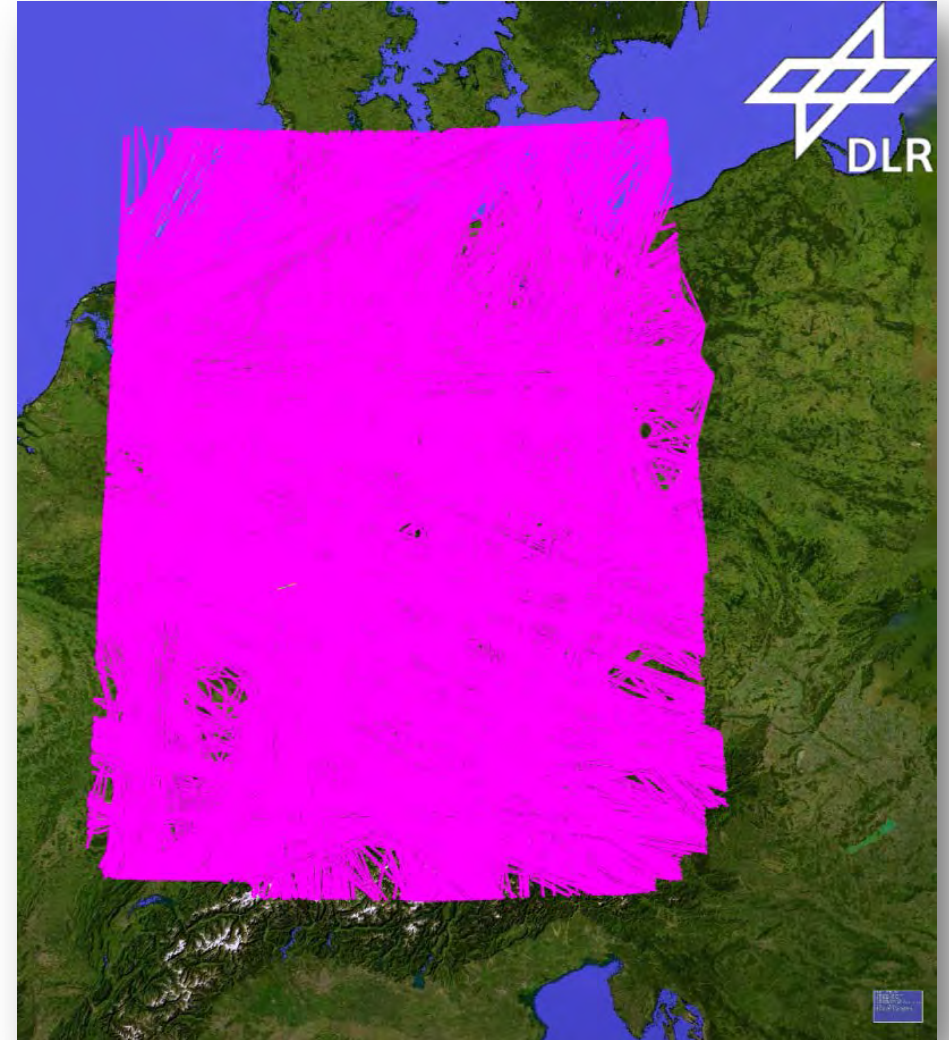
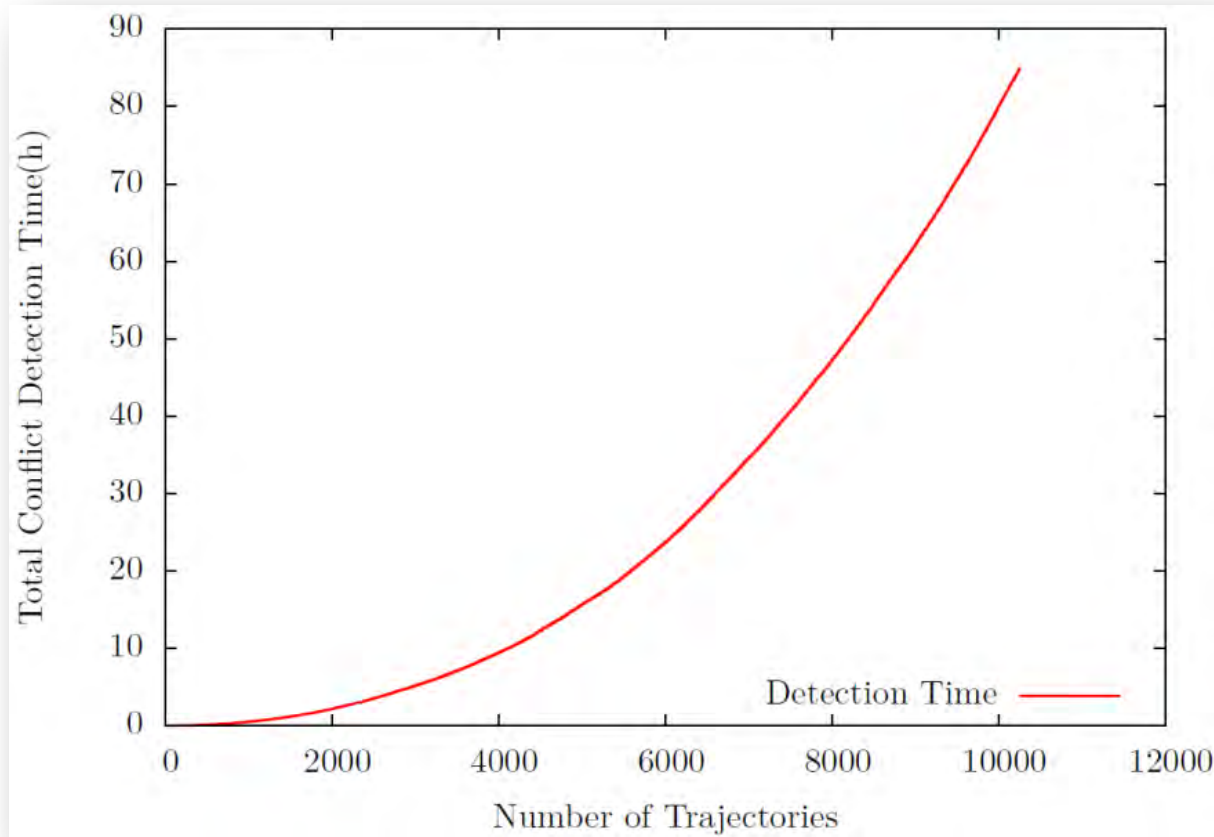
D > 915m: dependent → 2 NM  
 D > 1035m: independent



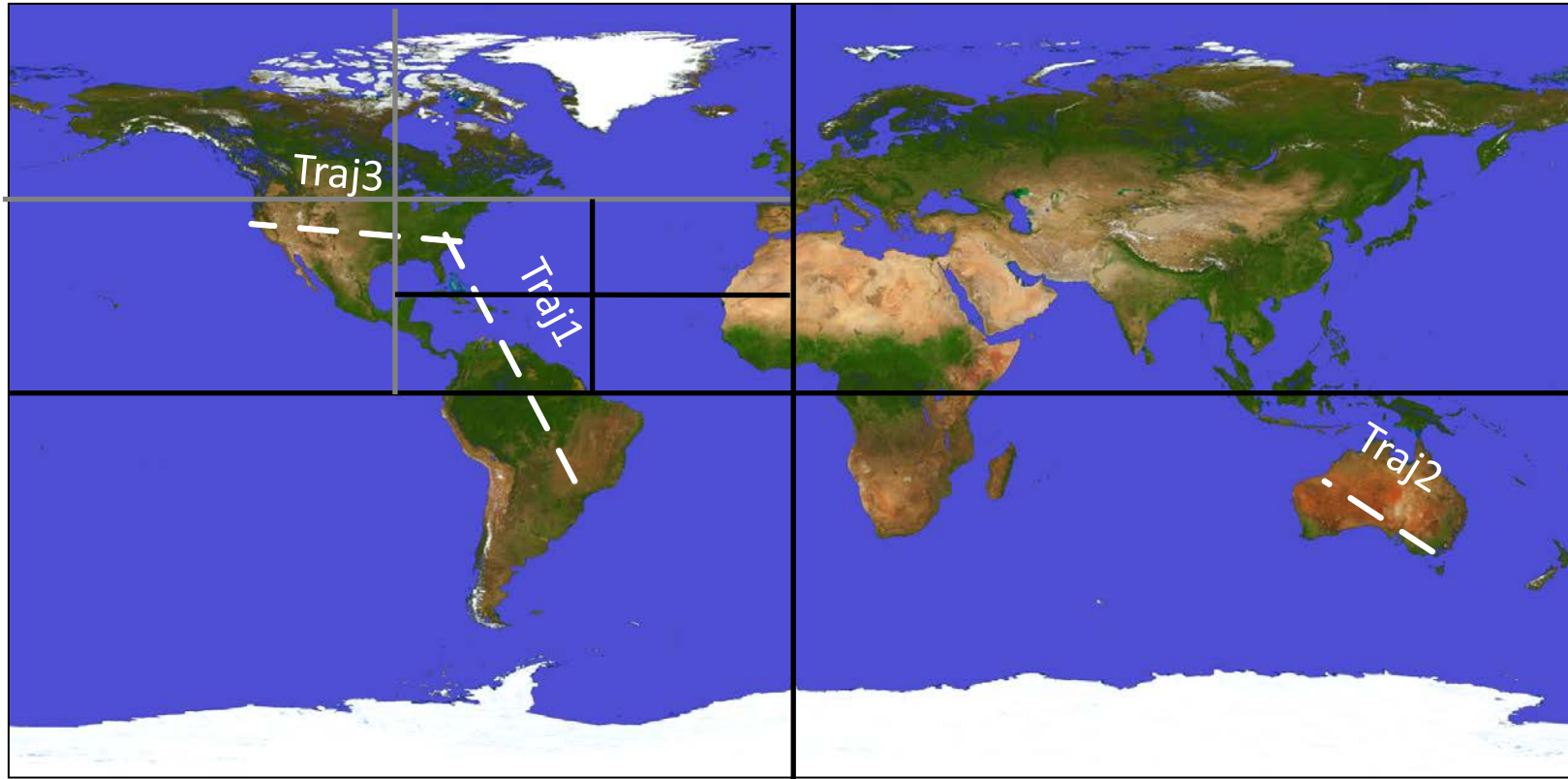


# One Day above Germany

- Densest net of airports and airfields (~550)
- ~10000 Movements/Day



# Example in 2D



Separation-Minima (5 NM, 1000 ft) reached with 12 steps!





# Conflict Detection Algorithm

- Store objects in tree structure using N-dimensional bisection
- Subdivide Airspace in (N=4) Dimensions → Hexadecimal Tree
- Global 4D-Airspace (The „Root-Tile“):

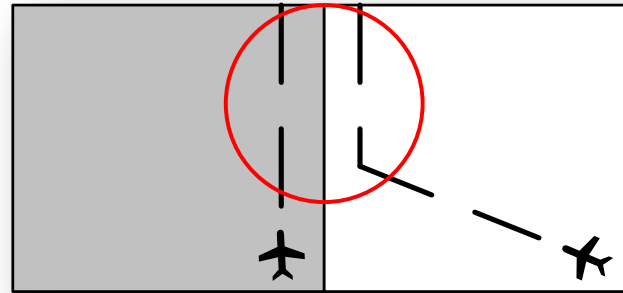
Dimension	Unit	Min	Max	S	D*
Longitude	Deg	-180	180	5/60	12,08
Latitude	Deg	-90	90	5/60	11,08
Altitude	ft	-1000	100 000	1000	6,66
Time	s	0	86 400	90	9,91

$$* D = \log_2 \left( \frac{\text{Max}-\text{Min}}{S} \right)$$

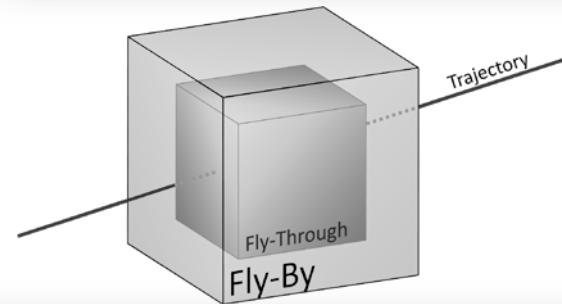


# Neighbourhood: Fly-Throughs and Fly-Bys

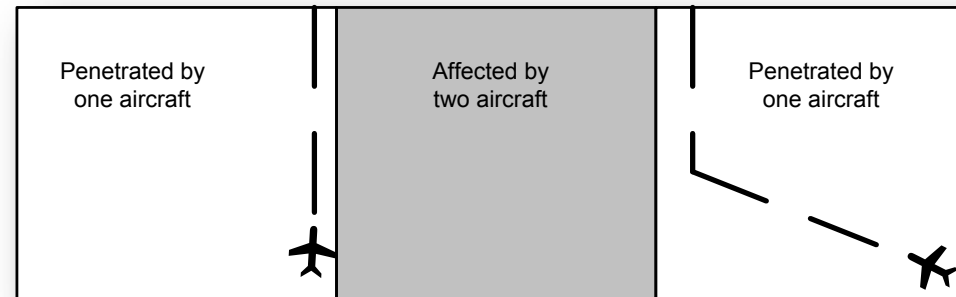
1. Fly-By: Distance from Tile < Separation-distance



2. Tile stores Fly-Throughs and Fly-Bys



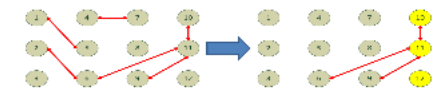
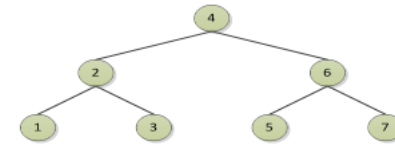
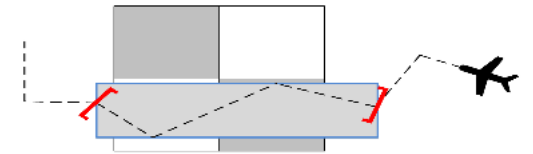
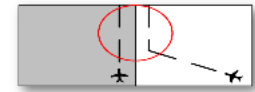
3. Conflict requires Fly-Through



# Some optimizations...

- Common Time
- Symmetric checks once only
- Concentrate on relevant segments
- Bounding Boxes
- Benefit from monotony
- Focus-Objects
- No time-based neighbourhood
- Support for low-memory hardware

$$\begin{pmatrix} x \\ y \\ z \\ t \end{pmatrix} \Rightarrow \begin{pmatrix} x \\ y \\ z \end{pmatrix} (t)$$



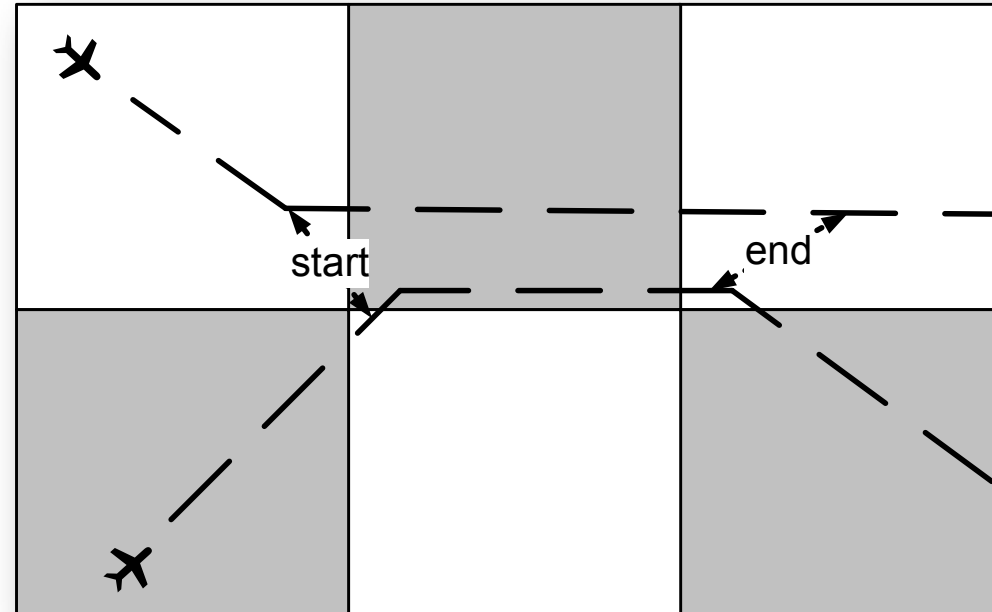
$$|T_1(\tau) - T_2(\tau)| < S$$





# Output of Conflict Detection

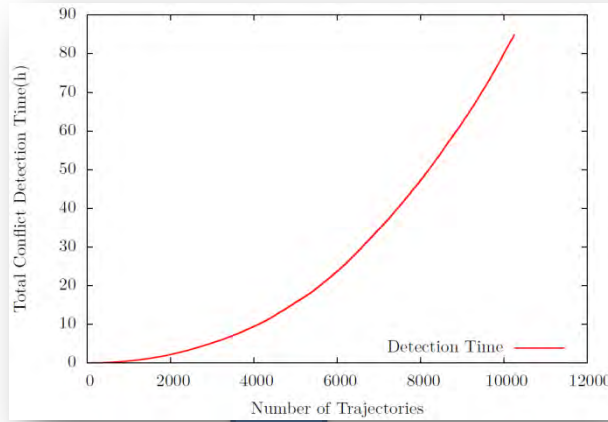
- Object ID<sub>1</sub>
- Object ID<sub>2</sub>
- Trend of Objects
- Flight phase
- Start-of-conflict
- End-of-conflict
- Closest point of approach



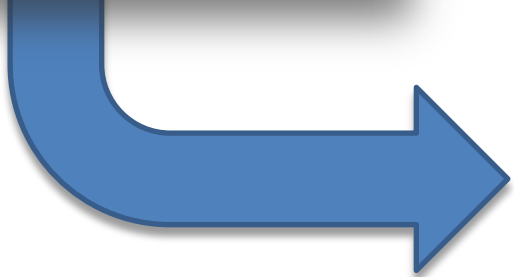
Conflicts are merged beyond tile boundaries



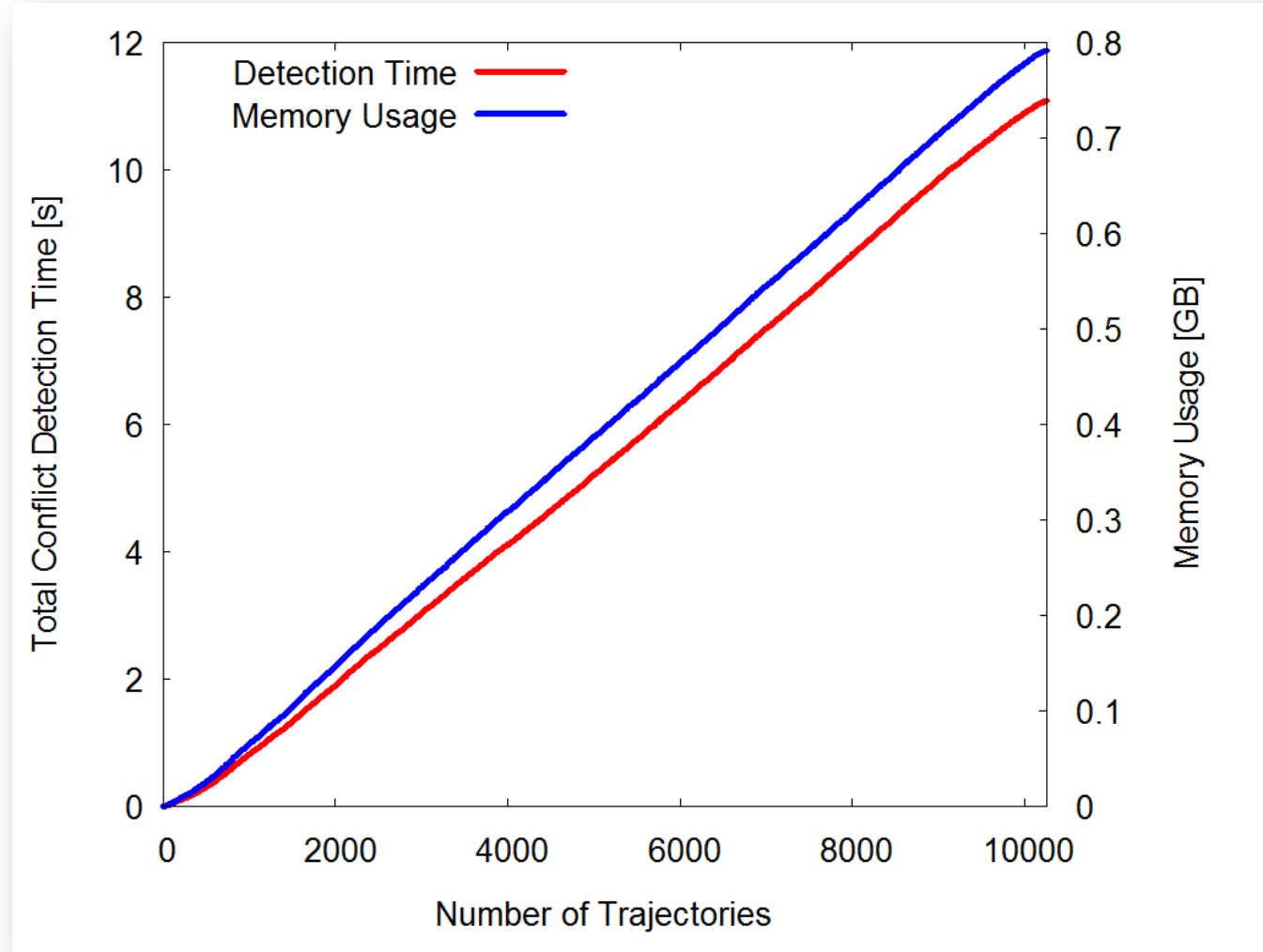
# Performance Germany



82 h



11 s  
+ 800 MB

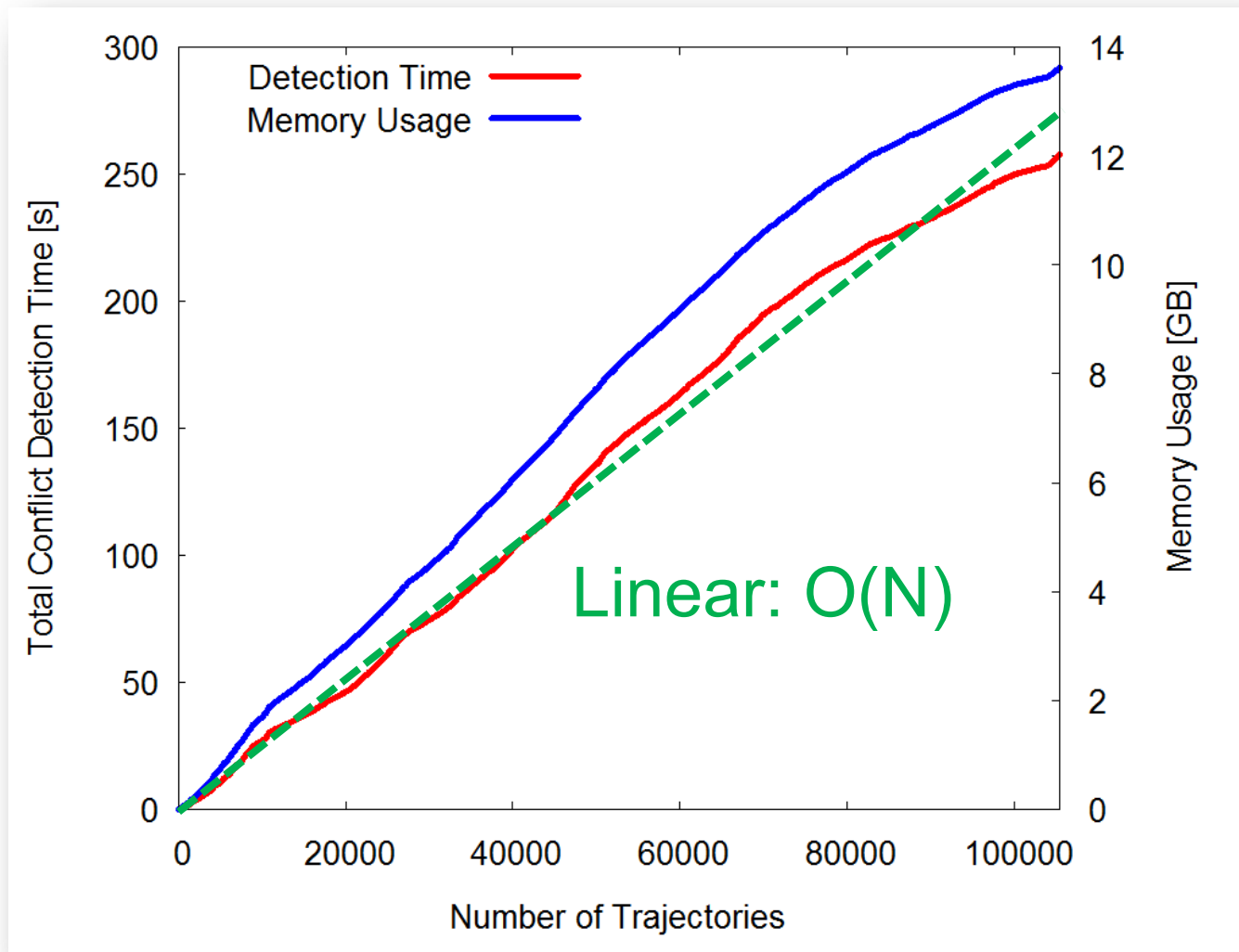
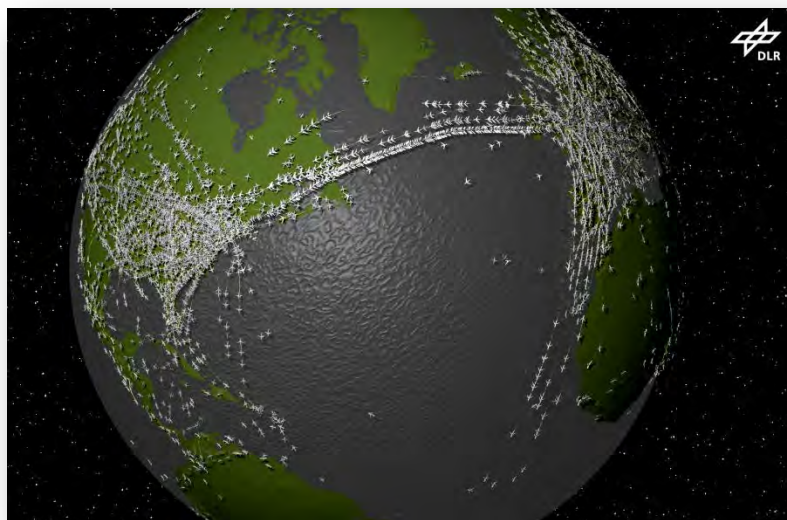




# Performance World-Wide-ATM

- 105k Flights
- 160k Conflicts

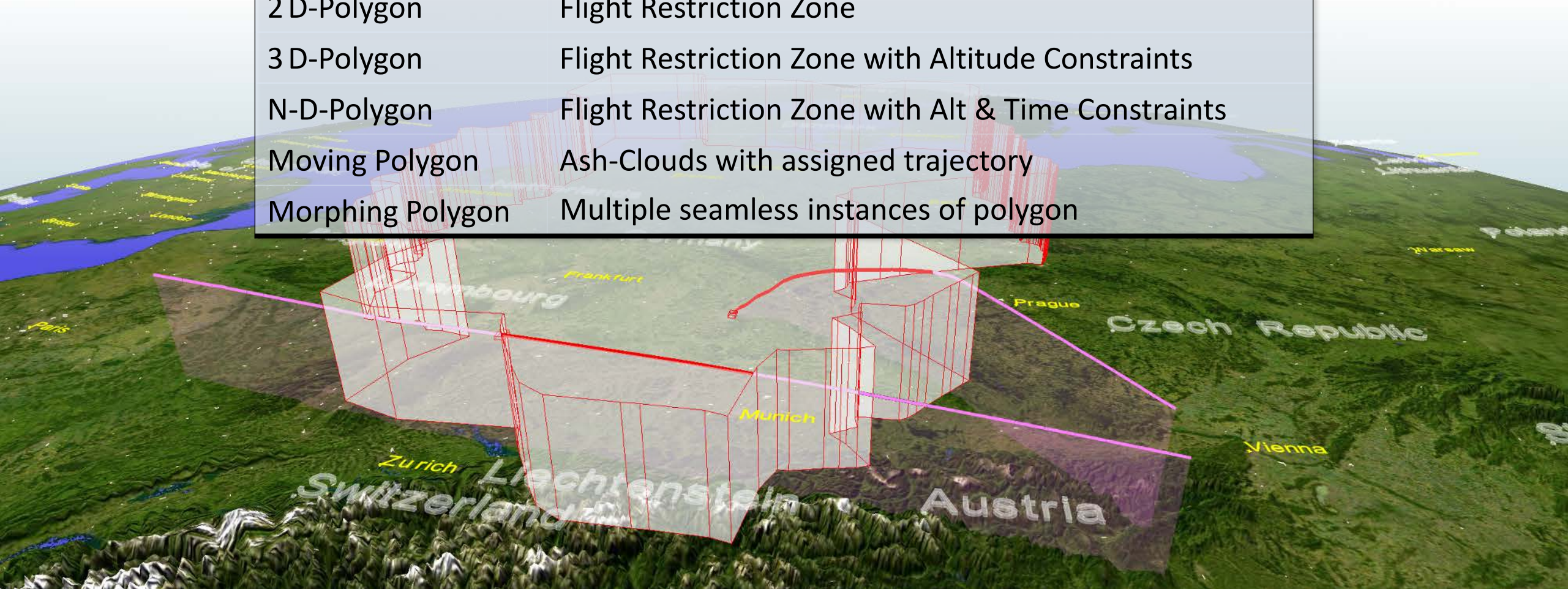
	Time	Memory
total	4:12 min	13.6 GB
per Traj.	2.4 ms	129 KB





# Supported Objects

Object Type	Example
N-D-Trajectorie	4 D-Trajectory
2 D-Polygon	Flight Restriction Zone
3 D-Polygon	Flight Restriction Zone with Altitude Constraints
N-D-Polygon	Flight Restriction Zone with Alt & Time Constraints
Moving Polygon	Ash-Clouds with assigned trajectory
Morphing Polygon	Multiple seamless instances of polygon



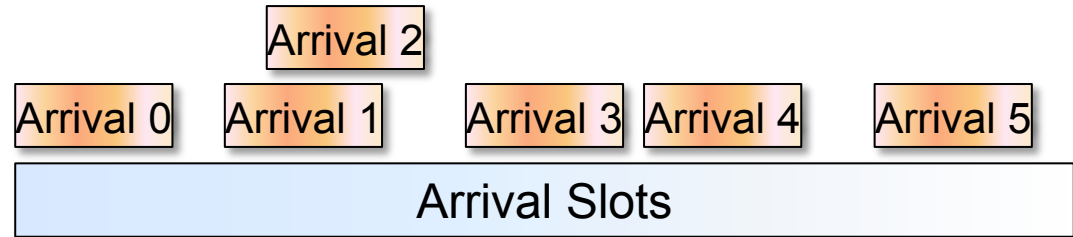
# Conflict Resolution

- Intelligent Trial-and-Error, ~300 probes/s

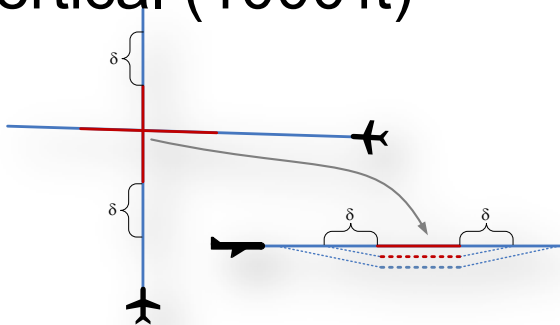
## 1. Time-Shift

- Shift flights in defined interval
- Discretized steps of 10 s

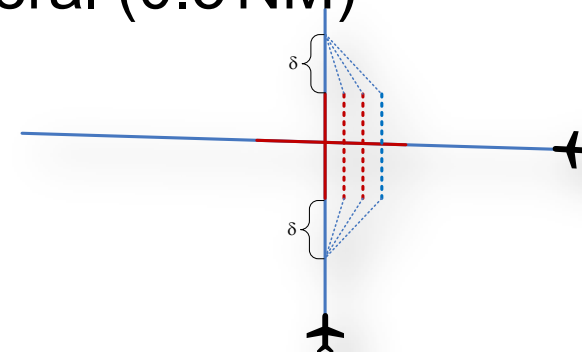
## 2. Recursive Time-Shift



## 3. Vertical (1000 ft)



## 4. Lateral (0.5 NM)



# Overview of Resolution Results (European Scenario)

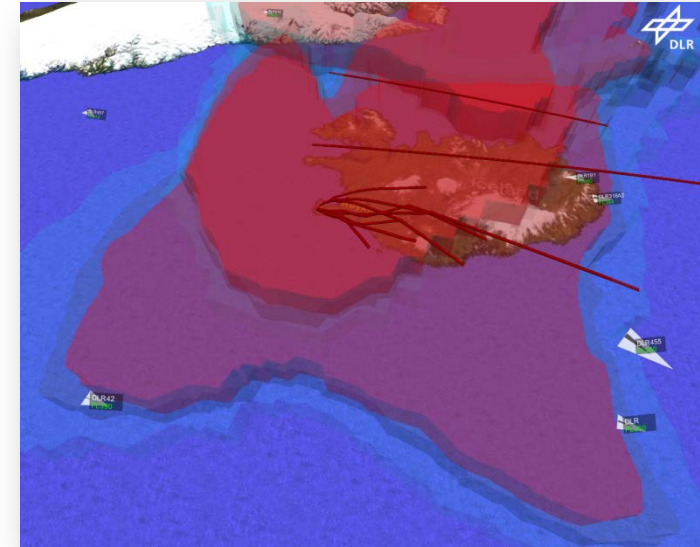
		Scenario					
		Standard	6.5 NM	8 NM	10 NM	12 NM	6.5 NM/1.3
<b>Conflict Metrics</b>	<b>Lateral Separation</b>	5 NM	6.5 NM	8 NM	10 NM	12 NM	6.5 NM
	<b>Lateral Freedom</b>	0 NM	0.75 NM	1.5 NM	2.5 NM	3.5 NM	0.75 NM
	<b>Wake Separation</b>	100%	100%	100%	100%	100%	130%
<b>Conflicts</b>	<b>Total Initial Conflicts</b>	24 162	28 328	33 115	40 562	48 942	28 493
	<b>En-Route Conflicts</b>	11 137	15 303	20 088	27 534	35 912	15 308
	<b>Airport-Related Conflicts</b>	13 025	13 025	13 027	13 028	13 030	13 185
<b>Resolution Costs</b>	<b>Average Time Shift</b>	93.9 s	120.8 s	143.4 s	191.2 s	200.2 s	145.8 s
	<b>Average Additional Climb</b>	16.9 ft	40.8 ft	59.8 ft	159.2 ft	220.0 ft	44.9 ft
	<b>Average Additional Distance</b>	0.002 NM	0.037 NM	0.074 NM	1.287 NM	3.477 NM	0.097 NM





# N-D? Example for 5th Dimension (1/2)

- Ash-Cloud contamination classes
  - Low with 0.2-2 mg/m<sup>3</sup>
  - Medium with 2-4 mg/m<sup>3</sup>
  - High with >4 mg/m<sup>3</sup>
- Most vulnerable parts: engines
- Hotter engines more severe (?)

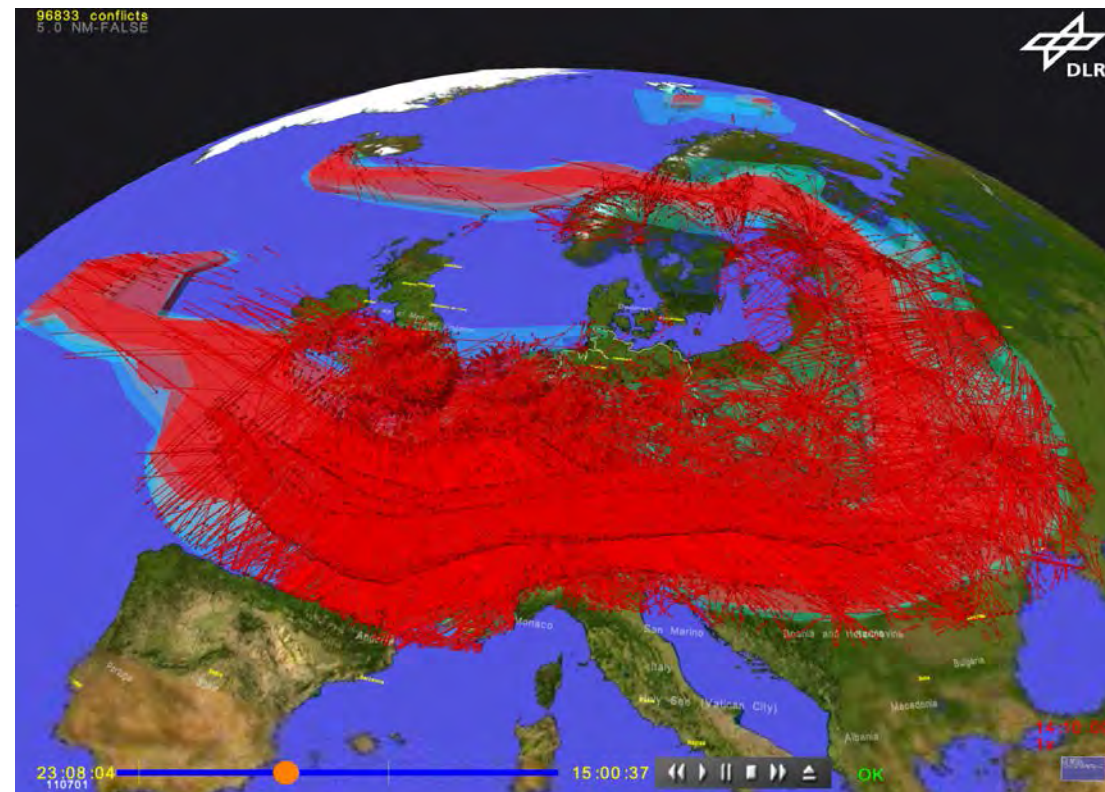


Ash Cloud Metrics		Ash Contamination		
		High [-0.5,2.5]	Medium [0.5,2.5]	Low [1.5,2.5]
Engine-Temperature	Hot (2)			
	Medium (1)			Allowed
	Cool (0)		Allowed	Allowed



# Technical Performance with 5<sup>th</sup> Dimension (Volcanic Ash)

- Aircraft data:
  - 1<sup>st</sup> July 2011, 33000 flights
  - Engine temperature high in climb, medium in cruise and low in descent
  - Real temperature, if available
- Ash clouds:
  - Eyjafjallajökull eruption in Iceland on 17<sup>th</sup> April 2010
  - 156 polygons, total of 5 585 sampling points
  - 8 time frames with 3 hours each
- 96 833 conflicts

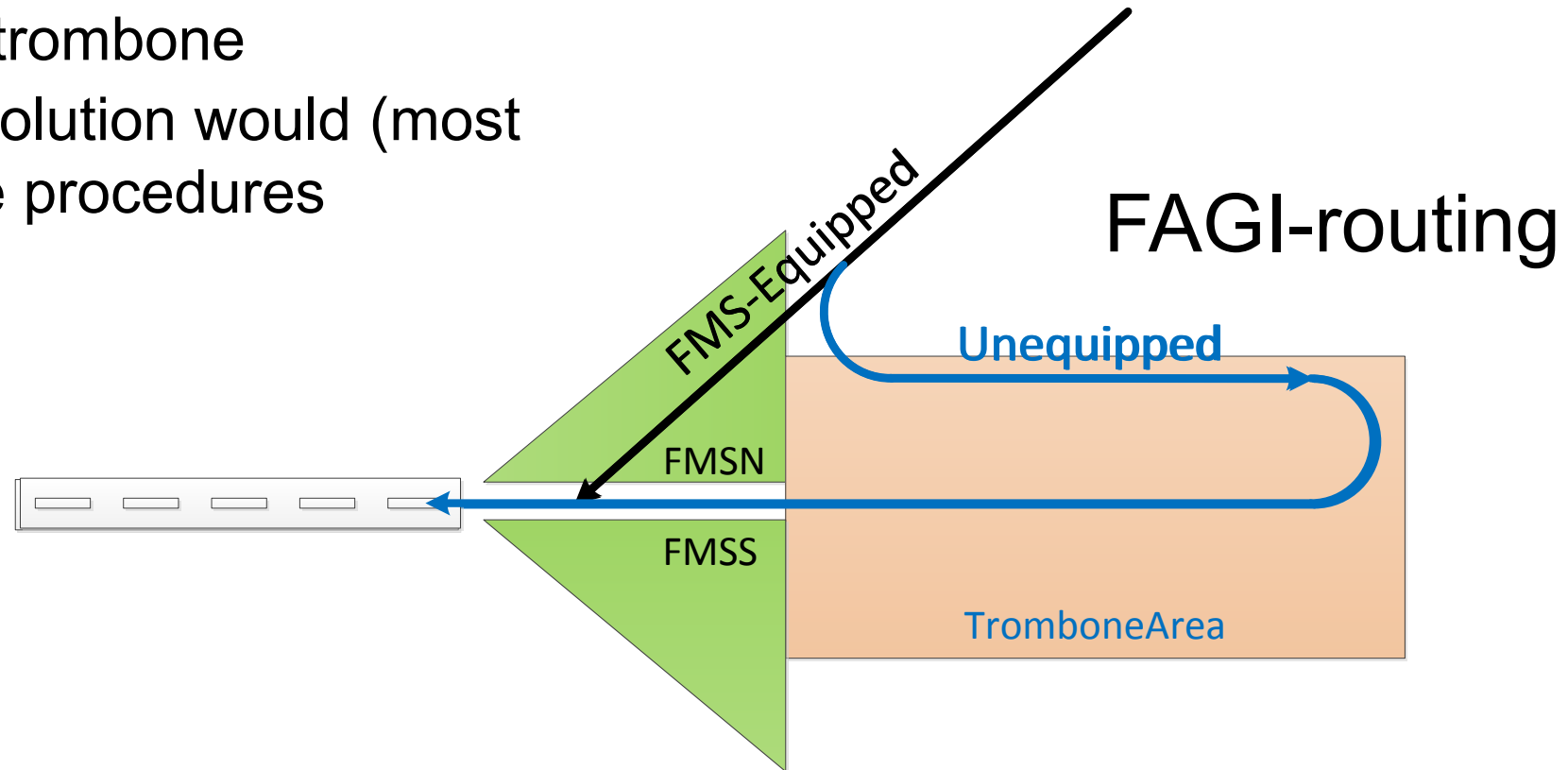


Dimensions	Conflicts	Calculation Time	Memory Usage
4	96 833	485 ms/poly	5.5 GB
5	58 954	536 ms/poly	7.5 GB

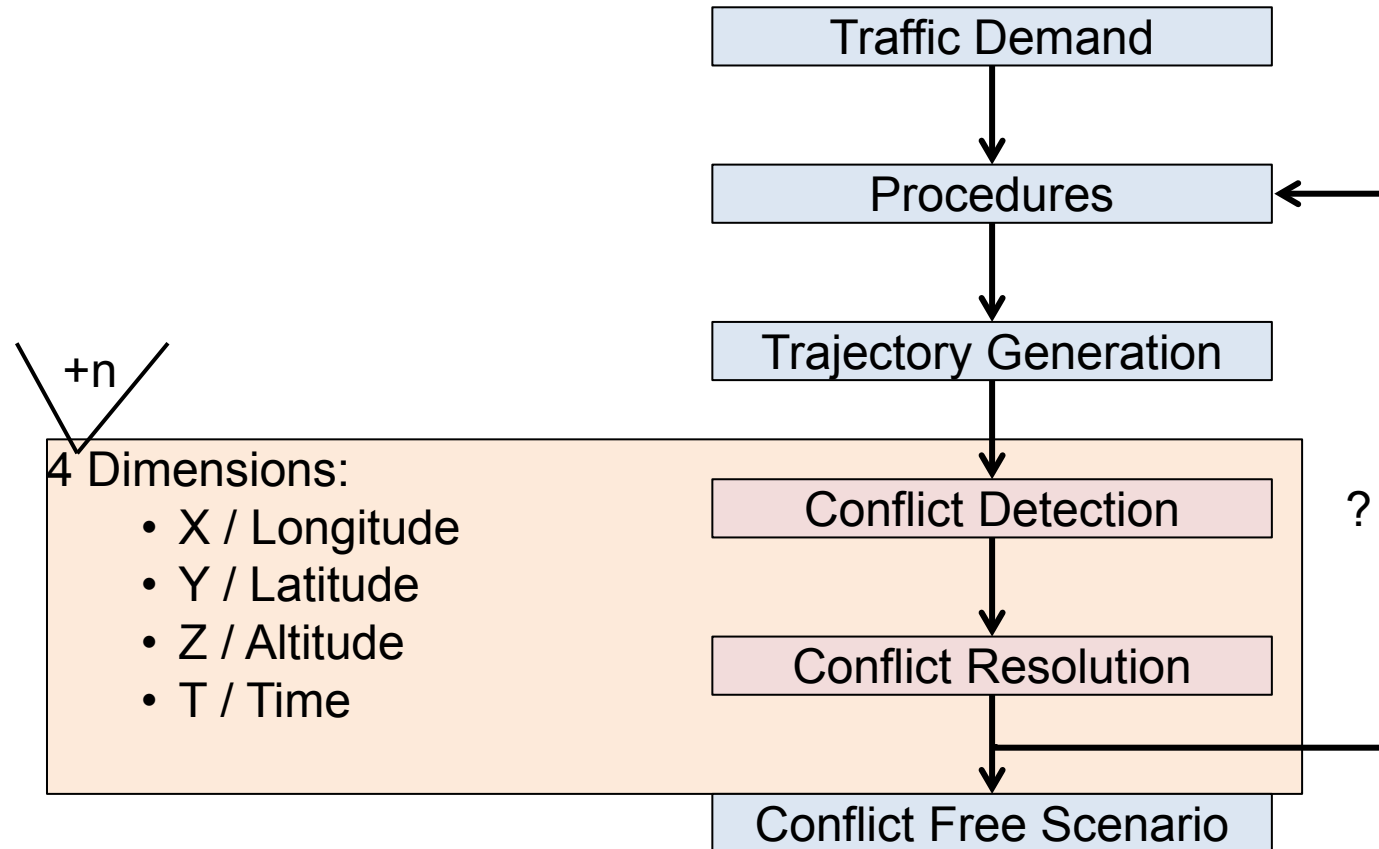


# N-D? Example for 5th Dimension (2/2)

- Routes depend on equipage
- FMS-equipped fly direct
- Unequipped fly trombone
- XYZT: Conflict solution would (most certainly) violate procedures



# Generation of a Conflict Free Scenario





# Summary

- Fastest conflict detection algorithm existing for large scenarios
- Only algorithm with linear complexity  $O(N)$
- Strategic Resolution, mainly based on time shift
- Up to 3.5 NM/23 s freedom
- N-dimensional: Procedures
  - ... can be integrated in conflict management (and thus validated)
  - ... are respected by conflict resolution
  - ... can be used to solve conflicts
  - ... Integration in conflict management avoids planning recursions





24162 conflicts  
6.9 NM



# Questions?

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## References:

- Kuenz, A., High Performance Conflict Detection and Resolution for Multi-Dimensional Objects. PhD Thesis, ISSN 1434-8454, <http://elib.dlr.de/98476/1/dissKuenzS.pdf>, 2015
- Kuenz, A. und Schwoch, G. und Korn, B. (2015) Designing freedom into trajectory-based operations. Proceedings of the Institution of Mechanical Engineers Part G-Journal of Aerospace Engineering. SAGE Publications. ISSN 0954-4100
- Kuenz, Alexander (2015) The 5th Dimension in Conflict Management – XYZT+Capability. 34th DASC 2015, 13.-17.09.2015, Prag, Tschechien.

