**Noname manuscript No.**
(will be inserted by the editor)

# The Emergence of Transportation Networks

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## 1 Introduction

Transportation networks are clearly critical infrastructures in our society. From a social perspective they create social connectivity, and from an economic point of view they have an enormous impact on a nation's economy and the global economy. There is a substantial amount of literature written about different types of transportation networks, from streets in a city [1], to busses [2] and aeronautical networks [3]. In recent years a new point of view has emerged thanks to the growth in Complex Networks theory [4, 5]. This mathematical tool is of great help in analyzing big structures and in measuring metrics describing their topology. Moreover, time constraints like scheduling or route durations can be easily included [6].

To our best knowledge, only a few works have studied how such transportation networks are born and evolve. Specifically we want to focus in how transportation networks are the emergent result of interactions of agents in a landscape of fitness. This approach is somewhat similar to the work of Yamins *et al.* [7], nevertheless our fitness landscape is not plain, and we do not focus only on urban transportation - the approach we propose can be applied to any kind of transport mode.

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**Fig. 1** Initial fitness landscape. Each agent chooses its initial and destination points randomly, and proportionally of the fitness of each position: black represents low fitness, while white represents maximum fitness.

## 2 Description of the model

Our model proposes that at each time an agent is created and starts, the destination points are assigned. Previous works have assumed that persons are located in cities with infinitesimal dimension. In other words, movements are allowed only from and to some given nodes - see example [8]. This assumption is indeed not realistic, as many people live in areas peripheral to cities or in areas between two urban centers.

To overcome this limitation, a landscape of fitness is created representing both the density of population and the relative attractiveness of an area. This fitness is constructed by adding the contribution of several randomly positioned cities - the field created by each one is a Gaussian function centered in the city itself, and with random deviation. The result represented in Fig. 1 is a better approximation of a real situation.

When an agent is moving, it is creating another landscape behind itself representing the probability for an agent

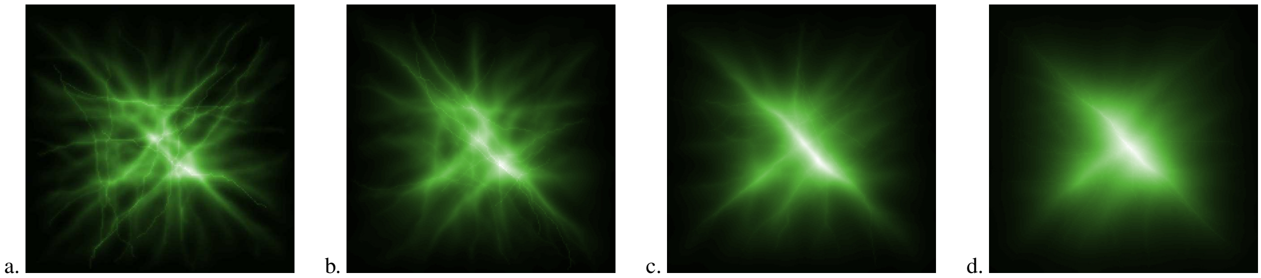

**Fig. 2** Evolution of the landscape of agent movements. The color scale represents the probability for an agent to pass in a zone (black means probability equal to cero). The four figures are the accumulative results for (a) 500, (b) 1000, (c) 2000 and (d) 4000 movements.

to have been in some zone of the space. The movement of each agent is defined at each step by two simple rules. Firstly it points toward its own destination, and secondly it compares the probability landscape of the square where it stands with the neighborhood. If the landscape is higher at its sides, it turns 20 degrees in that direction.

The aim of this second point is to aggregate the movements of agents thus creating preferential paths. Real transportation networks are also created using this kind of mechanism. For example, one can think about aeronautical networks where navigation aids are positioned along the preferred routes, and in turn aircraft utilise those flight paths.

The evolution of the landscape of agent movements can be seen in Fig. 2 for a different number of realizations. At an intermediate point, around 1000 - 2000 movements, a structure clearly arises, this structure is the resulting transportation network, as the emergent behavior of the whole system emerges, and is sketched out in Fig. 3.

## 3 Conclusions

In this work, a new approach is proposed to understand the birth and growth of a transportation network. This network is created according to the emergent behavior of a set of agents, which are trying to move from one point in space to another point in space, interacting with other agents and globally aggregating their movements. Further developments will include a better definition of rules governing the embedding of the probability landscape into the transportation network; more specifically, the resulting graph should minimize some given cost function, like the mean time spent by passengers or the fuel consumption. Moreover, some comparison of our model with data about the evolution of a real transportation network is being planned.

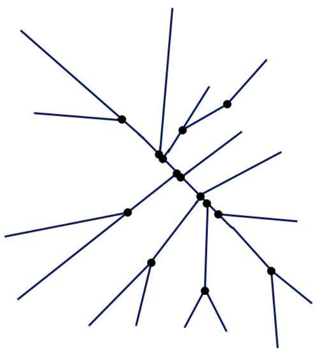

**Fig. 3** Transportation network calculated from the landscape of Fig. 2. This network represents the emerging result of agent movements.

## References


1. M. Rosvall, A. Trusina, P. Minnhagen, K. Sneppen, *Networks and Cities: An Information Perspective*, Physical Review Letters, **94**, (2005).
2. J. Sienkiewicz, J. A. Holyst, *Statistical analysis of 22 public transport networks in Poland*, Physical Review E, **72**, (2005).
3. R. Guimera, S. Mossa, A. Turtschi, L. A. N. Amaral, *The world-wide air transportation network: Anomalous centrality, community structure, and cities global roles*, Proc. Nat. Acad. Sci., **102**, 22 (2005) pp. 7794-7799.
4. S. Boccaletti, V. Latora, Y. Moreno, M. Chavez, D.-U. Hwang, *Complex networks : Structure and dynamics*, Physics Reports, **424**, 4-5 (2006) p. 175–308.
5. L. da F. Costa, O. N. Oliveira, G. Travieso, F. A. Rodrigues, P. R. V. Boas, L. Antiqueira, M. P. Viana, L. E. Correa da Rocha, *Analyzing and Modeling Real-World Phenomena with Complex Networks: A Survey of Applications*, arXiv:0711.3199v2 [physics.soc-ph], (2007).
6. M. Zanin, L. Lacasa, M. Cea, *Dynamics in Scheduled Networks*, Chaos, **19**, (2009) p. 023111.
7. D. Yamins, S. Rasmussen, D. Fogel, *Growing Urban Roads*, Networks and Spatial Economics, **3**, (2003) p. 69–85.
8. M. Zanin, L. Lacasa, M. Cea, S. Cristobal *A Dynamical Model for the Air Transportation Network*, in proc. $23^{rd}$ European Conference of Modelling and Simulation, Madrid, Spain (2009).