

Trace Emergence of Ants' Traffic Flow, based upon Exclusion Process

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Abstract—Biological evolution has generated a rich variety of successful solutions; from nature, optimized strategies can be inspired. One interesting example is the ant colonies, which are able to exhibit a collective intelligence, still that their dynamic is simple. The emergence of different patterns depends on the pheromone trail, leaved by the foragers. It serves as positive feedback mechanism for sharing information.

In this paper, we use the dynamic of TASEP as a model of interaction at a low level of the collective environment in the ant's traffic flow. This work consists of modifying the movement rules of particles "ants" belonging to the TASEP model, so that it adopts with the natural movement of ants. Therefore, as to respect the constraints of having no more than one particle per a given site, and in order to avoid collision within a bidirectional circulation, we suggested two strategies: **decease strategy** and **waiting strategy**. As a third work stage, this is devoted to the study of these two proposed strategies' stability. As a final work stage, we applied the first strategy to the whole environment, in order to get to the emergence of traffic flow, which is a way of learning.

Keywords—Ants system, emergence, exclusion process, pheromone.

I. INTRODUCTION

DIFFERENT species of animals use very sophisticated tools to communicate and assure continuity for their survival. In a similar situation, the environment plays an important role.

Typical examples exist within social insects, such as colony of ants and bees, capable to exhibit very complex spatio-temporal patterns, without centralized control. Indeed, the chemical substance or "the pheromone trail", leaved by the ants in the environment, it attracts the colony's ants to its traces space, and then, insure a best exploitation of their environment [5]-[6].

In this context, the cooperation between individuals in the same colony or between colonies is a fundamental basis [8]. Amongst social insects, ants are the best example; with their cooperation and the communication's system "stigmergy", they arrive at to the food source certainly and return back to the nest with a sophistic system called colonial visa. These chemical substances leaved by ant plays an important role in the formation of complex behaviour emerging at different levels in their life.

Referring to Muller and Channon [13]-[12]-[9], a phenomena is emergent if the dynamic interaction between entities in any system is expressed in a distinct theory different from the theory of observed phenomena.

Another example is the competitive environment, which is different from the social insect environment; *the predators*

employ a best strategy to mark their colony and defend their territory. In this case, the cooperation is familial. Whatever the kind of social insects or prey and predator animals, the emergence of different behaviours in their environment, exhibit a high level of interaction and cooperation proving their survival.

In the last years, the asymmetric simple exclusion process (ASEP) became a very powerful tool of research in many disciplines of science such as, physics [2][3][4], chemistry [1][4] and biology, ...etc. In computer science, few works were done using these processes as a way of dynamic modelling at micro level of complex system. We list as reference the work of Chowdhury and Nishinari [9], who developed particle-hopping models, formulated in terms of a stochastic cellular automaton (CA), interpreted as models of unidirectional and bidirectional traffic flow in an ant-trail. The model generalizes the totally asymmetric simple exclusion process (TASEP) taking into account the effect of the pheromone.

In this paper, we used the dynamic of TASEP as a model of interaction at a low level of the collective environment in the ant's traffic flow. This work consists of modifying the movement rules of particles "ants" belonging to the TASEP model, so that it adopts with the natural movement of ants. So, as to respect the constraints of having no more than one particle per a given site, and then avoid collision within a bidirectional circulation, we suggested two strategies: **decease strategy** and **waiting strategy**. As a third work stage, this is devoted to the study of these two proposed strategies' stability. As a final work stage, we applied the first strategy to the whole environment, in order to get to the emergence of traffic flow, which is a way of learning.

II. AN OVERVIEW OF ASEP AND TASEP

ASEPs, for asymmetric simple exclusion processes are one-dimensional lattice model, with L sites, where particles interact only with hard-core exclusion potential. Each lattice site can be either occupied by a single particle, or empty. During each lapse of time, a particle at the site i attempts to move forward into the up coming site with probability p if the site at the location $(i + 1)$ is empty. At the boundary condition , $i = 1$ and $i = L$ the dynamic is modified as follow; During each lapse of time, a particle is introduced into the system at site 1 with probability α , if it is site is empty, and leave the system at the site L , with probability β .

When the parameter α and β are varied, the model exhibits different phases transition [1][2][3][4] along the line

$p/2$. If $\alpha = p/2$ and $\alpha < \beta$ the model exhibits a second order phase, from the low density to a maximal current phase. When $\beta = p/2$ and $\alpha > \beta$, from a high-density phase to a maximal current phase. When $\alpha = \beta < p/2$, the model exhibits a first order phase transition, from the low density to the high density.

The TASEP “totally asymmetric simple exclusion process” is two parallel one-dimensional lattices, in which particles are moving, and each lattice owns L sites. The dynamic of the system is as follow: A particle at the site i attempts to move from left to right along the same lattice at the site $(i+1)$, if it is not occupied, as it can move to the same site i on the other lattice with probability p if this one is empty. In this situation, if the neighboring site is empty, the probability to move into the site $(i+1)$, is $1 - p$.

At the boundary condition, $i=1$ and $i=L$, the dynamic is as follow: During each lapse of time, a particle enter in the system at a site 1 in every lattice with probability α , if any of the first sites is empty. When a particle reaches site L , it can exit with the probability β when both last sites are occupied. Moreover, with the probability $\beta(1-p)$, if there is no vertical neighbor at the other lattice chain [4].

III. ADAPTATION STAGE

It is the extension and adaptation of the models described previously as TASEP model detailed in [2]-[4], and ASEP in [1]-[3]. The movement of the particles “ants” in our case, according to the Deneunberg model, referenced in [16], every ant located in site (i,j) in the grid can move in the three sites: in front left, front direct or front right.

The movement of ants is canalized into three canals of the traffic flow, as depicted in figure (1). The traffic’s flow management profits from the modified dynamic TASEP, where the principle scope is the inter-particles interaction.

A. The Dynamic

The system consists of three canals of length L , divided into a set of sites (i,j) .

Let $j = 0,1,2$ the three canals, and $i = 1,2,\dots,L$ a set of sites at each canal. The dynamic is random sequential, at any given lapse of time. The traffic flow is bidirectional.

In clockwise direction

- Ants can enter into the system at sites $(1,j)$ if each site is empty with the probability α .
- In the sites (L,j) the ants leave the system when the sites are occupied by a probability β .

In the opposite direction

- Ants can enter into the system at sites (L,j) , if they are empty, with probability α_1 .

- In the sites $(1,j)$, the ants leave the system when the sites are occupied by a probability β_1 .

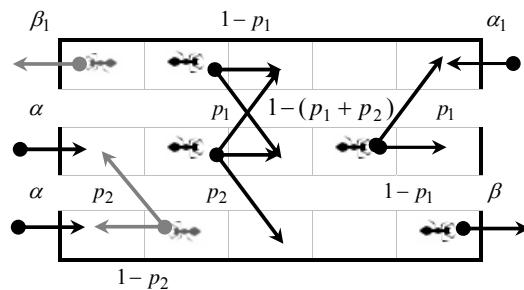
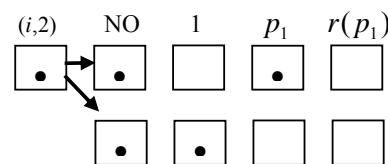


Fig. 1 Representation of the system with three lattices

In the sites, i , $1 < i < L$ the ants' movements are described in clockwise direction as follow:

When $j=2$

An ant located at site $(i,2)$, can move with the probability 1 to the site $(i+1,2)$, when this site is empty. The transition inter-canals, with probability p_1 to the sites $(i+1,1)$. The Fig. 2 shows all the movements’ possibilities.



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Fig. 2 Transitions possibility for the ant located at the left lattice, where r consists of random function. This case can serve for treatment of obstacles

When $j = 1$

An ant located at site $(i,1)$, can move with the probability 1 to the site $(i+1,1)$, when this one is empty and the other locations “front left or right” are occupied. The transition inter-canals, with probability p_1 or p_2 to the sites $(i+1,0)$ or $(i+1,2)$. The Fig. 3 shows all the movements’ possibilities.

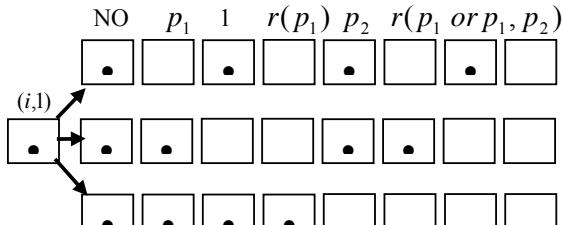
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Fig. 3 Transition possibility for the ant located at the middle lattice, where r consists of random function

When $j = 0$

An ant located at site $(i,0)$, can move with the probability 1 to the site $(i+1,0)$, if this one is empty. The transition intercanals, with probability p_2 to the site $(i+1,0)$. The Fig. 4 shows all the movements' possibilities.

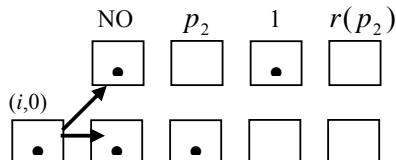
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Fig. 4 Transitions possibility for the ant located at the right lattice, where r consists of random function. This case can serve for treatment of obstacles

IV. NO VIOLATION CONSTRAINTS AND THE OPPOSITE FLOW

The flow in the opposite direction is subjected to the same dynamic, the probabilities of transitions are p_1 and p_2 . The problem is when two ants having different directions confront with each other “pushing”. Two ants approaching each other lean over with a small angle in order to avoid contact and then can pass [6]-[11]. This angle depends on the ant's body orientation and the antennae, which is about 45° .

In [10]. The system is represented with two lattices, which are an extension of ASEP models, and where the traffic is bidirectional with a possibility of migration within canals. In this model, and with presentation of the pheromone trail, when an ant is subjected to collision with another in front of it, this later move to the next location with a probability k .

In our case, we suggest two strategies for the treatment of no violation constraints caused by the opposite flow. These strategies are called the **decease** and the **waiting strategies**.

A. Decease Strategy

Without presentation of pheromone, the hypothesis of the model consists of killing one of the ants causing the collision. The constraint environment consists of a unique ant will be in

a site at a lapse of time. The choice of the ant that dies is based upon the Principle, where an explorer ant will be in a delicate situation to arrive to the food source due to the environmental conditions: obstacles, evaporated pheromones..., etc. In the other hand an ant carrying food returning to the nest has more chances to attempt the nest.

Based upon this principle, an ant that moves in a clockwise direction, when it is in a collision situation must die. Assuming that, the boundary conditions of the system, sites $(1, j)$ and (L, j) , are the nest and the food source. The dynamic of traffic flow in a clockwise direction depends on the parameters α and β , and the other traffic depends on the parameters α_1 and β_1 with ,

$$\begin{cases} \alpha = \alpha\beta \\ \beta = \alpha \end{cases} \quad (1)$$

The choice of the system parameters is based on the fact that explorer ants, which find the source food have a probability to turn back to the nest (carrying food), depend upon the parameter α and β . The ants enter the nest with the same probability of their existence in exploratory phase, which is α .

As a second step, we need to find the adequate parameters α and β basing upon the simulation in artificial environment “swarms intelligence”. The different phases are discussed in many references [1]-[2]-[3]-[4].

To avoid the situation that does not fit with the dynamic for which we are looking, and with a similar situation to that in nature. We define two parameters measuring the system efficiency.

Let $NA(t)$ be the accumulated number of ants arriving to the nest and $FA(t)$ the accumulation of ants number arriving to the food source, t represents the progression of simulating time. The scope is to have an equilibrium traffic flow, with neither an empty system nor unidirectional traffic flow, i.e. it is the finding of parameters α and β checking (2).

$$NA(t) \approx FA(t) \quad (2)$$

A1. Simulation of the Strategy

Basing upon a swarming intelligence environment, we develop a platform in order to simulate the strategies. The simulation environment consists of grid $(N \times N)$, constituted of patch agents, which are the sites in our case, and turtle agents which are the ants. In our platform, these turtles can move inside the grid. The results obtained were tested several times, in a simulations going till 300 000 time units, and with different length of lattice from 10 till 100.

At the beginning of the simulation the system, is empty, with randomization in the boundaries of the system, which exhibits different phases. Our goal is not to study different theoretical phases of the system, there is not a mathematical

theory till now and that gives us the exact models [4]. Most of the works are based on simulation, whose scope is the search of order inside the disorder.

In the first strategy, we look for a regular traffic flow of ants in the two directions, taking into consideration the different phases of the system and the observed behaviour.

Assume $p_1 = p_2 = p = 0.3$ and $L = 40$.

- If $\beta = p/2 < \alpha$, from a high density phase to a maximal current phase. The traffic flux converges to a regular flux with $p/2 < \alpha < 1/2$ as depicted in Fig. 5. If α converge towards 1 the system converge to a unique traffic flow with direction counter clockwise.

- If $\alpha = p/2 < \beta$ from a low density phase to a maximal current phase. The system converges to a regular traffic flux with $p/2 < \beta < 1/2$ as depicted in Fig. 6. If β converge towards 1, the system converge to a unique flux of circulation counter clockwise.

- If $\alpha, \beta < p/2$ from a high density to the low density phase. If β converge to 0 the system converge to a unique flow of clockwise direction. If α and β converge to 0 the system is almost empty.

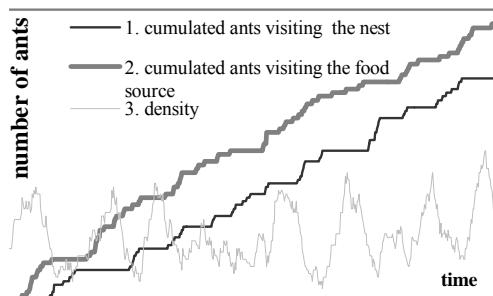


Fig. 5 Graphs (1) and (2) show the cumulated ants, graph (3) shows the density in the system. $\alpha = 0.34$, $\beta \approx \alpha/2 \approx p/2$

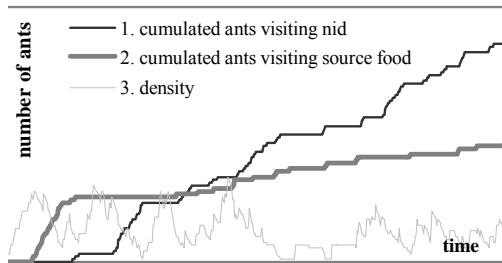


Fig. 6 Graphs (1) and (2) show the cumulated ants, graph (3) shows the density in the system. $\alpha \approx \beta/2 \approx p/2$, $\beta = 0.34$

A2. Strategy Decreases with Pheromone Presence

The dynamic of traffic flow is the same as described in the previous section. The model of the pheromone is based upon the Brückner models [15]. In each lapse of time and each site

in the different lattice in the system the density of the pheromone is increased with,

$$R * \left(\frac{1}{1 - r_e} \right) \quad (3)$$

And limited with,

$$R * |P| * \left(\frac{1}{1 - r_e} \right) * \left(\frac{1}{1 - r_p} \right) \quad (4)$$

Where, R is the limit of an input pheromone, $|P|$ is the number of neighbouring for concerned places, r_e is the evaporated rate and r_p is the propagated rate. The probability of transition between lattices depends upon the pheromone concentration, and it is as described in [7].

At the edge of the system, the probability of transition is as follow:

$$p_i = \frac{e^{\eta c_i}}{\sum_{k=1,2} e^{\eta c_k}} \quad i = 1, 2 \quad (5)$$

Or;

$$p_i = \frac{e^{\eta c_i}}{\sum_{k=0,1} e^{\eta c_k}} \quad i = 0, 1$$

With;

$$p_{select} = \max\{p_i\}$$

$$p_i = \frac{e^{\eta C_i}}{\sum_{K=0,1,2} e^{\eta C_K}} \quad i = 0, 1, 2 \quad (6)$$

With;

$$p_{select} = \max\{p_i\}$$

Where; c_i , c_k and c_j are the pheromone concentration in the concerned vertical sites, η is a parameter.

The steps of the algorithm are:

- Init Phase of different parameters (make the initialized pheromone)
- While the time of simulation is not finished do
 - Evaporate the pheromone with a rate r_e and a limit according to the relation (4)
 - Move the ants with dropping pheromone according to the first model (each ant possess its appropriate probability)

- Propagated the pheromone with a rate r_p

- The input and the output are taken in the canal which vehicles the bidirectional flow.

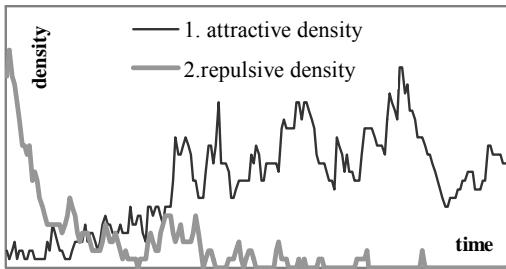


Fig. 7 Graphs (1) and (2) show attractive and repulsive density with pheromone presence and without neither evaporation nor propagation rate. This result is obtained with, $\alpha \approx \beta / 2 \approx p / 2$, $\beta = 0.34$

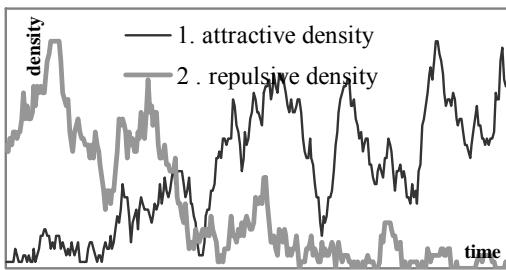


Fig. 8 Graphs (1) and (2) show attractive and repulsive density with pheromone presence, evaporation and propagation rates. This result is obtained with $\alpha \approx \beta / 2 \approx p / 2$, $\beta = 0.34$, $r_e = 0.01$,

$$r_p = 0.01$$

The graphs shown in Fig. 7 and Fig. 8, display the attractive density; the ants follow the pheromone trail, and repulsive density the remained ants. The crossing point between graphs depends on the evaporate rate and propagated rate. The obtained result is similar to those in [14]-[7].

B. Waiting Strategy

Contrary to the first strategy, this one keeps the traffic flux as generated. With the similar situation, it is impossible to have parameters α and β assuring a dynamic interaction without blockage.

For this reason, it is necessary to modify the representation of the Fig. 1, in order to solve the problem of blockage. This second strategy consists of the "superposition" of two models TASEP. The rules below govern the strategy, and are defined as follow:

- The lattice $(i,0)$, vehicles in a counter clockwise flow.
- The other $(i,2)$, vehicles a clockwise flow.
- The canal in the middle vehicles a bidirectional flow.

B1. Simulation of the Strategy

Every ant possesses two characteristics (p_1, p_2) defining the possibility of the transition between lattices. In order to use two models TASEP in a three-lattices system, it is mandatory to associate to each ant that circulates in a clockwise direction, a probability of $(p_1, 0)$ to transit inter-canal, and the other flow in a counter direction a probability of $(0, p_2)$. Keeping the same dynamic as defined in the first strategy, and the same probability of entrance and leaving, respecting the relation (1). The strategy exhibits a dynamic without blockage, when $\beta \neq 0$.

After simulating, we obtained the following results:

- With $\alpha > 1/2$ and $\beta > 1/2$ the dynamics follow the bulk density in the system, which is,

$$(1 + \alpha)/2 \quad (7)$$

- With $\alpha < \beta$ and $\alpha < 1/2$ The system is in the low density phase and bulk density given by,

$$\alpha \quad (8)$$

- With $\beta < \alpha$ and $\beta < 1/2$ The system is in the low density phase and bulk density given by ,

$$\alpha(1 - \beta) \quad (9)$$

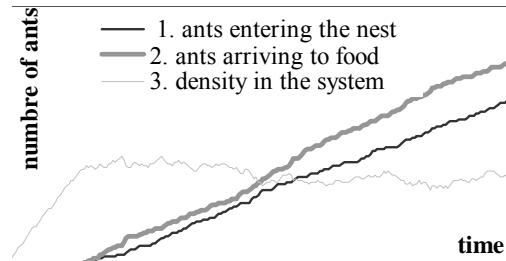


Fig. 9 Graphs (1) and (2) show the cumulated ants, graph (3) shows the density in the system. $\alpha \approx 1$, $\beta \approx 1$

B2. Waiting Strategy with Pheromone Presence

The dynamic of traffic flow is the same as described in the previous section. The model of the pheromone is the same as described in the section "Decease Strategy with pheromone presentation". The transition's probability depends upon the traffic direction.

In clockwise direction:

$$p_i = \frac{e^{\eta c_i}}{\sum_{k=1,2} e^{\eta c_k}} \quad i = 1,2 \quad (10)$$

With;

$$p_{select} = \max\{p_i\} \quad i = 1,2$$

In counter clockwise direction:

$$p_i = \frac{e^{\eta c_i}}{\sum_{k=0,1} e^{\eta c_k}} \quad i = 0,1 \quad (11)$$

With;

$$p_{select} = \max\{p_i\} \quad i = 0,1$$

The lattice in the middle is reinforced with the pheromone concentration, and we can observe that the maximum of traffic circulate through it. The graph of attractive and repulsive density is similar to the one shown in Fig. 7 and Fig. 8.

V. EMERGENCE AS AN APPLICATION

In this case, we are limited into the decease strategy. The aim of the section is how to emerge the same traffic flow as it is described in the previous section, and based upon elementary action described in section (A).

According to PEPPER 1926 Writing many years ago, referenced by Damper in "Emergence and level of abstraction" [9],

"The theory of emergence involves three propositions.

1. That there are levels of existence...
2. That there are marks that distinguish these levels from one another...
3. That it is impossible to deduce marks of a higher level from those of a lower level ..."

To fix ideas, we can give an example that explains the idea of emergence as solution for many problems in complex systems. The example resolves the TSP "Travelling Salesmen Problem" in a swarm intelligence environment [17].

After some time of interaction between ants in the environment, we observe the emergence of pattern as a solution of TSP problem. We have realized this work recently, the cases studied: Number of Towns ≤ 50 . We obtain the emergence at a record time: number of cycle 20 to 30, and the time between 150 and 250 unit of time.

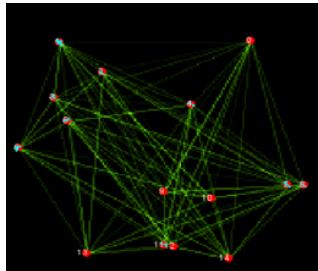


Fig. 10 Initial state with 15 town

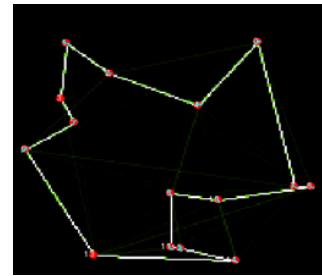


Fig. 11 Emergence of pattern as a solution of problem

Similar to this example, our case studied is the emergence of traffic flow whose dynamic was well explained before. It follows the three propositions cited in [9].

The following figures show the different levels of abstraction.

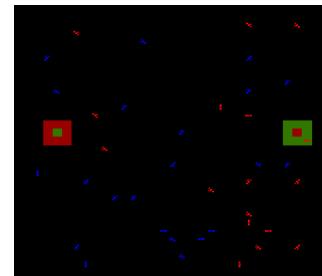


Fig. 12 The environment in initial state shows the nest at the left and the source food at the right, the ants carrying food with red color and, the others with blue color

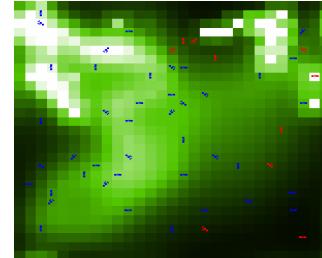


Fig. 13 This figure shows an intermediate phase of interaction, the white and green color show the pheromone concentration

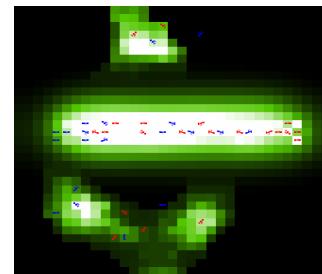


Fig. 14 This figure shows the emergence of pattern in the middle of the image. It consists of the traffic flow between nest and source food. The strategy studied here is the decease strategy

VI. CONCLUSION AND FUTURE WORKS

In this work, we suggest two strategies: decease and waiting strategies, aiming at solving the problem of collision, caused by the interaction between ants in the environment.

We suggest firstly the simple strategy; different phases obtained in the system are similar to those in TASEP models. Our system converges successfully at a regular flow in the natural environment. This dynamic of the flow depends on the model's parameters. The wealthy of the model by the pheromone is to prove that the traffic flow follows the pheromone trail, thereby we emerge the trace proprieties, which depend in the evaporated and propagated rate.

Secondly, we suggest a strategy where the density of traffic flow in the system is kept. Therefore, we obtained the searched dynamic, which depends on the parameters of the strategy. The use of the accumulative parameters, in the boundary of the system, is to show a regular behavior.

Finally we applied the first strategy to the hall environment and therefore we obtained the emergence of traffic similar to the natural environment. As future work we need to compare those strategies and generalize the model overall environment enriched with obstacles.

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