A proposal for our application to the INTAS project (Year of 2004-2005)

A Design of Intelligent and Autonomous Public Transportation System by Co-evolution

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Abstract

Nowadays every big city has its own public transportation system, like the one with city-buses as we can see everywhere all over the world. This article describes a design of such system. Usually, public vehicles follow the pre-set courses with a pre-set schedule determined by human. Our goal is to make each of these vehicles determine autonomously and intelligently by themselves their appropriate behavior such as, what time should it start; which course should it follow; how long should it stay at one stop, and so on. The design will be by co-evolution between the system of transportation versus traffic environment. The latter includes three items: (i) a map of roads which is created randomly at the start; (ii) not-so-intelligent-but-rather-with-random-movement people, like us; and (iii) cars with not so intelligent behavior either. The transportation system evolves to be more and more intelligent while environment evolves to be more and more difficult to be explored.

keywords: *autonomous-intelligent-public-vehicle, road-map-of-evolving-complexity, co-evolution, neural-network, finite-automaton, multi-agent-system, evolutionary-computations, artificial-immune-system, artificial-ants, swarm-intelligence.*

1 INTRODUCTION

One day in late autumn in the year of 2003, at a conference held in Minsk, Kurosh Madani from Paris addressed a question to us.

> *Assume we have two alternatives to fly from Paris to Tokyo: one with human pilot, the other by a totally autonomous navigation system with no human pilot at all. Which would you prefer to choose?*

I want *a monkey with uniform like a pilot* in the cockpit who pretends to navigate the jet in order for the flight to look safe. Still, however, I would rather choose a human pilot at this current stage of development of auto aviation system. Subconscious part of my mind would tell me it's too risky to choose an auto pilot system even with a reliable looking monkey pilot. The jet without pilot, however, is not so difficult technology these days. As a matter of fact, air force in certain countries employs such a system for military purpose practically enough. This article is to tackle probably a more challenging task than a jet-auto-navigation-system, that is, to design a public transportation system in a fairly big town.

Recently I read an article in New York Times which wrote:

> *The private bus service has long been criticized by its customers, by rider advocacy groups, and even by city officials ··· as being shoddy and sporadic ··· But officials at the authority, which currently runs 4,500 city buses and is the largest bus system in the country, insist that it is fully prepared to take over the lines, ··· an authority spokesman said that the takeover was "a challenge we're looking forward to" and that the authority was already studying the private routes in detail. The authority hopes to make the bus routes more efficient, he said, possibly by consolidating some routes that are near one another ··· The transition will be a challenge, but in a year from now I think service will be better," he said. "The M.T.A. runs better service on their lines than the private lines." — from New York Times, 26 April 2004.*

Public transportation problem is already quite an established field, as Pursula [1] wrote in his scientific paper titled *"Simulation of Traffic Systems — An Overview."*

> *During its more than forty years long history computer simulation in traffic analysis has developed from a research tool of limited group of experts to a widely used technology in the research, planning, demonstration and development of traffic systems ··· Road transportation, that is, efficient movement of people and goods through physical road and street networks is a fascinating problem. Traffic systems are characterized by a number of features that make them hard to analyze, control and optimize. The systems often cover wide physical areas, the number of active participants is high, the goals and objectives of the participants are not necessarily parallel with each other or with those of the system operator (system optimum vs. user optimum), and there are many system inputs that are outside the control of the operator and the participants (the weather conditions, the number of users, etc.). In addition, road and street transportation systems are inherently dynamic in nature, that is, the number of units in the system varies according to the time, and with a considerable amount of randomness. The great number of active participants at present at the same time in the system means a great number of simultaneous interactions.*

Sorry for such a long quotation, but how this description is similar to, and thus, well motivates our initially spontaneous idea of evolving a public transportation system! Then what is new of our plan? It is the concept of *Co-evolution* to elaborate the traffic system, which is innovative idea as far as I know, (though I might admit it's quite limited). The co-evolution will be between the transportation system and the geography of the town. Both evolve gradually from a simple one to a complex one, competing with each other.

2 METHODS

We now are going to design a public transportation system which contains N_v public vehicles giving services for N_m passengers/pedestrians among N_c cars, all scattered on a road system in a fictitious town. The system will gradually become an elaborate one via the *co-evolution* with behavior of cars and humans as well as the geographical road system of the town. Cars and humans in the town move using some *biologically-inspired computational techniques.* To be more specific, behaviors of public-vehicles, humans, and other cars will be by either of *Neural Network*, *Finite Automaton*, or whatever else, as three independent *Multi Agent Systems*, which is quite a standard approach these days whatever the combination might be. The town also could have an *Anomaly Detecting System* to detect such as traffic jams, accidents, ... etc, and it will be constructed by *Artificial Immune System*, *Artificial Ant System*, *Swarm Intelligent Particles*, or something like that. In the following sub-sections, each of these concepts is described a little more in detail.

2.1 Co-evolution

In 1991, in the conference called ALIFE-II whose proceedings contain a full of ideas of still very interesting even now, Hillis [2] showed us a very elegant evolution of a sorting network whose goal was to sort out 32 items efficiently, that is, with comparisons as few as possible. He employed a co-evolution between sorting network versus a set of 32 items to be fed to the sorting network. Result suggested that as 32 items evolved to be more and more difficult to be sorted out, while sorting network evolved to be more and more efficient and eventually the network sort any set of 32 items within 60 comparisons, and still we have not known more efficient sorting network. Hence we might say *Co-evolution* found a solution at least as good as a solution found by human.

Since then, this concept of co-evolution has become familiar also in *Evolutionary Computations'* community (see, e.g. Bullock [3] which also gives us not only an excellent survey on *Co-evolution* but discussed it as a computational design technique for Evolutionary Robotics). [1]

In our project, the *co-evolution* will be intended as *multiple bus-like-public-vehicle not intelligent at the beginning* versus *fictitious road map starting with very simple geography.* The road map evolves to be more and more difficult to be controlled, and the transportation system, on the other hand, evolves to be more and more effective, efficient, and safe.

2.2 How the autonomous vehicle will be driven?

Then the first question is, in what way those intelligent autonomous vehicles can be driven? The general concept is that a vehicle is taken as an agent and a population of agents evolves in

[1] The term *Co-evolution* was originally coined by P. R. Ehrlich and P. H. Raven (1964) in their paper *"Butterflies and Plants: A Study in Coevolution. (Evolution 18, pp. 586-608)"* in which authors discussed butterflies and plants interaction as host-enemy co-evolution, though the concept *per ce* had been appeared before, such as in V. G. Dethier's (1954) *"Evolution of Feeding Preferences in Phytophagous Insects. (Evolution 8, pp. 33-54)"*. However, in the context of computational co-evolution, in addition to the Hillis's paper above, D. H. Janzen's (1980) *"When is it Coevolution? (Evolution 34, pp. 611-612)"* is often cited as a landmark because of his redefinition of Ehrlich and Raven's co-evolution. All of these three papers were from an aspect of biological evolution. Then Bullock above discussed co-evolution as a *computational design technique.*

a given environment over many generations and the some of the best agents survive. As such agents we have some alternatives as follows:

Neural-Networks: When I am to try to simulate an autonomous and intelligent vehicle, the first inspiration that flashes through my mind is that we would employ a feed-forward neural networks (NNs) with sensor inputs from the environment and motor outputs to control its wheels to move forward, backward turn right or left and so on. In such a dynamic environment, it is an artificial evolution that we could exploit effectively when we train the neural network, not only its weight but also its architecture if necessary. See Ruppin's [4] paper: *"Evolutionary Autonomous Agents: A neuroscience Perspective"*, for example.

Finite-Automaton: What attracts me more to exploit for the purpose is a *Finite-state Automaton (FAM).* When we evolve FAM aiming to make it some tasks, starting with a very simple structure, it will be very impressive to observe the way it evolves to grow into very sophisticated structures and, as a result, very elaborate behaviors. In the above mentioned proceedings of ALIFE-II conference, we can see many such examples. The most I was impressed was the one by MacLennan [5] in which he created, not a moving objects but, objects who communicate with each other intelligently by growing their structure from generation to generation in a breathtaking way. Thus, we might assume that when we mention "evolving FAM", it implies evolving its structure, while if we are to evolve NNs for that purpose, we have to design chromosomes in somewhat of a tricky way (see for example Stanley et al. [6]).

Artificial Immune System: Lei Wang et al. [7], for example, controlled Khepera robot with 8 infra-red sensors and 2 wheels under *Braitenberg's model* [8] with employing *Artificial Immune System (AIS),* and concluded that *if environment changes dynamically from time to time and effects strongly on the robot's behavior, AIS is theoretically better than the ordinary evolutionary algorithms on the learning capability from its experiences, partly because degeneration issue could be eliminated more quickly than GA since AIS has the function of long-term memory while GA usually can only remember the gene information from its parent generation.* We can see yet another example of controlling its walking of mobile robot by AIS in Ishiguro [9].

Artificial Ant Algorithm: Ant algorithms proposed by Dorigo [10] could also be employed to optimize the courses of our public vehicles, since, as he wrote, *it was originary inspired by the observation of real ant colony's foraging behavior of how ants can find shortest paths between food sources and their nest.* See Di Carlo and Dorigo [11] for an application of this *adaptive multi-agent routing algorithm inspired by ants behavior.* However, I doubt it will not be so easy to control our vehicles by this *Artificial Ant Colony Algorithm* in real-time, if not impossible.

What else? Instead of employing those already exploited techniques mentioned above, it could be also a part of our project to find other innovative methods of controlling our public vehicles.

2.3 What about other cars and human movement?

Then what about other cars and passengers/pedestrians moving around everywhere on the road-map? Behavior of other cars and human should be not so intelligent, like us, in order for the simulation to be more realistic.

Analysis of the Behaviors of drivers have been reported fairly a lot: Unsal [12] proposed three different *human driver models* which were designed for an *automated highway-vehicle systems (AHS)*; Brackstone et al. [13] models *driver behavior* in their *Intelligent Transport Systems (ITS)*; Al-Kaisy et al. [14] evaluated *ITS strategies* by simulating *Lane Changing Rules* of drivers at freeways.

As for behavior of pedestrians, Helbing [17] modeled a *pedestrian dynamics.* [2] He proposed

> *A microsimulation of self-organization phenomena occurring in traffic systems including formation of jammed states in freeway or city traffic as well as the various collective patterns of motion developing in pedestrian crowds like oscillatory changes of the walking direction at narrow passages or round-about traffic at crossings.*

2.4 Evolution of Road-map

In the more recent article, Helbing et al. [18], which was the paper I was most impressed during my survey for this project proposal, casted a question of

> *Whether there is a common underlying dynamics which allows for a generalized description of the formation and evolution of trail systems?*

Authors went on to say,

> *Trails are adapted to the requirements of their users. Frequently used trails become more developed, making them more attractive, whereas rarely used trails vanish again. Trails with large detours become optimized by creating shortcuts. New destinations or entry points are connected to an existing trail system. These dynamical processes occur basically without any common planning or direct communication among the users. Instead, the adaptation process can be understood as a self-organization phenomenon, resulting from the non-linear feedback between the users and the trails.*

Then they proposed

> *A particle-based, multi-agent approach to structure formation using the class of active walkers which subject to fluctuations and influences of their environment, while also the walkers change their environment locally, which in turn influences their further movement and their behavior, in particular changes produced by some walkers can influence other walkers. Hence, the non-linear feedback can be interpreted as an indirect interaction between the active walkers via environmental changes, which may lead to the self-organization of spatial structures.*

[2] In their paper, authors gave us also an excellent survey on what they call *a history of modeling approaches to pedestrian dynamics.* Here, let me pick up three of them: (1) *A. Borgers and H. J. P. Timmermans's (1986) "City Center Entry Points Store Location Patterns and Pedestrian Route Choice Behavior: A Microlevel Simulation Model (Socio-Economic Planning Science 20, pp. 25–31)"* which models the route choice behavior of pedestrians according to pedestrians' demands, their current locations and store location. (2) The model using Navier-Stokes equations of fluid-dynamics to predict pedestrian crowds suggested in *L. F. Henderson's (1974) "On the Fluid Mechanics of Human Crowd Motion (Transportation Research 8, pp. 509–515)".* Furthermore, (3) *A fluid dynamic pedestrian model* uses the basis of a *pedestrian specific Boltzmann-like gas-kinetic model* in *D. Helbing's (1992) "A Fluid-dynamic Model for the Movement of Pedestrians (Complex Systems 6, pp. 391–415)".*

Finally, in the last section

> *An application of the model to the optimization of trail systems.*

was suggested. Wow! How fascinating! This could be almost perfect tool for our public vehicle, not walker though, to co-evolve to form the complicated trail in the town and elegant system of transportation.

2.5 Anomaly detection

Dasgupta [15], for example, designed *a multi agent system for intrusion and/or anomaly detection in a computer network using reinforcement learning of Artificial Immune System (AIS) to sense its dynamic environment, to detect and eliminate pathogens and to memorize them for future recognition. AIS has its ability to adapt to continuously changing environments, dynamically learning the fluid patterns of 'self' and predicting new patterns of 'non-self'.* Why don't we apply this to our public transportation system? In fact Dasgupta wrote:

> *A real environment produces new network traffic continuously in real time. Thus antigens faced by the AIS will be different every day. More importantly, normal behaviors of network traffic on one day, which are considered as self antigens, can be different from normal behaviors of network traffic on another day. Therefore, the AIS needs to be extended, firstly to learn normal behaviors by undergoing only a small subset of self antigens at one time. Secondly its detectors should be replaced whenever previously observed normal behaviors no longer represent current normal behaviors.*

How interesting! If we removed the term *"network"* from the above quotation, it would look like a description of our public transportation system, would it not? He went on to write

> ··· *extended AIS creates new detectors every day after the system experiences new network traffic which has not been presented before.*

2.6 A measure of complexity of a road-map

In order to make the co-evolution work, we need to know the degree to how the road-map which started with a very simple one evolves its complexity. Hence the project should include a proposition of mathematically valid measure of complexity of the road-map. This would be a *fitness function* on the part of road-map, which is, to my (limited) knowledge, still one of open issues.

3 WHAT COULD BE OF OUR INTEREST?

What have described so far is the first stage of the project. Then observation we might be interested in would be as follows.

3.1 Discrepancy between in-screen and on-tabletop

Simulations on a PC screen would be usually more preferable since simulations on a real tabletop would be under very limited resources due to some physical and/or financial reasons. The problem, however, is that it will be more likely to have different results from a real one. Hence, discrepancy between real simulations and the ones in PC, as well as why and how much is the discrepancy, will be one of our important topics.

3.2 Generalization

Could we make the vehicles have a capability of generalization, that is, after learning to be intelligent, do they still could keep the intelligence in a different environment?

3.3 To know "what-could-be" rather than "what-have-been".

This is once very popular phrase in Artificial Life community used by C. Langton (see his preface in the above several times mentioned proceedings of ALIFE II). Such simulation as in this article is also interesting from different aspect like *Civil Engineering* point of view, and in order for us to create a real innovative system, it is sometimes important to forget *what-have-been* but enjoy *what-could-be*.

4 A TOY IMPLEMENTATION

First, we have to design how we make one public transportation vehicle move. This would be by means of, say, a simplest FAM with two states, one sensor input, and two motor output. Second, we design a few passengers, pedestrians, and cars whose behaviors are quasi-random but follows, not perfectly, each of their own behavioral rule and a traffic rule which are determined by us in advance. Each of these objects is not so intelligent and moves also by a simplest FAM. Third, these four different types of objects are put, at the start of a run, on a very simple environment as shown in Figure 1.

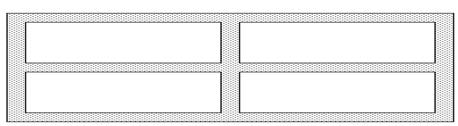

Figure 1: An example of road-map to start evolution with.

Then, all of them start evolution with the goal of increasing their fitness value. The fitness evaluation of evolving road-map is the degree to how they decrease the fitness of the public vehicles.

5 SUMMARY

In short, actually not so short as usual though, our possible sub-topics during the project would be as follows.

- How we design each of those public-vehicles passengers/pedestrians and cars?
- Could we develop a not-exploited-so-far method to control these moving objects?
- How we evolve road system (geography, traffic signals, etc)?
- How we evaluate the fitness of road system (especially the complexity of the map)?
- How we co-evolve transportation system with the road system?
- How we simulate in a real environment (on table-top)?
- Why is simulation in-screen could be different than on-table-top?
- How could our results be applied to a real world traffic system?

Each team in our international collaboration chooses a couple of topics from the above list or other interesting topics, and develops the project independently communicating from time to time with each other via Internet.

They say the competition among INTAS applications to Brussels will be very tough. Even if, however, the proposal will not be accepted unfortunately, we still could proceed the project, though the scale should be a little down-sized. Why not? We have some high quality on-line international conferences these days where no fee for registration, transportation, nor accommodation is needed; we have Internet to communicate with each other. In any case, let's start the project now, whatever the final decision will be, with the goal, for example, being publication(s) of our results in one of high quality international journals.

I now can see hundreds of inspirations are dancing before me. I hope the day will come very soon when we don't need the clever-looking-pilot-monkey in our auto-pilot jet.

6 ACKNOWLEDGMENT

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