

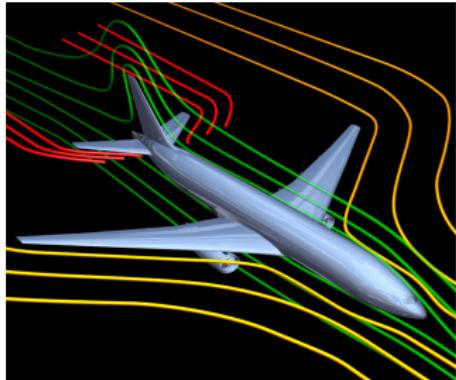
Trajectory optimization considering contrails

Gaspard DANNET

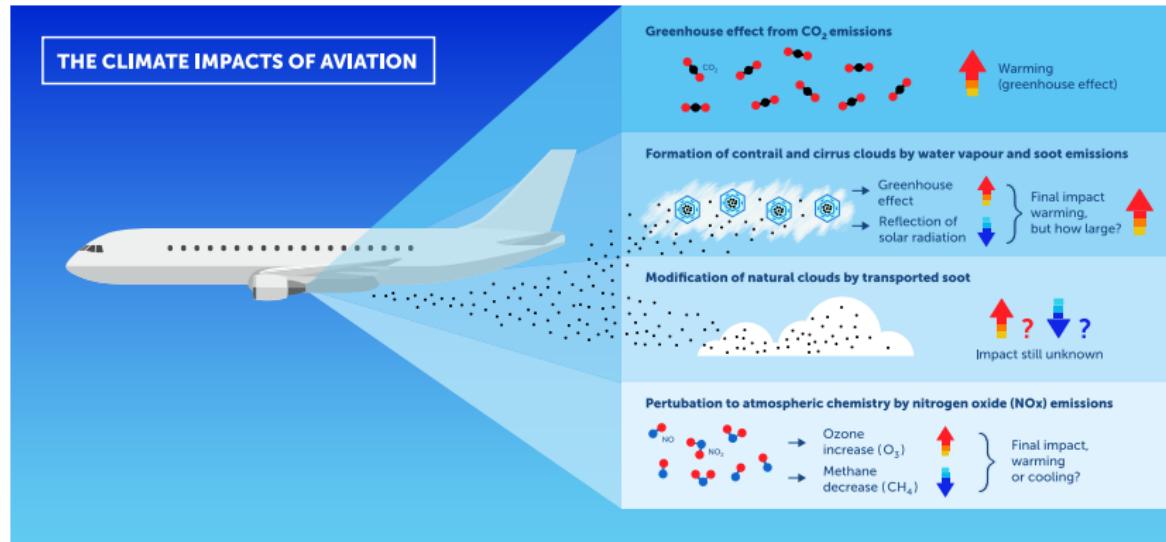
ENAC

January 17, 2023

Reducing CO₂ emissions



Reducing non-CO₂ emissions



Climate warming



Climate cooling



Soots



Ice crystals



CO₂



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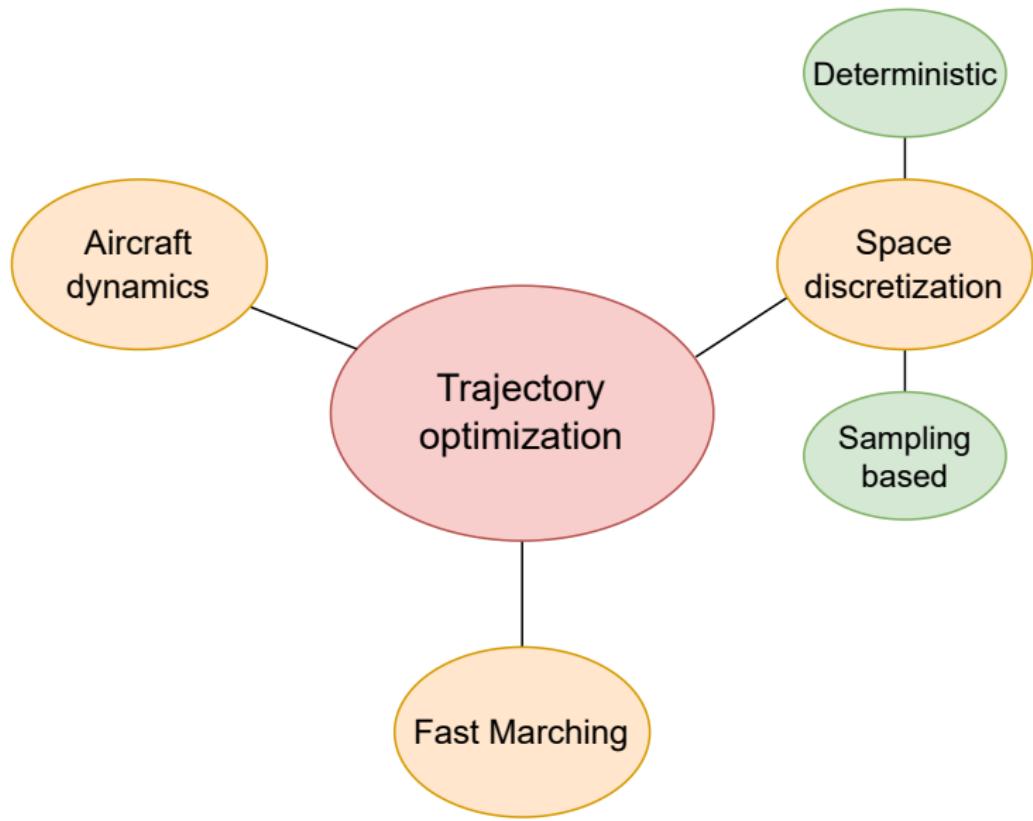


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Modeling

Model of the problem

$$\underset{\gamma}{\text{minimize}} \quad \int_{t_0}^{t_f} C_t + C_r r(x, y) dt \quad (1)$$

subject to $\gamma \in \Gamma$

C_t is the cost coefficient of time, C_r the cost associated with contrails, $r(x, y)$ the penalty function and Γ the set of flyable trajectories.

$$r(x, y) = \begin{cases} \text{constant} & \text{if aircraft in penalty area} \\ 0 & \text{otherwise} \end{cases} \quad (2)$$

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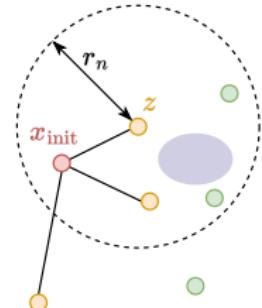
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FMT* Algorithm

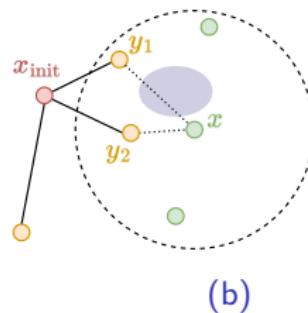
● V_{closed}

○ V_{open}

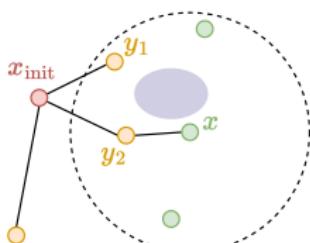
● $V_{unvisited}$



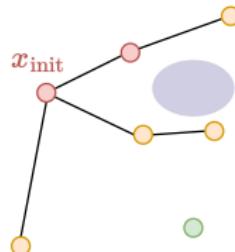
(a)



(b)



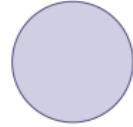
(c)



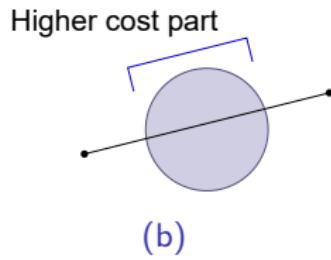
(d)

Figure: An iteration of the FMT* algorithm.

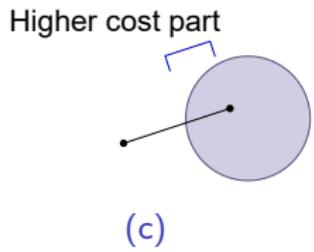
Ability to cross obstacles



(a)



(b)



(c)

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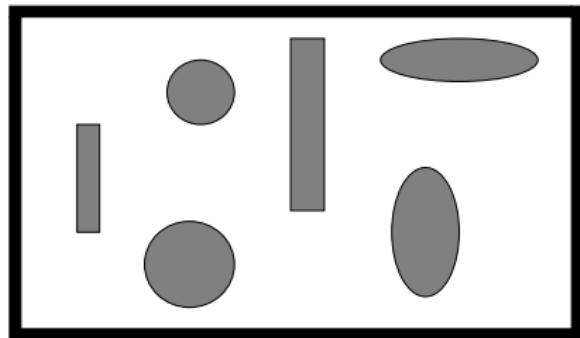
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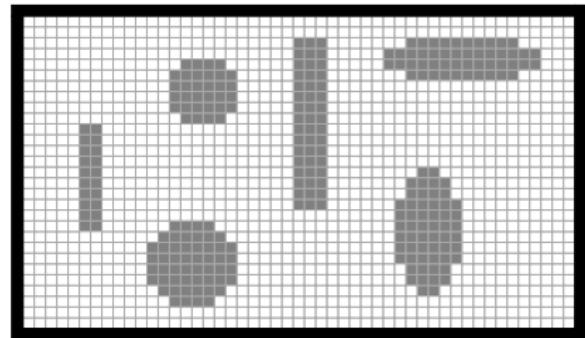
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Discretization



(a) Initial environment



(b) Discretization of the obstacles

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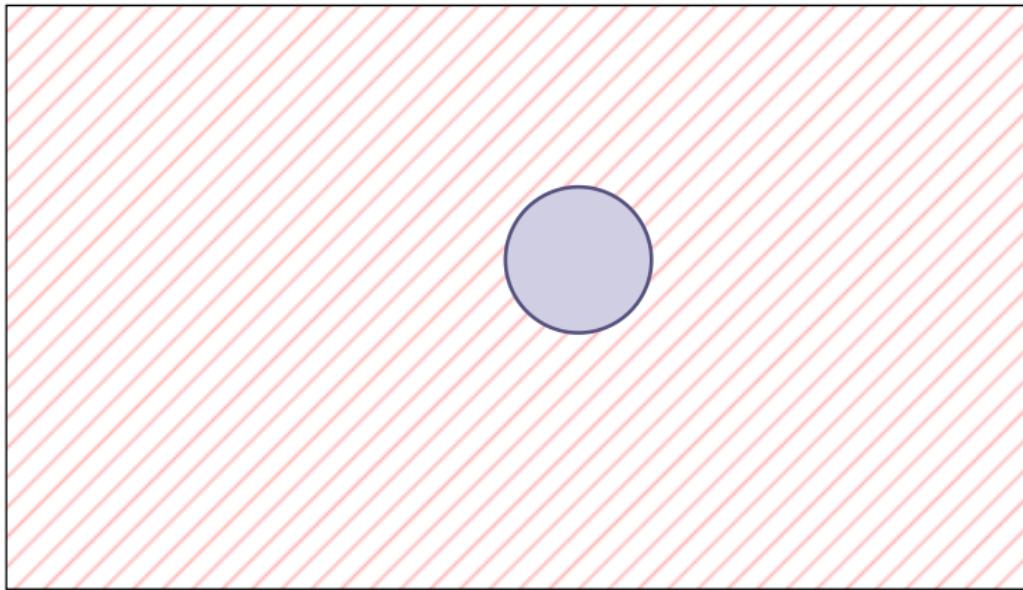
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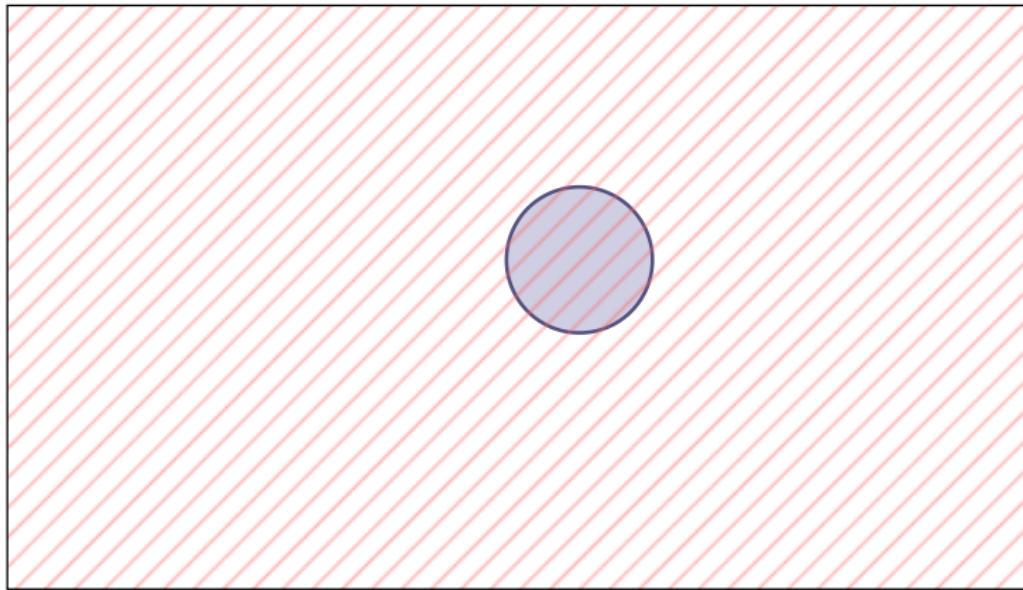
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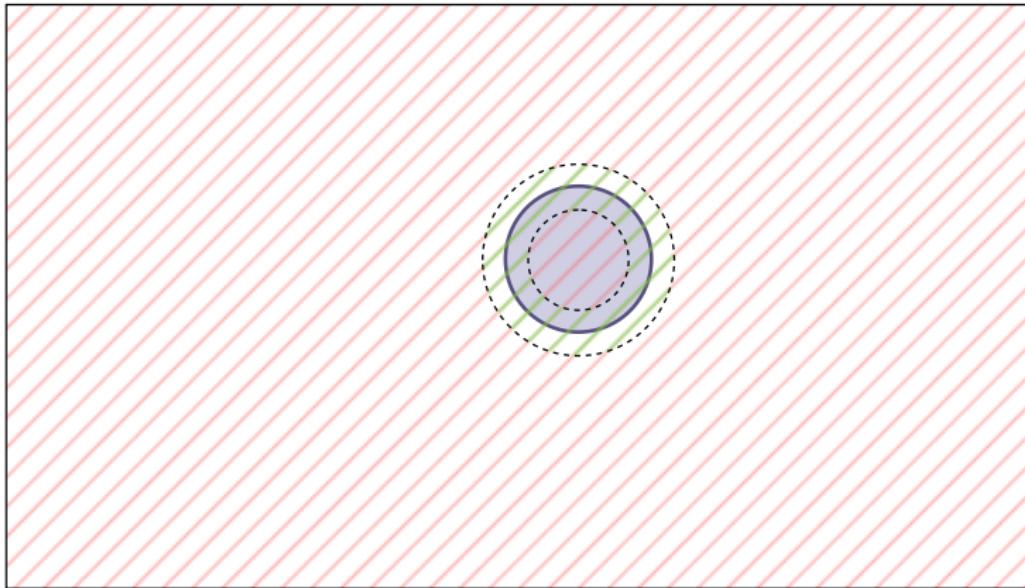
Uniform sampling without obstacles



Uniform sampling with obstacles



Obstacles sampling



Add a distribution for each obstacles to sample more around the boundary of the obstacles

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Uniform sampling

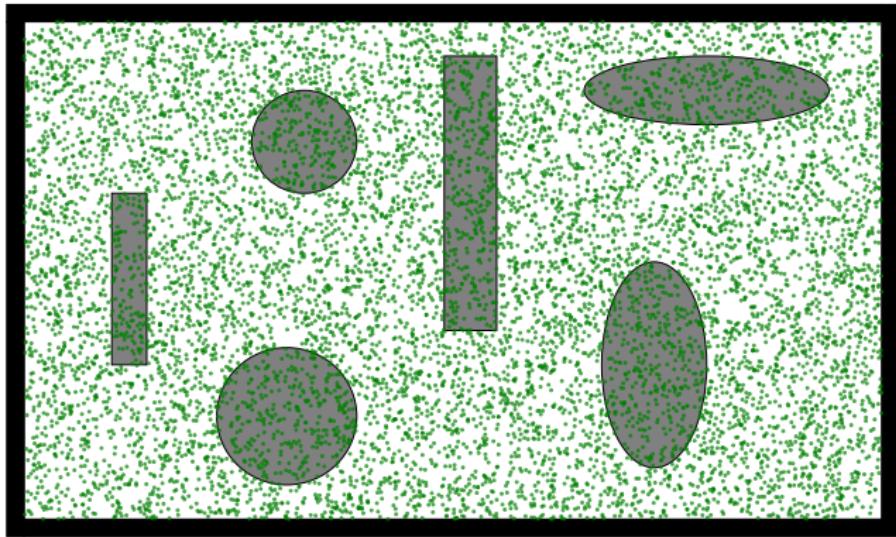


Figure: Sampling uniform obtained with 10 000 samples. The samples are represented by green dots.

Sampling considering obstacles

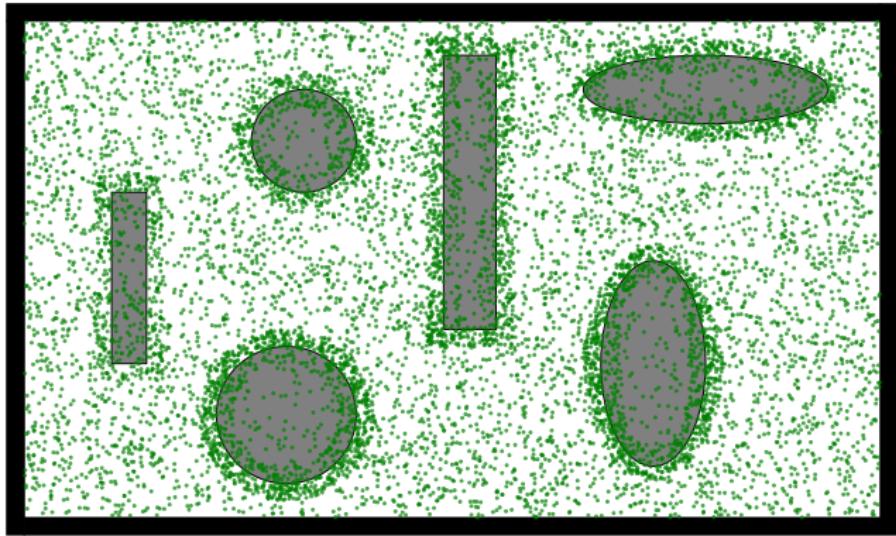


Figure: Sampling considering obstacles obtained with 10 000 samples. The samples are represented by green dots.

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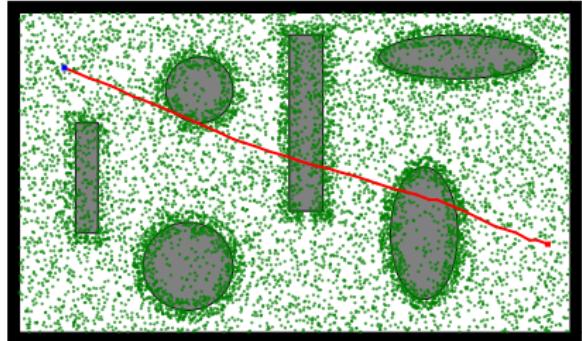
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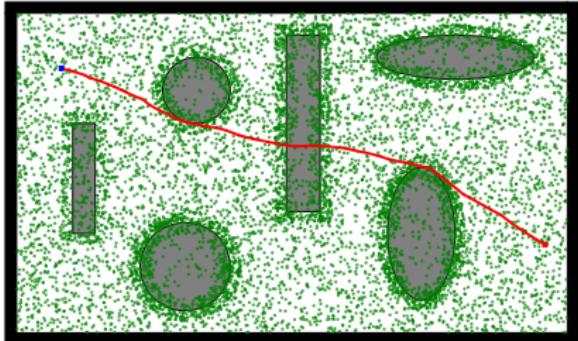
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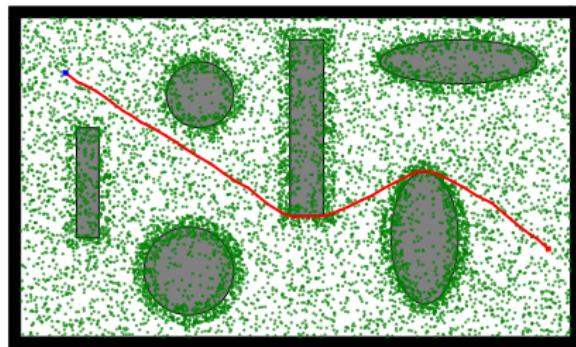
Euclidean distance



(a) $C_r = 0$



(b) $C_r = 1$



(c) $C_r = 2$

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Great-circle distance

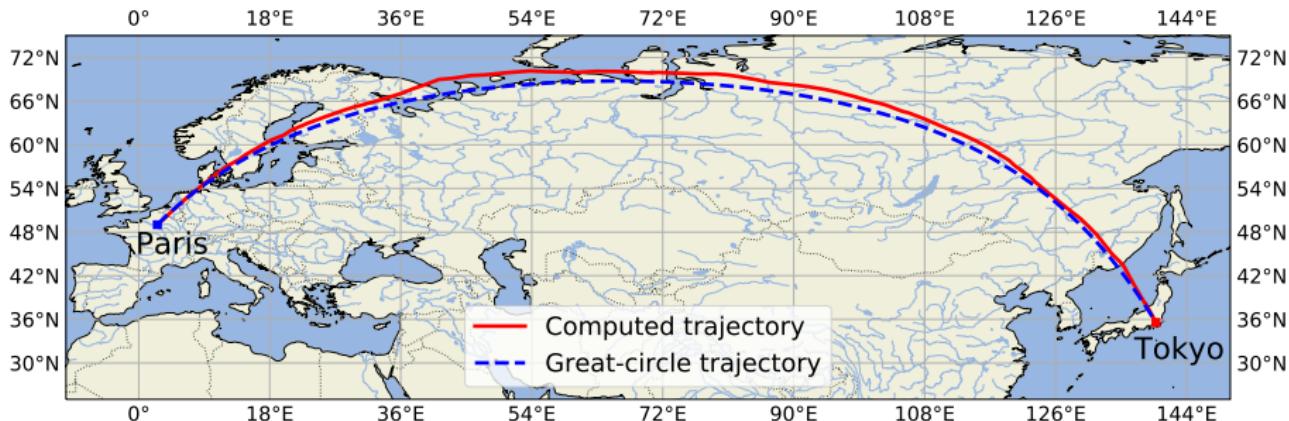


Figure: Comparison of the computed trajectory and the great-circle trajectory with longitude on abscissa and latitude on ordinate.

Great-circle distance with obstacles

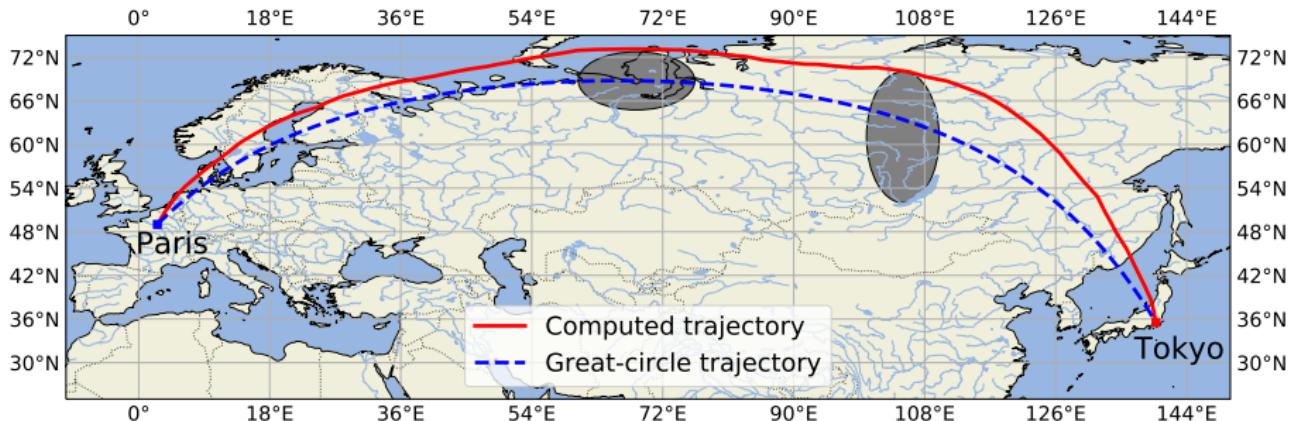


Figure: Using great-circle distance with obstacles, $C_r = 1$.

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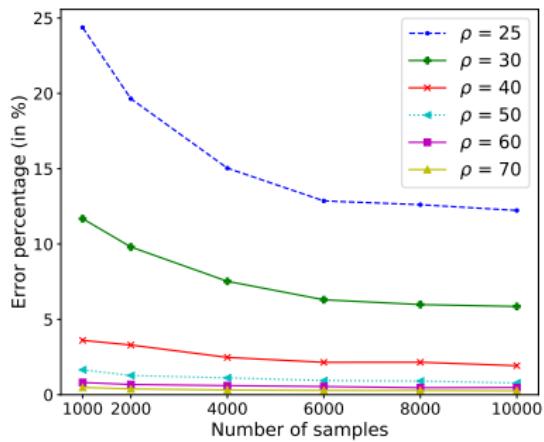
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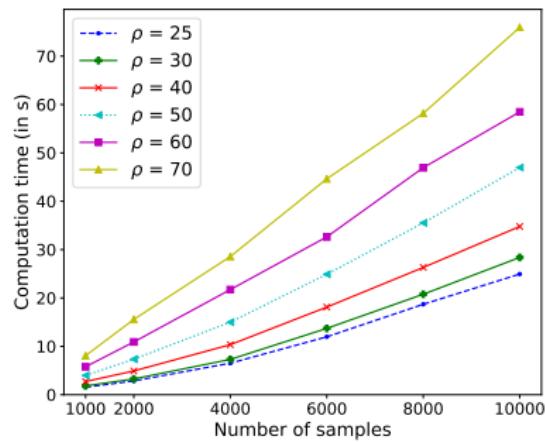
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$$r_n = \rho \sqrt{\frac{\log(n)}{n}}$$



(a)



(b)

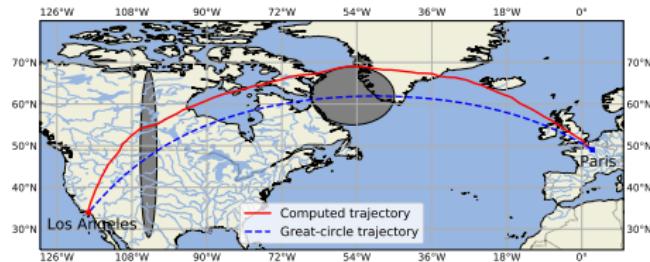
Figure: Two graphs comparing the number of samples and the connection radius on a given environment.

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Conclusion

- Sample more around obstacles
- Soft obstacles
- Great-circle distance



Perspectives

Upgrades :

- Use only a grid, bitmap
 - Smooth the trajectories
 - Add wind data
 - Use real data

