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ART1 Neural Networks for Air Space Sectoring

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ABSTRACT
In this paper it have been shown that how ARTMAP (ART1) neural networks can be used to compute automatically a balanced sectoring of airspace to increase air traffic control capacity in high density airspace area. Crossing points between two airports may generate conflicts between two aircrafts when their trajectories converge on it at the same time and induce a risk of collision.

General Terms
ART1, neural networks, unsupervised learning, air space sectoring

Keywords
ARTMAP neural network, air traffic control, air space sectoring, collision avoidance

1. INTRODUCTION
Many approaches to the problem discussed have been proposed in [1]. Delahaye et al. applied genetic algorithms for regrouping of sectors [2], [3], [4]. They set up artificial scenarios, which simplified the air traffic into networks with major routes and intersections, and finally grouped the modeled networks. There is still no evidence that such algorithms would work in practice because no one has applied these approaches to real traffic.

Genetic algorithms for conflict resolution have given good results [5], [6]. When joining two airports, an aircraft must follow routes and beacons. These beacons are necessary for pilots to know their position during navigation and because of the small number of beacons on the ground they often represent crossing points of different airways. A try based on fuzzy logic and expert knowledge had been developed [7], for which daily operational data about decisions of experts were used. “if then” rules were found and automation decision tool was developed and produced good results compared with real data [8].

Generally at the dawn of civil aviation, pilots resolved conflicts themselves [9], because they always flew in fine weather conditions i.e. good visibility. On the other hand modern jet aircraft do not enable pilots to resolve conflicts because of their high speed and their ability to fly with bad visibility. Therefore pilots must be helped by air traffic controller on the ground that has a global view of the current air traffic distribution in the airspace and can give orders to the pilots to avoid collisions.

But when many aircrafts simultaneously present in the space, a single controller is not able to manage all the traffic. In most of the countries, airspace is partitioned into different sectors, each of them being assigned to an air traffic controller. Sectoring is done in an empirical way by some airspace experts who apply rules they have learned with experience. After a time every sector when overloaded must be modified as soon as possible usually due to traffic congestion. One can try to improve and complete the process of sectoring with an automatic approach in order to give a solution to the sectoring problem in the whole airspace and that can be later refined by experts. In this paper it is shown that how well ARTMAP Neural Networks (ART1) [10], [11] manage the problem after some relevant simplifications. Earlier this approach has successfully been applied for air traffic runway allocation and collision avoidance [19], [20].

2. A SIMPLIFIED MODEL

2.1 Introduction
Since it is very long to train an air traffic controller on his sector (3 to 4 months), it must not be investigated a real time sectoring optimization according to the variations of the traffic load. Instead a registered maximum loads traffic period on the working network is considered. The problem is then to partition the air space to get a balanced control workload. When examining the physical air traffic network, it is noted that airways are superposition of several routes which have the same projection on the floor but different altitudes according to their semi circular rule, an airway can be modeled by a bidirectional link which gathers several individual aircraft routes (Fig 1). Further three dimensional transportation networks will be modeled by a classical two dimensional network on a horizontal plane.

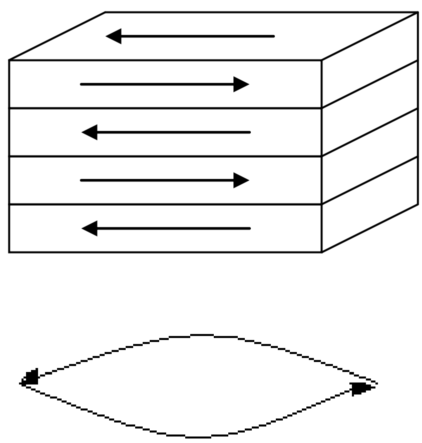

Fig 1: Airways Modeling

The controller workload has several origins that can be divided into two categories:

2.1.1 Quantitative factors
This includes the number of flights, the numbers of conflicts etc. which can be precisely modeled in a mathematical way and handled by an optimization algorithm.

2.1.2 Psychological factors
This includes like stress, concentration etc. which have no evident mathematical formulation but are in direct relationship with the previous ones according to the controllers themselves.

Here only quantitative elements have been considered. Having now a model, goals can be defined more precisely in the following way:

An air traffic transportation network is considered in a 2 dimensional space with flows on it inducing workload distributed over the space. This workload must be equilibrated convex sectors in a way that minimizes coordination. This sectoring must take some constraints into account, coming from air traffic control system:

1-A pilot must not encounter twice the same controller during his flight to prevent useless coordination; this means that an aircraft crossing a sector will encounter only 2 and only two sector frontiers. To guarantee that sectors met this constraint it is forced them to be convex in the topological sense. This constraint gives a sector polygonal shape.

2-A sector frontier has to be at least at a given distance from each network node (safety constraint). As a matter of fact, when a controller has to solve a conflict, he needs a minimum of time to elaborate a solution. Each controller managing individually his sector, if a sector frontier is too close to a crossing point, he is not able to solve any conflict because he has not enough time between coordination step (with the previous sector where the aircraft comes from) and the time the aircraft reaches the crossing point. The minimum delay time is fixed at nine minutes

ad can be converted into a distance knowing the aircraft speed.

3-An aircraft has to stay at least a given amount of time (9 minutes) in each sector it crosses to give enough time to the controller to manage the flight in good conditions (min stay time constraint). This constraint by a minimum distance between two frontiers cutting the same network link.

The last two constraints will be implemented the same way by forcing a minimum length for any link segment between two consecutive frontiers or between a node and frontier.

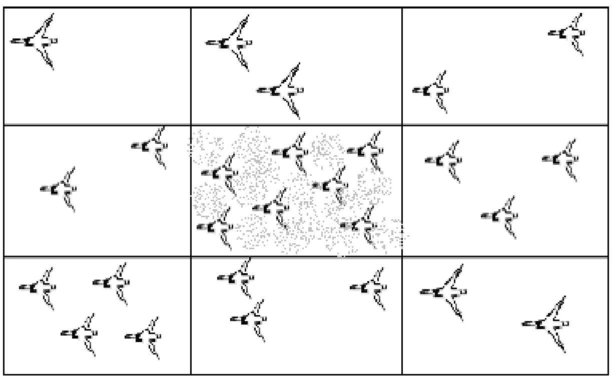

Fig.2: Example of Network Sectoring with 9 sectors

2.2 Mathematical Formulation

2.2.1 Transportation Network

Transportation network is defined as a doublet (N,L) in which N is the set of nodes (with their positions in topological space) and L is the set of links each of them transporting a quantity $f_{i,j}$ of flow from node i to node j [12].

2.2.2 Construction of Sectors

According to the previous section, the sectors to build is to be convex (with a polygonal shape included by the convexity property). To reach this goal Forgy aggregation method is used coming from dynamic clustering in exploratory statistics which aims at extracting clusters from a set of points randomly distributed in a topological space [13]. This method randomly throws K points (the class centers) in the space domain containing the transportation network and aggregates all domain points to their nearest class centers. This method ends up in a K partitioning of our domain into convex sectors with linear frontiers. Figure 3 gives an example of 5 partitioning of a rectangle.

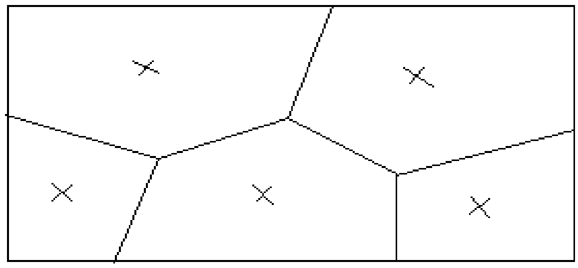

Fig 3: Example of a 5 partitioning

2.2.3 Workload Induced in a Control Sector

Here quantitative criterions are taken into account to compute controller’s workload [14]. According to the controllers themselves, workload can be divided into three parts which correspond respectively to the conflict workload, the coordination workload, and the trajectories monitoring workload of the different aircraft which are present in a sector. The conflict gathers with different actions of the controller to solve conflicts. The monitoring aims at checking the different trajectories of the aircraft present in the sector and induce the workload.

2.2.4 Constraints

Different constraints previously introduced are handled in the following way:

Sector Convexity: This constraint is already satisfied by the construction method of sectors.

Safety and Minimum stay time constraints: Those two constraints can be synthesized by an artificial increase of the coordination workload on links.

In figure 4 we give some examples where the three previous constraints are not satisfied.

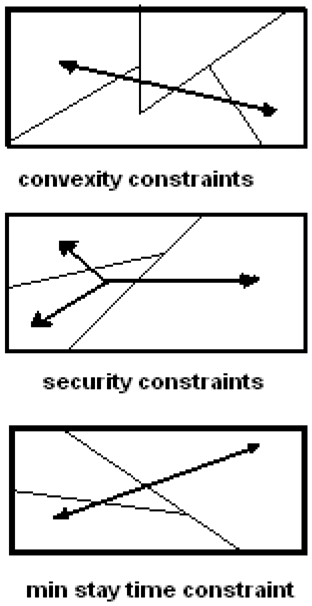

Fig 4: Constraints Examples [17]

3. PRINCIPLE OF RESOLUTION

3.1 Complexity of our problem

The problem which is to be solved can be divided in two different parts corresponding to different goals:

1-Equilibrium of the different sectors workload according to the number of aircrafts and conflicts in each sector.

2- Minimization of the coordination workload.

The second criterion is typically a discrete graph partitioning problem with topological constraints and then is NP_HARD [15]. Having chosen a continuous flow representation the first criterion the discrete continuous problem which is also NP_HARD.

So according to the size of our network (about one thousand nodes), classical combinatorial optimization is not relevant and stochastic optimization seems to be more suitable. Moreover this kind of problem may have several optimal solutions(or near optimal) due to the different possible symmetries in the topological space etc. and one must be able to find all of them because they have to be refined by experts and not known at this step which one is really the best. This last point makes rejection of classical simulated re-annealing optimization which updates only one state variable, even if it might give better results in some cases [16].

On the other hand ARTMAP Neural network (ART1) [10], [11] maintain and improve a numerous population of states variable according to their fitness and will be able to find several optimal (or near optimal) solutions. Then, ART1 seems to be relevant to solve our sectoring problem.

4. RESULTS

This method has been successively applied to different kind of networks with several hundred nodes. To investigate the performance of the algorithm, a series of networks with exact solutions have been used. In all cases, the expected exact solution have been found but sometime further exact solution have been discovered by the sharing mechanisms. Figures 5 & Figure 6, represent two test networks with exact solutions (324 nodes and 400 nodes respectively).

In the first one, an exact solution with 81 components can be identified (this symmetrical solution is trivial for a human being because of our brain ability to investigate symmetries); in the second one an exact solution with 100 components has been hidden in this random network. From the computer, both networks represent the same difficulty but for a human being the first one is much easier. The associated ART1 neural network parameters are the followings:

L = 45
ρ =0.9 (low vigilance), 0.4(low vigilance)
Initialize weights:
$b_{ij}(0)$ =0.2
$t_{ji}(0)$ = 1

Nine sectors in airspace are used, each sector is presented as an input pattern one by one in a sequence and the top down weight matrix is updated. The sector sequence is defined as the:

0001- Sector1 (s1)
0010- Sector 2 (s2)
0011- Sector 3 (s3)
0100- Sector 4 (s4)
0101- Sector 5 (s5)
0110- Sector 6 (s6)
0111- Sector 7 (s7)
1000- Sector 8 (s8)
1001- Sector 9 (s9)

The associated fitness evolution for high vigilance parameter (series-1) and low vigilance parameter (series-2) for each iteration is given in Figure 7 for the symmetrical network and on Figure 8 for the random network. In both cases, the fitness reaches “1.0” which is the optimum according to the fitness calculations [17]. The execution time was about of 25 minutes for both networks on a Dual Core Pentium processor **(**2.0 GHz).

5. CONCLUSION

This study showed that how ART1 is suitable to solve the space sectoring problem with very special constraints. To reach this aim ART1 concept of vigilance parameter is changed from low to high. This modification really improved the algorithm performances regarding the resolution speed and the result accuracy. This change brought good improvements to the algorithm convergence rate. Like in genetic algorithm, the key of success lies in the modeling and the operators. One possibility to improve this algorithm would be to reinforce the Simulated Annealing concept used in the different operators as Goldberg did in his PRSA [18] algorithm (with binary chromosome). This brings in fact some convergence theorems coming from the Simulated Annealing theory.

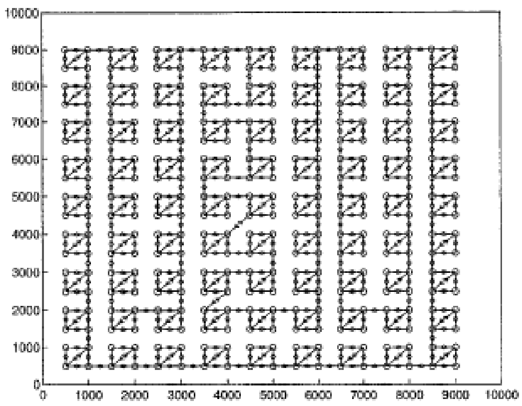

Fig 5: Symmetrical Test Networks [2]

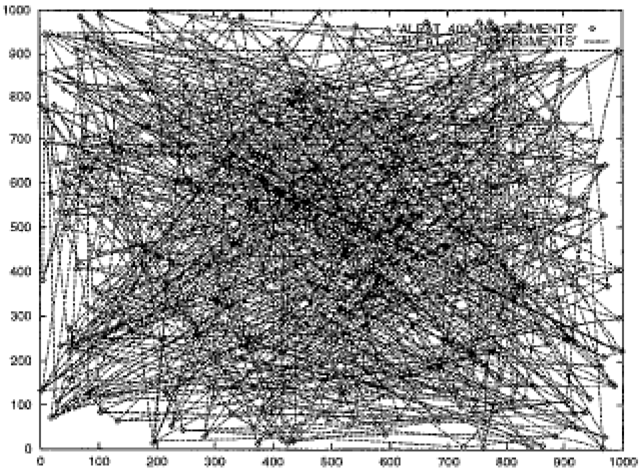

Fig 6: Random Test Network [2]

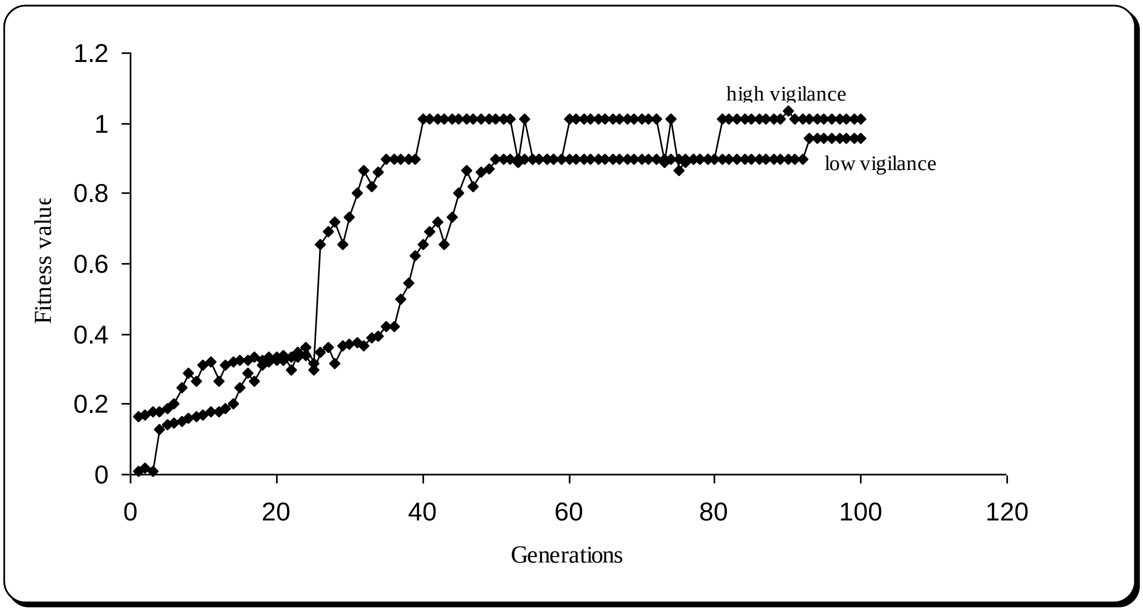

Fig 7: Results for Symmetrical Network

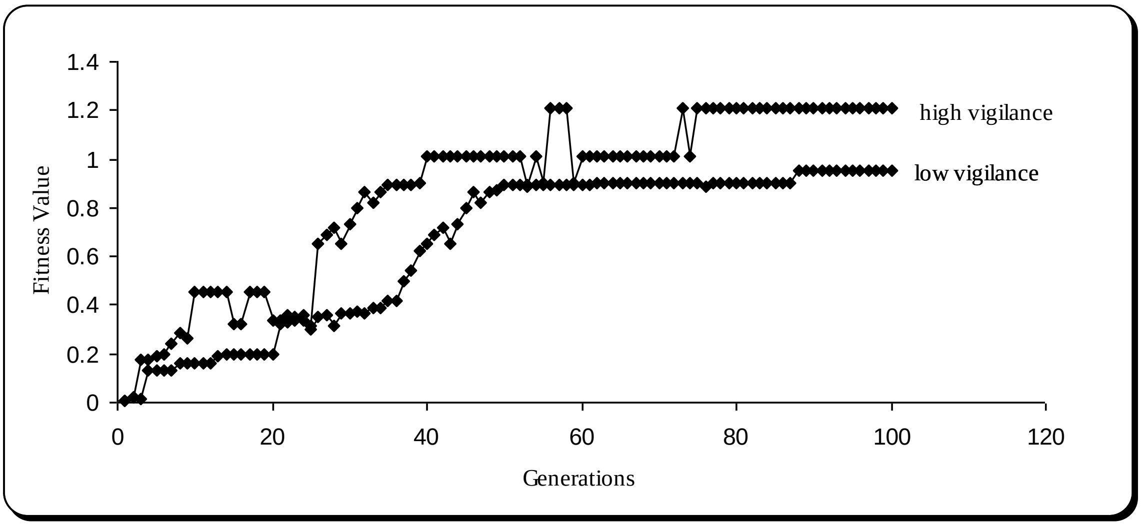

Fig 8: Results for Random Test Network

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