



Conflict-free trajectory optimization using B-splines and Genetic Algorithm

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Agenda

- ATM context
- Problem presentation
- Trajectory model
- Optimization method
- Numerical results
- Applications



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- **ATM context**
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ATM context

- Air traffic control (ATC) has always been a critical safety matter
- Previously, ATC dealt with traffic growth by reducing airspace sectors' size
- The number of flights is going to double over the next 20 years
- The airspace will reach its limits with the current means of control.



SESAR and NextGen

- More automation :
 - delegation of some spacing and separation tasks to aircraft,
 - decision support for controllers.
- Integration of new technologies,
- A new concept of air traffic control: Trajectory-based operations,
- Human centered system



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Problem Presentation

Our objective

- Generate N aircrafts trajectories for an en-route conflict situation,
- Conflict-free trajectories,
- Optimal trajectories regarding distance and time.

Optimization's problem features

- The conflict resolution has been proven NP-hard,
- No derivative available,
- Black box stochastic global optimization well suited.



Problem Presentation

Our methodology

- A combination between a stochastic optimization method: Genetic Algorithm (GA),
- and smooth trajectory model: B-splines.
- **B-splines are controlled by GA via their control points**

Data and constraints

- **Data:** Start and end points, and speed for each aircrafts
- **Constraints:**
 - Constant speed along the aircraft trajectory,
 - No vertical deviation (2D resolution).



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Trajectory model: B-splines

Start and end points





Trajectory model: B-splines

Business Trajectory



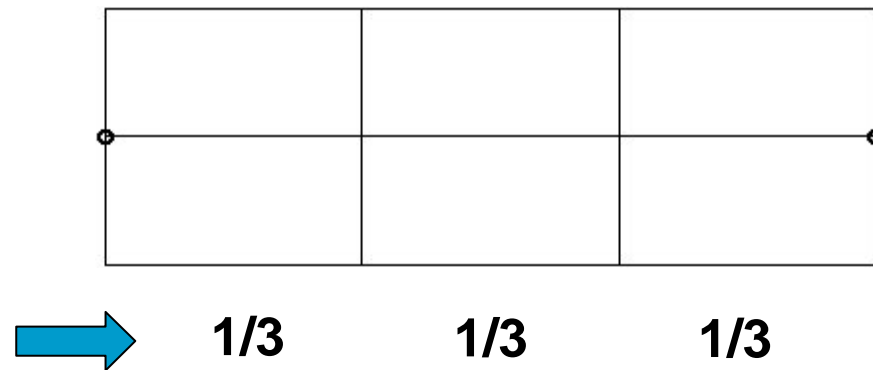
Trajectory model: B-splines

**Maximum
deviation
bandwidth**



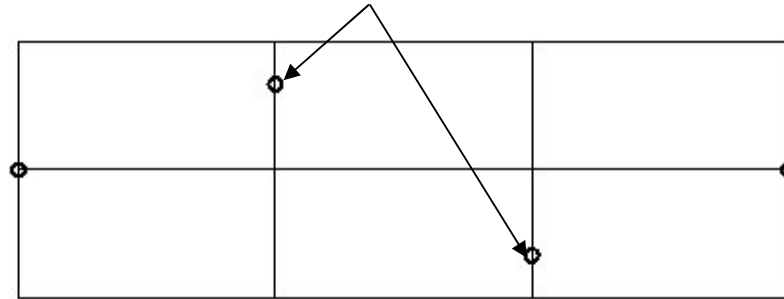
Trajectory model: B-splines

Uniformly distributed control points along the BT

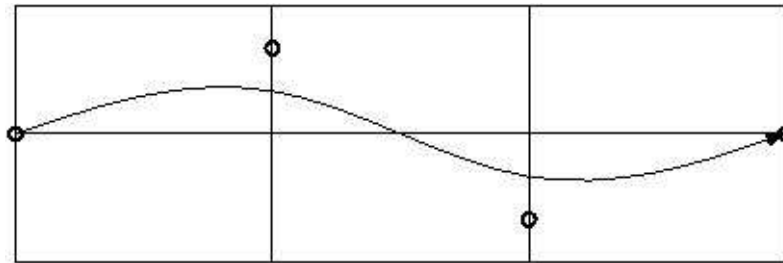


Trajectory model: B-splines

Location of the control points



Trajectory model: B-splines



Corresponding B-splines



Trajectory model: B-splines

B-Splines benefits:

- A very efficient tool for curve approximation,
- allows to reduce the solution space dimension,
- and a good compatibility with GA requirements.

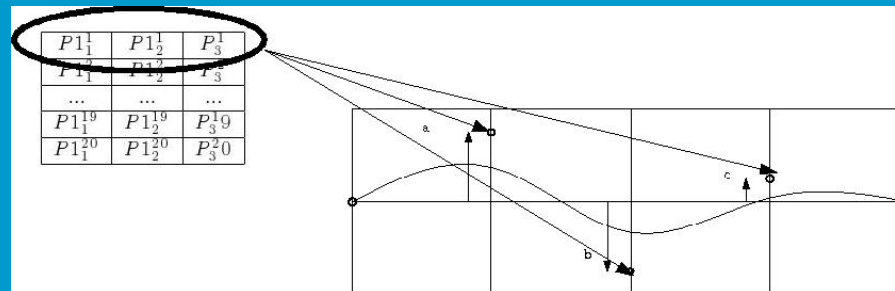


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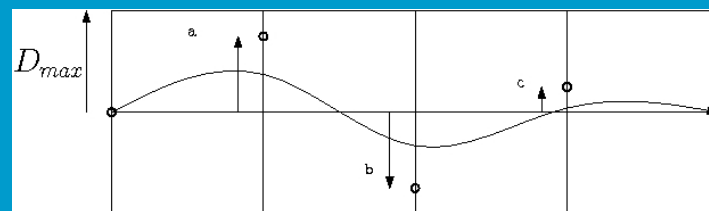
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Optimization method: genetic algorithm

- A solution space's individual is encoded in a chromosome.
- Definition of the encoding for an example $N = 20$ and $Nb_{pt} = 3$:



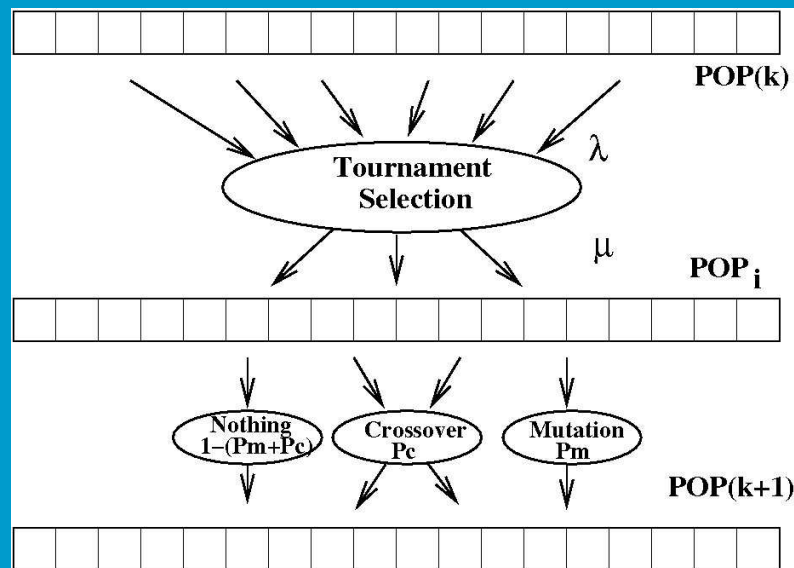
- Each point is defined by a bandwidth percentage:



- Example:
- $$P_1^1 = \frac{a}{D_{max}}$$
- $$P_2^1 = \frac{b}{D_{max}}$$
- $$P_3^1 = \frac{c}{D_{max}}$$

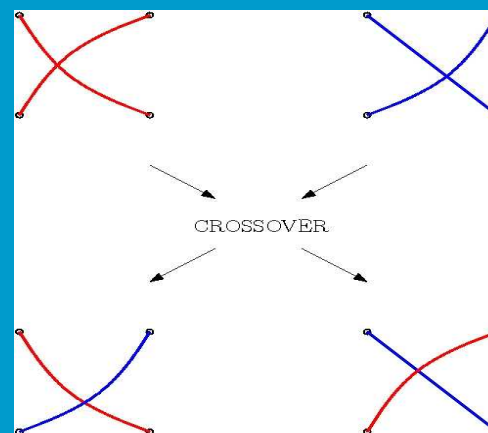
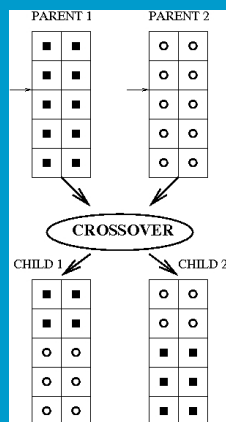
Optimization method: genetic algorithm

- A population of solution evolves using evolution concepts
- Evolution from generation k to $k + 1$:

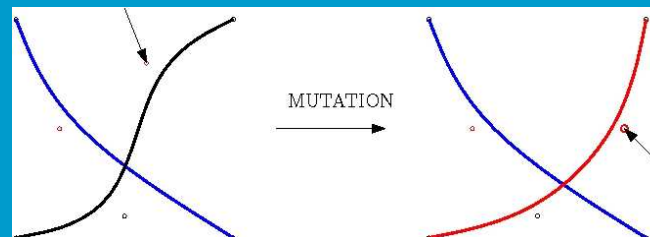
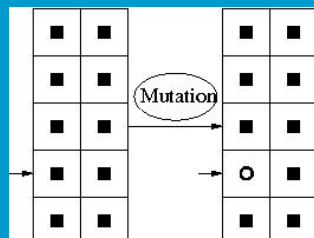


Optimization method: genetic algorithm

- **Slicing crossover** : aims to exploit the good solutions



- **Mutation** : aims to explore randomly the solution space



Optimization method: genetic algorithm

Chromosome encoding

- Necessity to evaluate solution space individuals to make a selection
- Fitness = ability to address the problem
- Fitness expression:

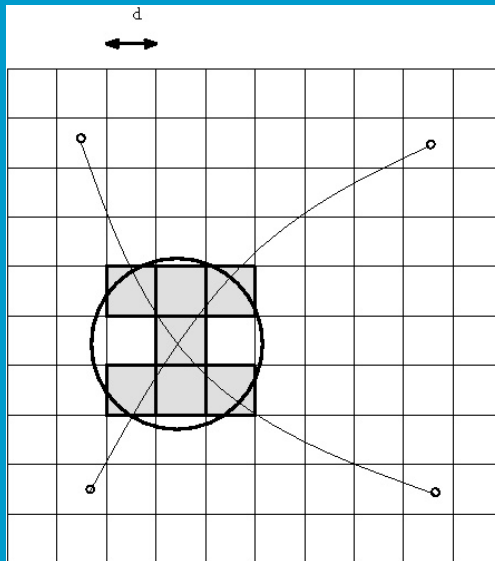
$$f(X) = \sum_{i=1}^n (C_{onf} + D_{ist})$$

- A compromise between the conflict number and the distance's enlargement

Optimization method: genetic algorithm

Conflict Detection

- Simple example :



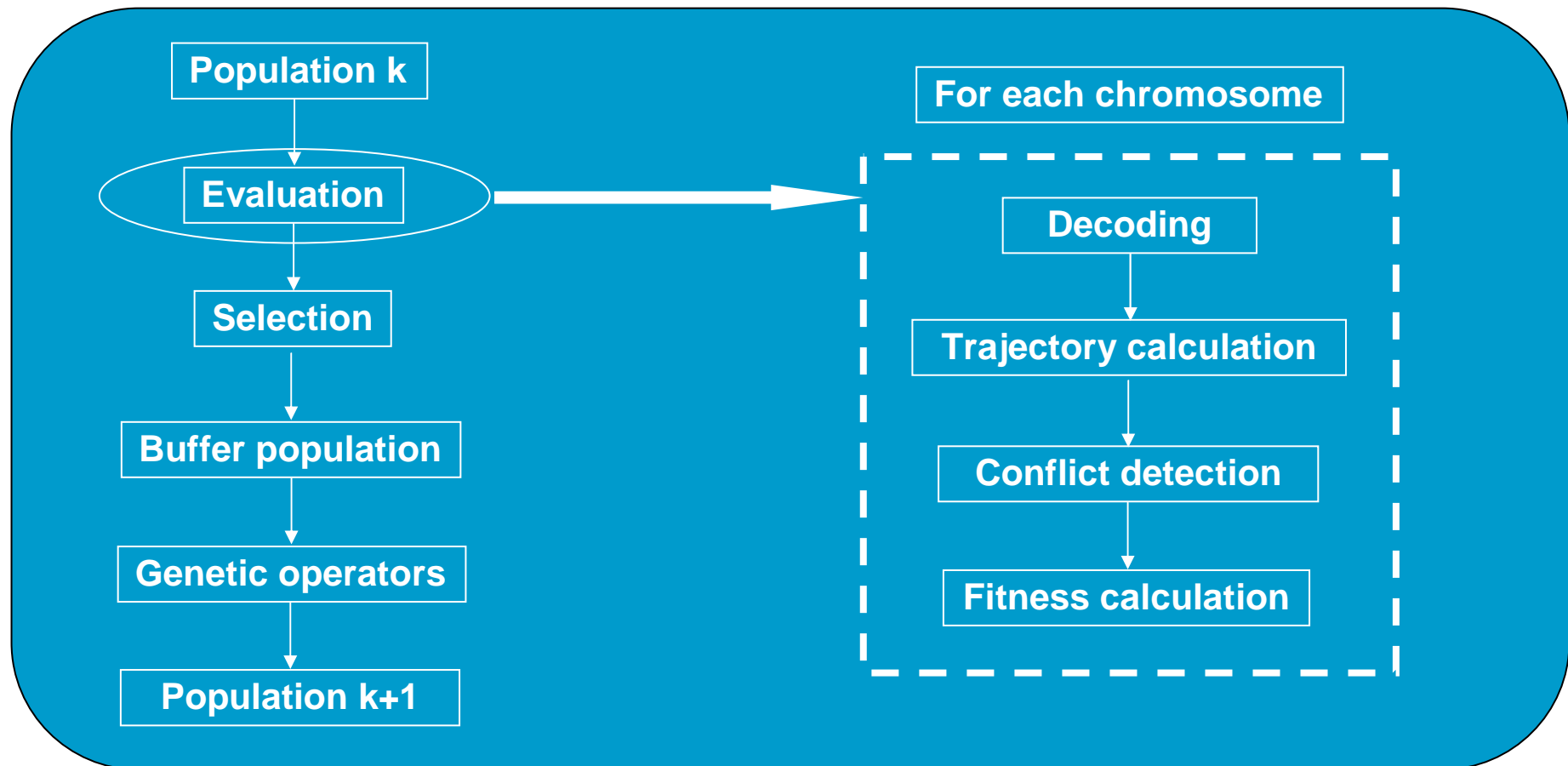
Two steps:

1. Fill each cell with entry and exit time for each airplane
2. Check for time conflict the eight neighboring cells for each cell

- Allows us to calculate each chromosome fitness

Optimization method: genetic algorithm

Summary



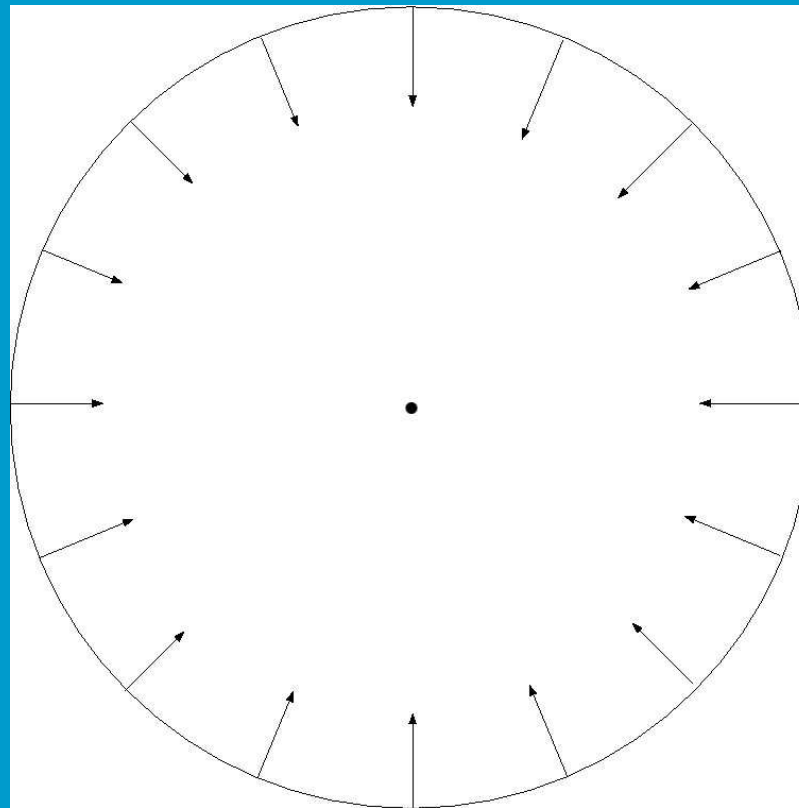


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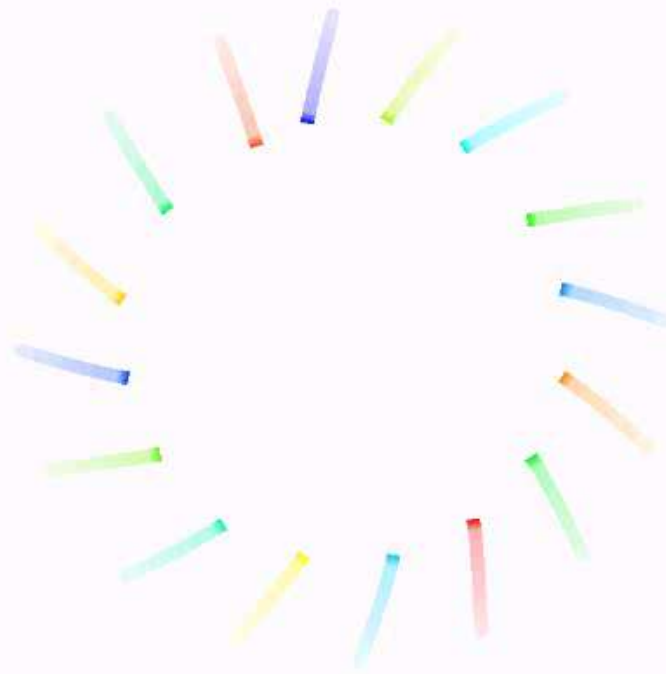
Numerical results

The roundabout test problem



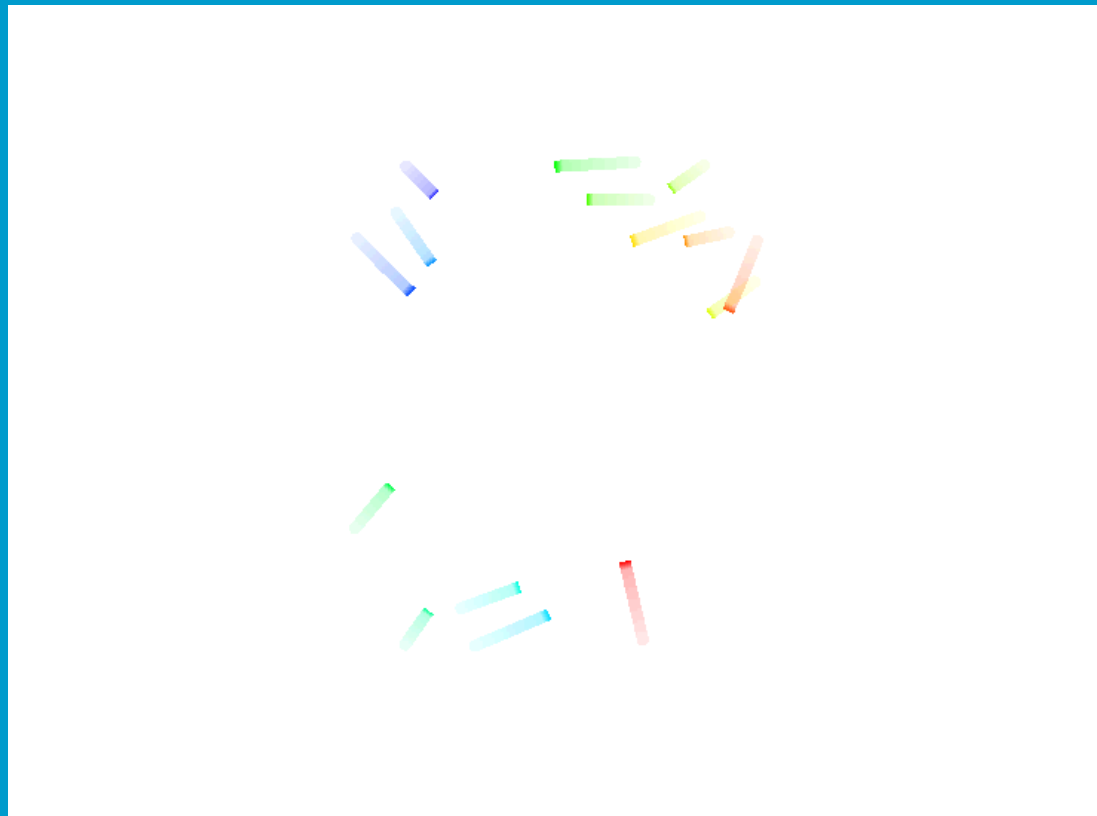
Numerical results

The roundabout test problem



Numerical results

An operational situation





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Applications

Two approaches

- Synthesize trajectories from airport-to-airport.
- Plug our conflict solver to a cluster algorithm.
- Not yet operationnal :
 - Full automation strategy,
 - Trajectory unrealizable for controllers.

Solutions?

- Keep several possible solutions of conflict resolution.
- Create a trajectory transformation to fit controllers' expactations.

Conclusion and perspectives

Conclusions

- The combination between B-splines and optimization method is promising for conflict resolution.
- Our methodology obtains encouraging results on theoretical and operational situations.
- Many researches can be lead from this preliminary work.

Perspectives

- Improve our GA using sophisticated operators
- Try other trajectory model
- Try other optimization methods such as DFO



**Thanks for your attention,
Questions?**

