Aircraft Conflict Resolution by Genetic Algorithm and B-Spline Approximation

ENRI/EIWAC Workshop 2010

D. Delahaye, C.Peyronne, M.Mongeau, S.Puechmorel

Applied Math Laboratory, ENAC, Capgemini, IMT (Toulouse Mathematical Institute)

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Agenda

- Context
- What is our approach ?
- Trajectory model: B-splines
- Optimization method: Genetic Algorithm
- Results

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Air traffic management context

Environment

- 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.

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Air Traffic Management requirements

- Aircraft Separation,
- Staying close to the original trajectory.

NextGen and SESAR Context

- 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

Previous related works: Navigation Functions

How does it work ?

- The Navigation Function produces a potential field which drives the aircraft toward the destination and away from obstacles,

Previous related works: Navigation Functions

Benefits

- Provable convergence to a desired configuration,
- Guaranteed collision avoidance.

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Drawbacks

It does not take into account constraints present in ATC such as:

- Bounded velocity,
- Smoothness requirement for the path.

Previous related works: Genetic Algorithm

How does it work ?

Two types of simple maneuvers are used :

- The Turning point model:
- The Offset model:

Operation of crossover and mutation are applied to the initial trajectories.

Previous related works: Genetic Algorithm

Benefits

- Generates path with feasible operational maneuvers (ATC),
- The magnitude of the speed is within a bounded range.

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Drawbacks

- Is able to manage a limited set of trajectories (straight line segments).

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What is our approach ?

Our objective

- Generate N aircrafts trajectories for an en-route conflict situation,
- Conflict-free trajectories,
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Optimization problem features

- A full-automation strategy.
- The conflict resolution has been proven NP-hard,
- No derivative available,
- Black box stochastic global optimization well suited.
- B-splines allows to reduce the solution space dimension.

What is our approach ?

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**

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Data and constraints

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

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Trajectory model

- Start and end points

Trajectory model

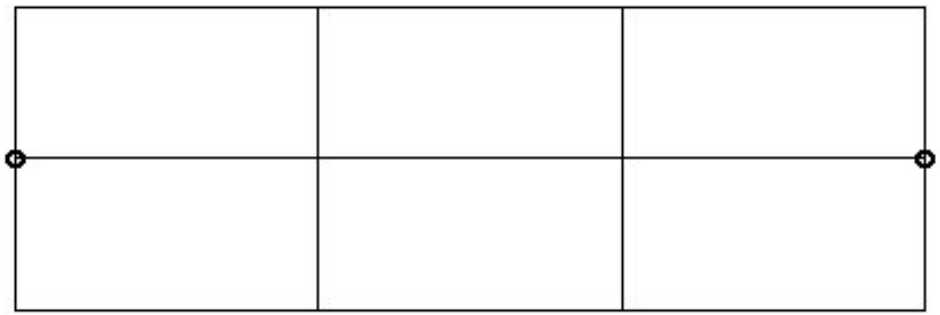
- Business trajectory

Trajectory model

- Maximum deviation bandwidth

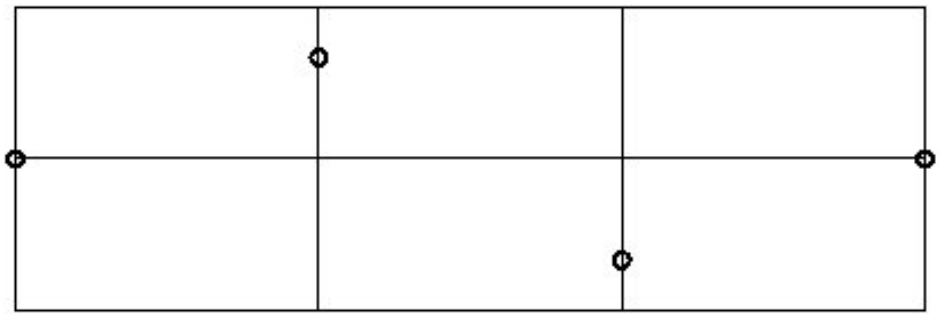
Trajectory model

- Uniformly distributed control points along the trajectory



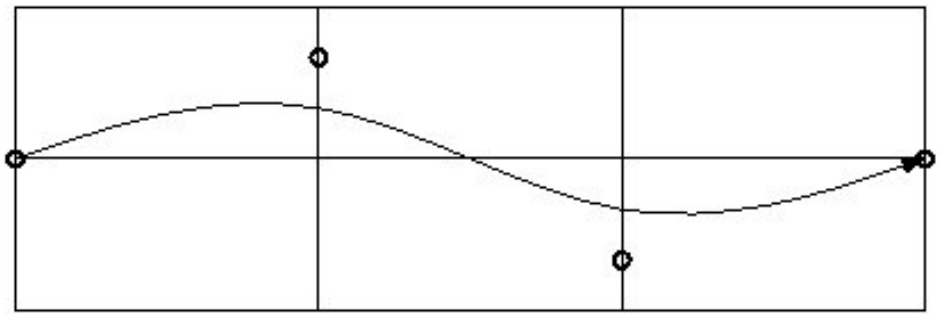
Trajectory model

- Location of the control points



Trajectory model

- Corresponding B-splines



B-splines benefits

- A very efficient tool for curve approximation,
- $\mathcal{C}^2$-continuity (crucial for modeling fliable aircraft trajectories),
- Allows to reduce the solution space dimension,
- A good compatibility with GA requirements.

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Optimization method: Genetic Algorithm

- A solution space's individual is encoded in a chromosome.

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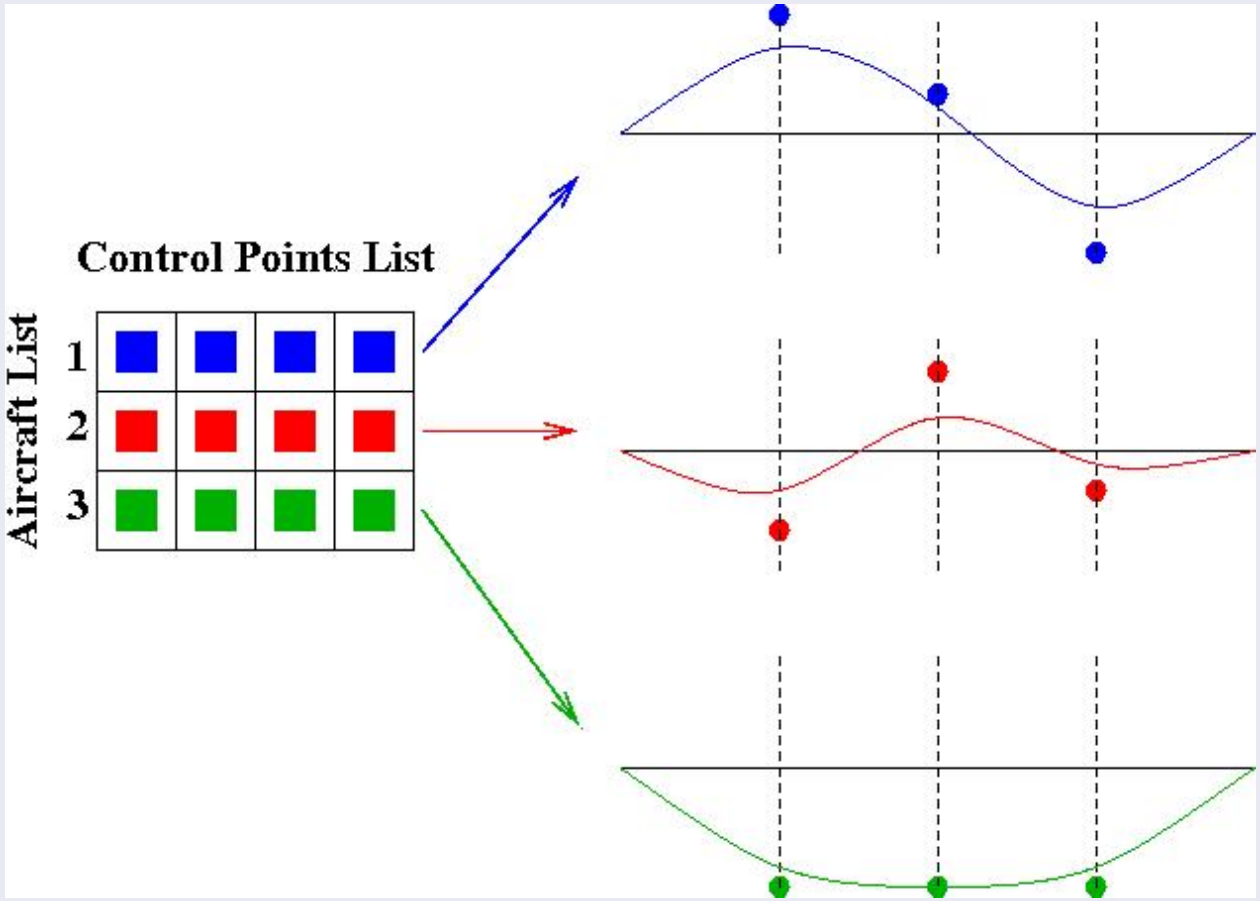
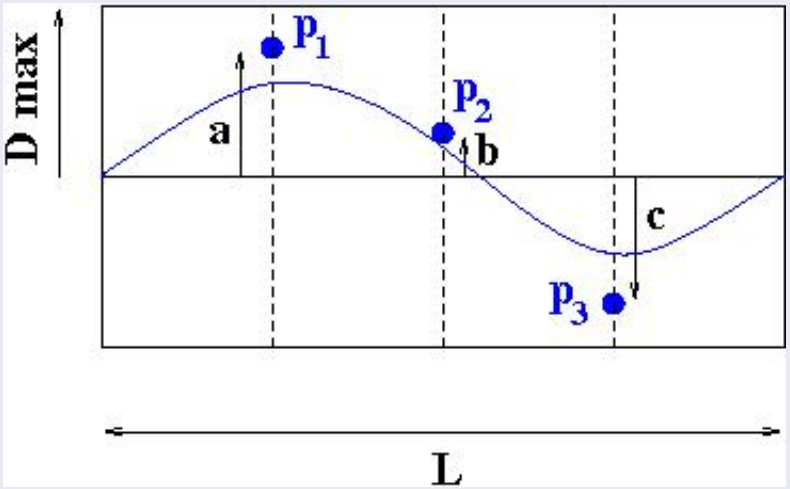
- A solution space's individual is encoded in a chromosome.
- Definition of the encoding for an example $N = 20$ and $Nb_{pt} = 3$:



Optimization method: Genetic Algorithm

- Each point is defined by a bandwidth percentage:



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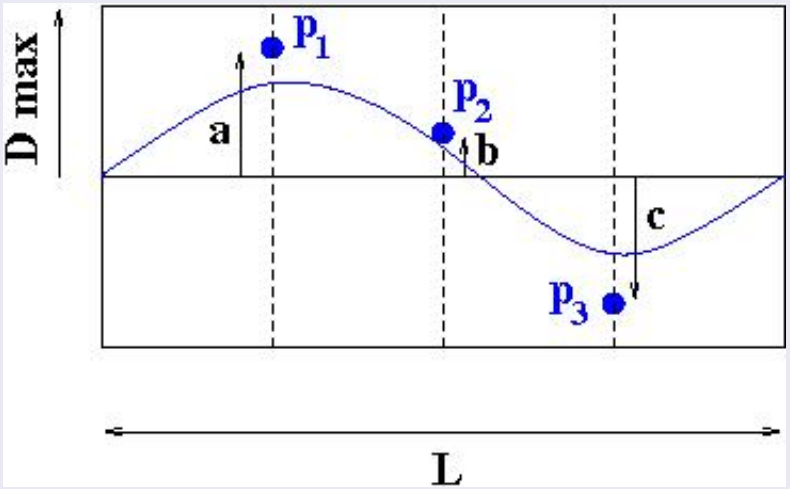

- Example: $P_1^1 = \frac{a}{D_{max}}$, $P_2^1 = \frac{b}{D_{max}}$ and $P_3^1 = \frac{c}{D_{max}}$

Optimization method: Genetic Algorithm

- A population of solution (chromosome) evolves using evolution concepts

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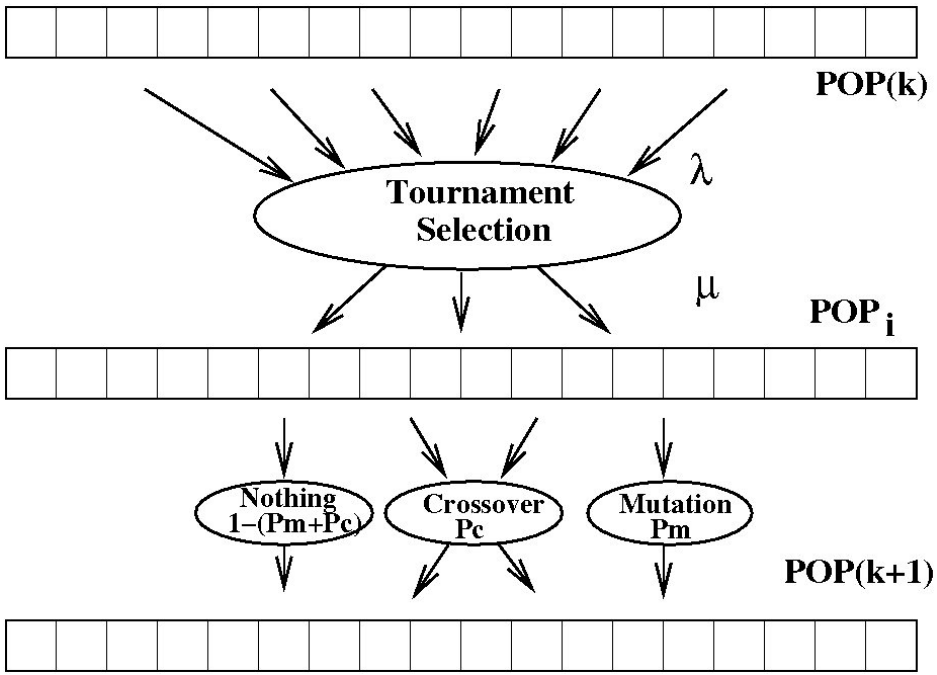
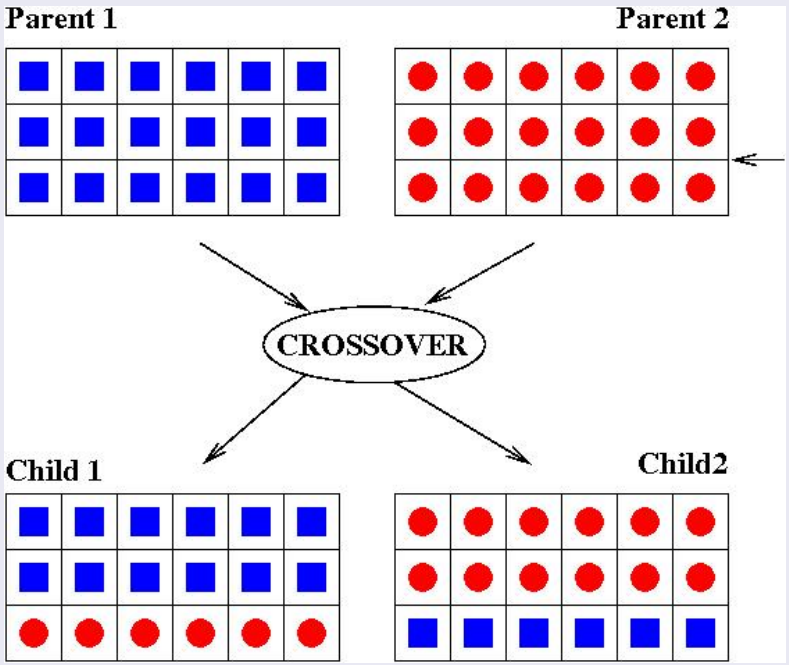
- Evolution from generation k to $k+1$

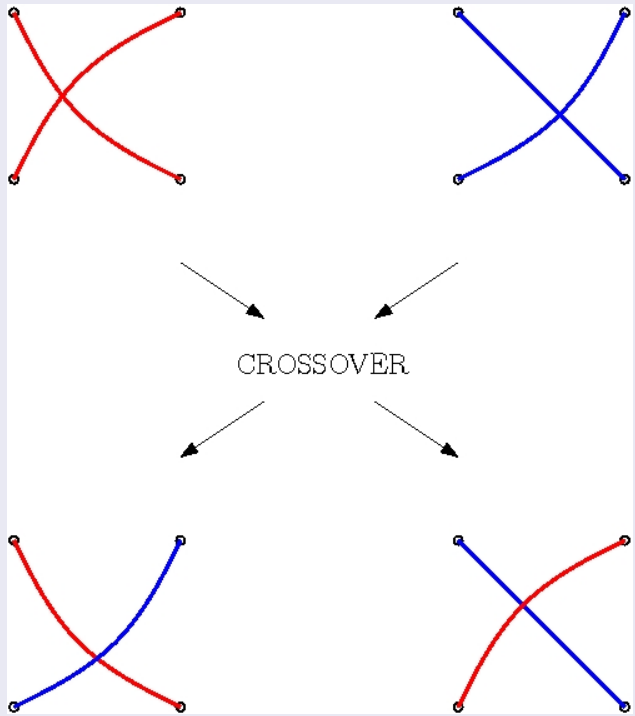


Genetic Algorithm : Operators

Slicing crossover

Aims to exploit the good solutions

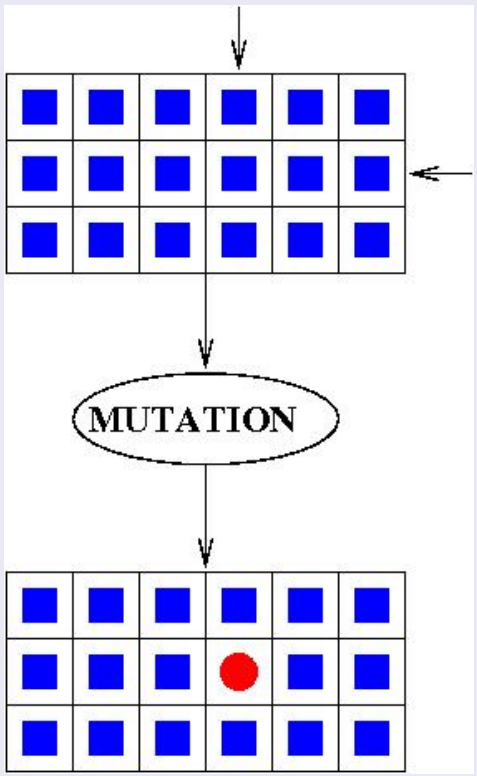


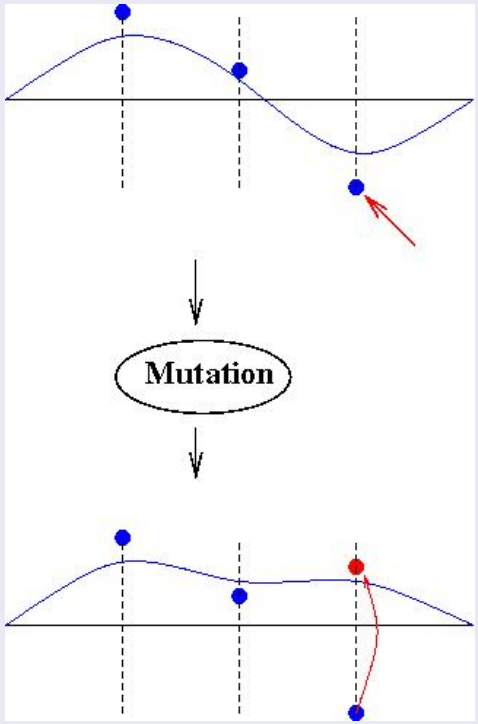


Genetic Algorithm Operators

Mutation

Aims to explore randomly the solution space





Optimization method: Genetic Algorithm

Chromosome evaluation

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

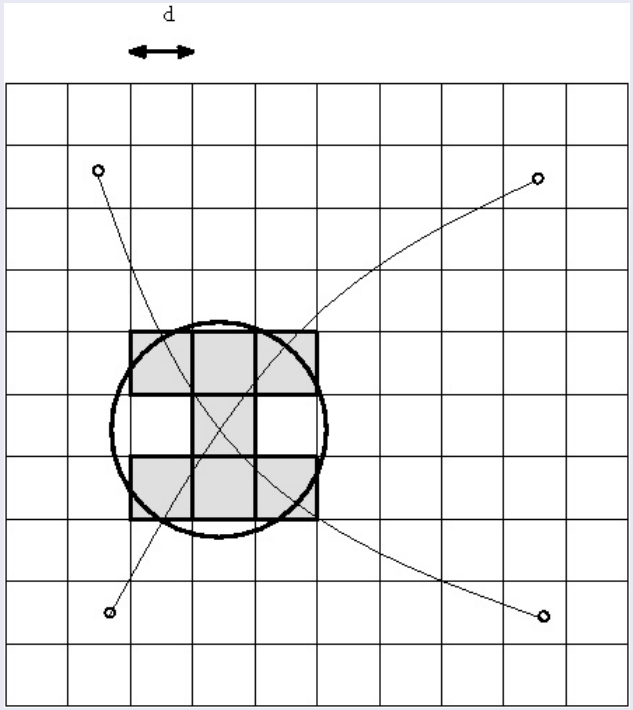
$$f(X) = -\sum_{i=1}^{n}(\alpha.CN_i + \beta.(\frac{dist(NR_i)}{dist(BT_i)}))$$

- where CN_i is the conflict number involving the aircraft i
  NR is the new route corresponding the aircraft i
  BT is the business trajectory

Optimization method: Genetic Algorithm

Conflict detection

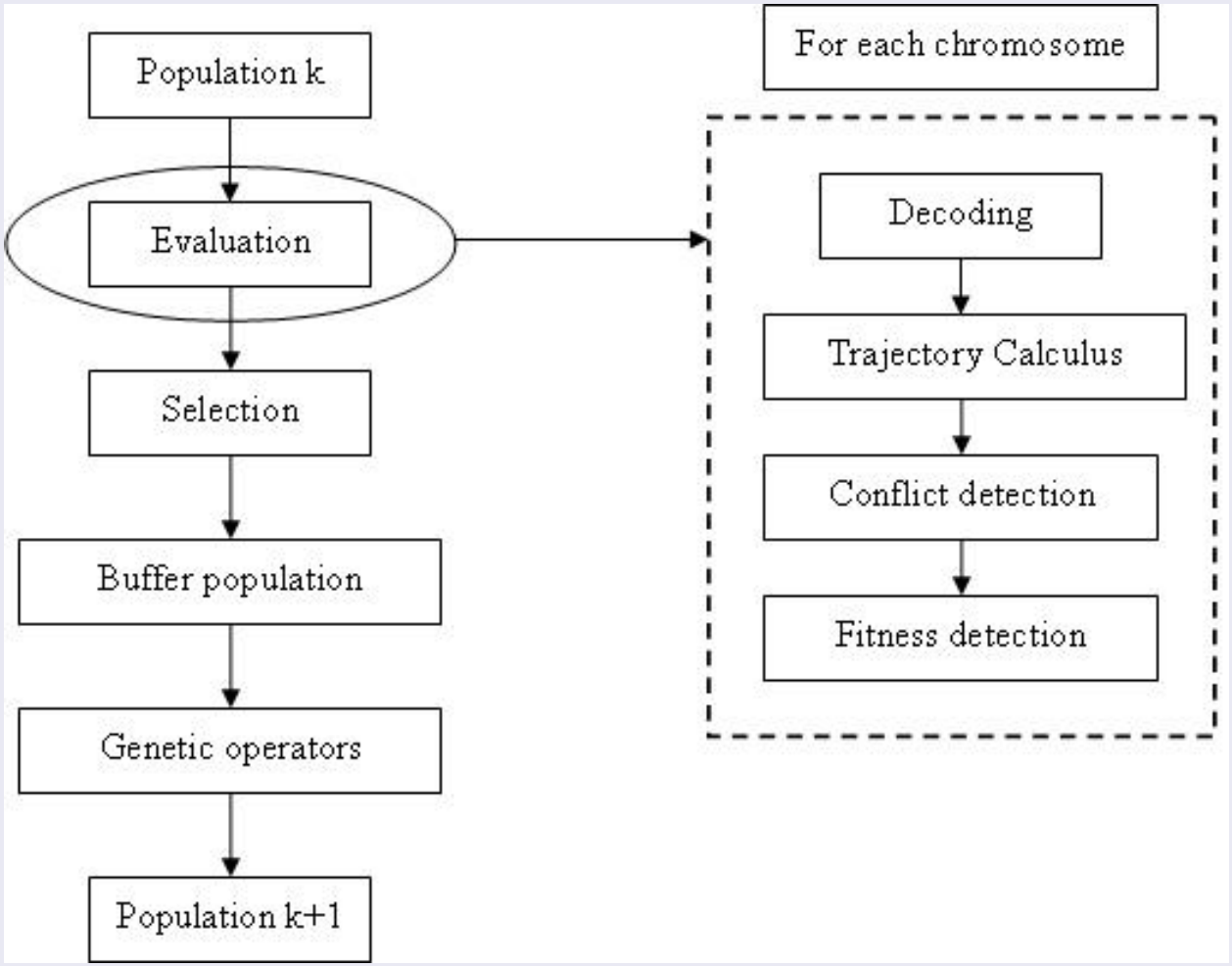
- Two-aircraft scheme:



- Allows us to calculate each chromosome fitness

Optimization method: Genetic Algorithm

Summary



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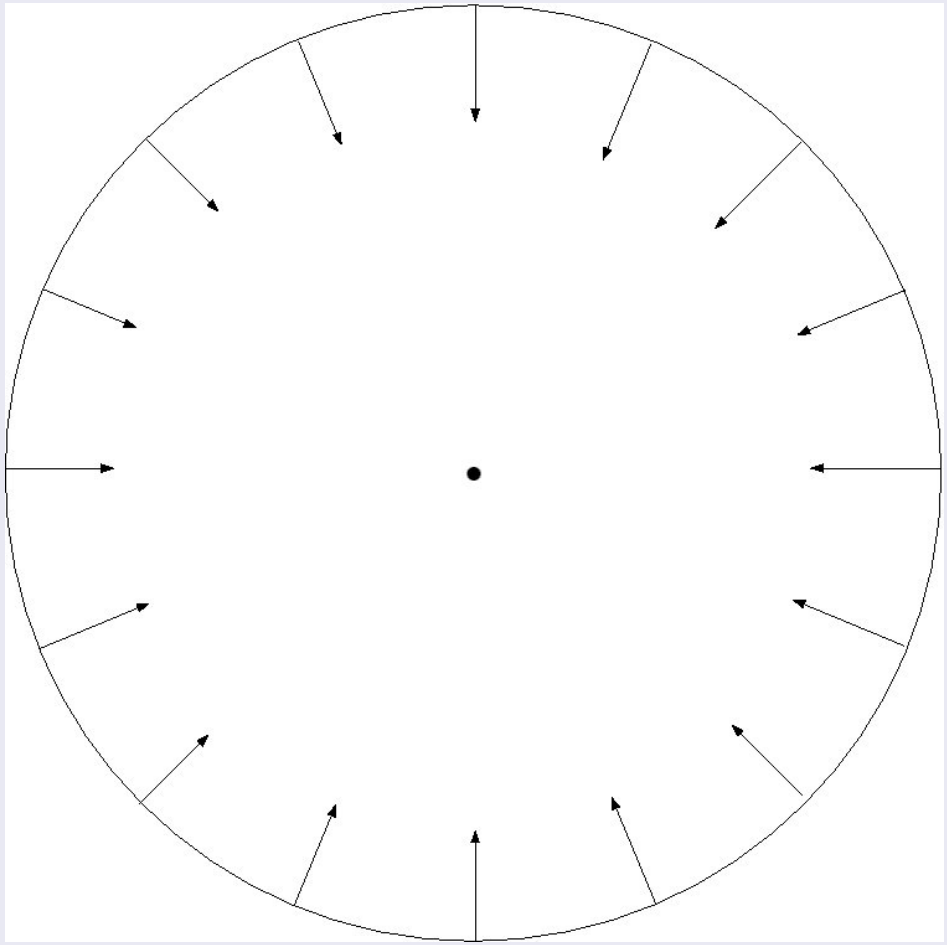
Roundabout test problem



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Perspectives

- Improve our GA using sofisticated operators.
- Try B-splines under tension.
- Try other direct optimization method.

Thank you for your attention,
Questions?