Vector Approaches to Urban Morphogenesis Modelling

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1. Introduction

The contemporary city, from the richness of the interactions between architectural programs, with their natural and built environment, and through scales, is a **complex dynamic system** that can be seen as **autogenously organized**. Its development is processed not only in a planned or hierarchical way, but also "horizontally". It becomes extremely difficult to understand and *a fortiori* to control its shape and evolution.

According to Berger and Nouhaud (2004, p.184), *we continue to analyze the city by categories, reducing the object of the study to a juxtaposition of specialized significances which are not sufficient to give a global image of the invention of urban forms.* If we want to be able to control the development of the metropolis (or at least understand it), we need an intelligent system where the city is modelled as a complex system equipped with a cognitive architecture based upon a principle of collective intelligence, by analogy to the functioning of any living organism. Our project aims at developing a software platform for urban morphogenesis simulation based upon architects' expertise. Such a platform will provide efficient decision support, by allowing to assess scenarios, such as impacts induced by new architectural programs.

There is a lot of papers on urban géosimulation, mainly dealing with cellular agents, notably: Arentze et al, 2006), (Batty, 2005), (Benenson and Thorrens, 2004), (Caneparo et al, 2006), (Couclelis, 1997), (Portugali, 2006), (Waddell and Ulfarsson, 2004), etc.. Hammam et al (2003) explained limits of cellular agents which are same as for cellular automata (CA). Our approach is quite innovative as it is based upon multi scale Vector Agent modelling of buildings and their physical neighbourhood, their spatial and topological relationships and their states and behaviours according to modelled dynamic laws of urban morphogenesis from micro level (surfaces in buildings, buildings and programs) to macro level (metropolis).

The purpose of this abstract is to give a brief overview of our project and to present our first results. Section 2 provides a synthetic view of morphogenesis laws which are modelled for simulation. Section 3 gives an overview of our multi-scale vector agent model. Next section (4) shows results of first vector and CA like implementation, while section 5 concludes by presenting our current work on multi-scale vector agent approach.

2. Morphogenesis laws

We define metropolis morphogenesis as the auto-organisation of its physical shape by the constraints of the constitutive natural and built environment from local level (functions and buildings within architectural programs) at global level (metropolis and city hull, main axes, etc.) through intermediate level (districts or suburbs).

At local scale, the localization and programming of architectural programs obeys not only to the laws of architecture and urban planning, but also to the laws related to their functions (residence, school, shop, office, factory, etc.) and relationships with the natural (topography, lakes, rivers, etc.) and built environment (neighbour programs, identity and morphology of the district, road infrastructures, etc). At the global scale, the metropolis itself obeys its environment while inducing, according to its identity and its own morphology, the localization of the programs.

We have distinguished 5 kinds of laws in the system:

- Influence: functional influences between programs (services or injures), same function neighbourhood, view and symbolic power of particular building or natural attractions (lake on the *Riviera*, *Cervin* in *Zermatt*, etc.),
- Growing and density: density increase within unchanging metropolis hull, services apparition (schools, churches, trade, industries, etc) according to residence increase,
- Stability: natural end of life, law changes, events,
- Morphology: optimization according to '*hidden shapes*' (Berger and Nouhaud 2004),
- Physical constraints: neighbourhood threshold, slope, adequacy to land use, exposition to sun, wind, etc.

3. City modelling

We briefly present hereafter our conceptual schema in Unified Modelling Language (UML) model of the city in section 3.1, and the way satisfaction degree (method *ds( )* of an agent) is computed in section 3.2 while section 4 explains its use in simulation process.

3.1 UML diagram

From Boffet (2002) who proposes a multi scale analysis of the city, we consider in our model the following cognitive vector agents:

- At micro level, surfaces of a function (SF) hosted by a building (fig. 1) and buildings
- At meso level, city districts and architectural programs
- At macro level, cities (city hull) and metropolis

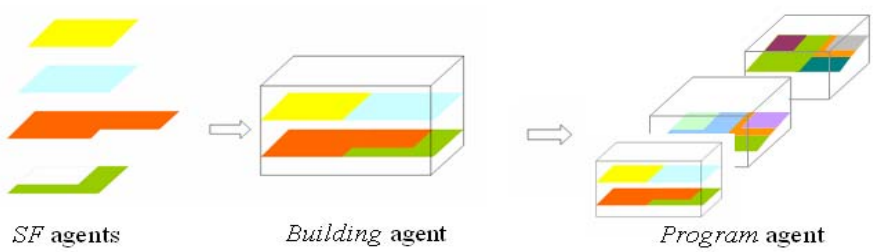

Figure 1. Example showing 4 *SF* agents hosted by a *building* agent, which is part of an architectural program (e.g. a shopping centre)

Environment objects consist of natural objects: rivers, lakes, parks, elevation, ground properties (flooding areas, etc.), and built objects: road network, public transport network, etc.

Fig. 2, is a simplified view of the main part of our UML diagram.

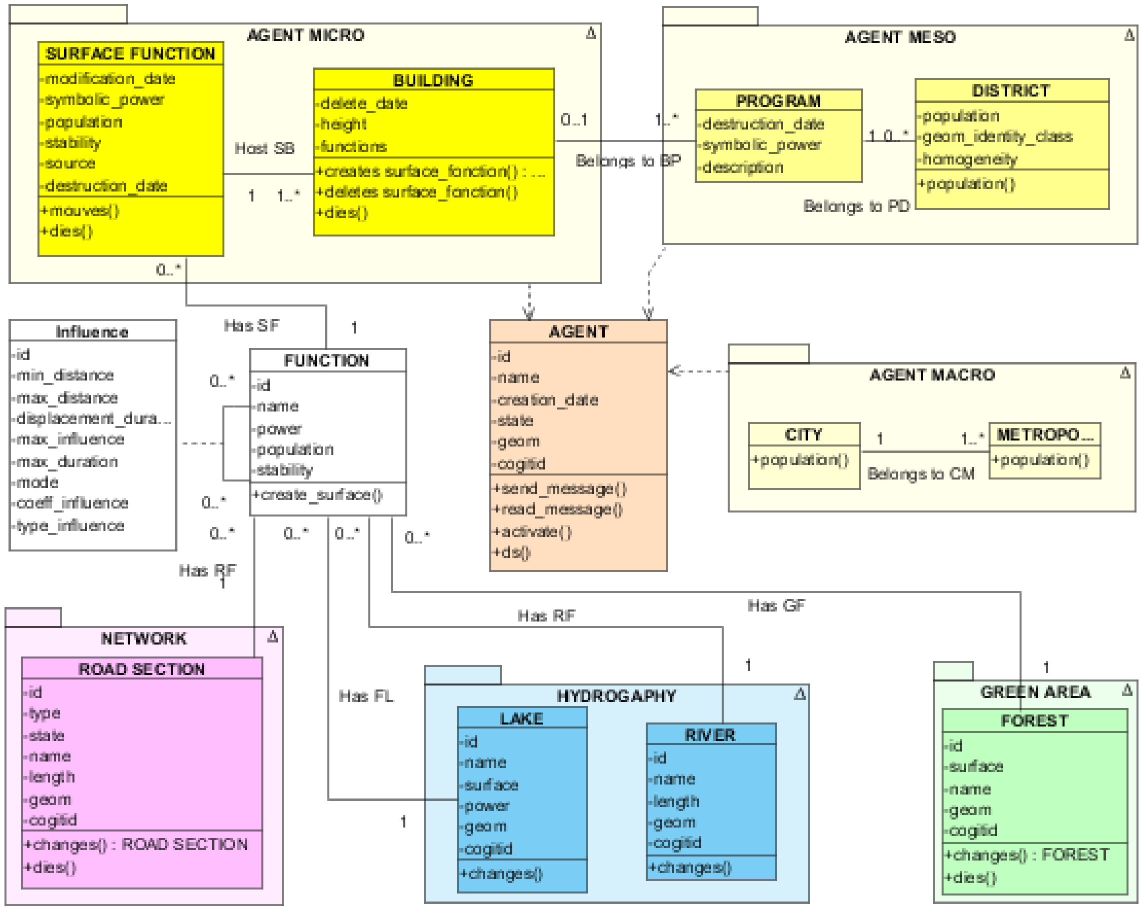

Figure 2. UML city diagram.

3.2 Satisfaction degree

Each agent has his own desires and computes its satisfaction degree function according to its desires, thus translating answers to the questions: Am I happy with the proximity with services which it needs or unsatisfied because of injures in my neighbourhood?

The computation principle is close to Newtonian model of gravity. Many authors already integrated this criterion in their model, notably: Arentze et al. [2006], Benenson and Thorrens [2004], Engelen et al. [1997], Pumain et al. [1989], etc. The closer the building is to a service (taking into account minimum distance threshold), the higher its satisfaction degree. On the contrary, more the building is close to an injury, more its satisfaction is weak.

For example, we define function of satisfaction DS (expressed as a percentage) of a building agent, according to functional influence and neighbourhood, as follows (fig. 3):

- an agent ***ai***, one of the *n* agents influencing an agent ***a***,
- **Type_influence (ai,a)**: kind of influence of the *ai* agent on *a* with **S** as service and **N** as Noise (injury)
- **Coef_influence (ai,a)**: importance value of influence of *ai* on *a* (from 0 to 10)
- **Max_influence (ai,a)**: maximum influence radius in metres of *ai* on *a*
- **δ(ai)**, minimum separation threshold between *ai* and any agent (corresponding to the height(*ai*) according to architectural law),

- **DS(a,ai),** satisfaction degree of *a* according to *ai*

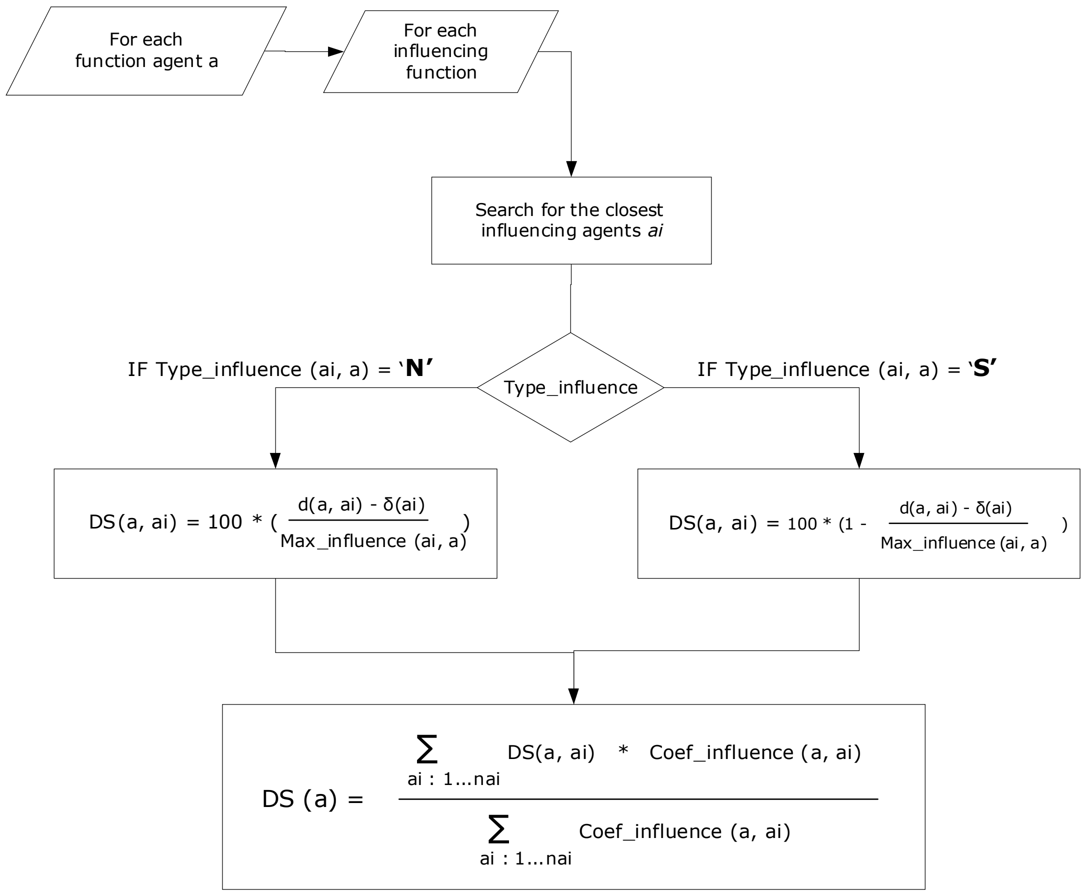

Figure 3. Computation of satisfaction degree of a *Building* agent

4. First results with CA like simulation system

In order to conduct first experiments and validate the approach, we have implemented a first prototype on Manifold 7.0 GIS. The model was initially simplified by attaching one function per building. Space is discretized as a grid of 20x20 meters cells. Buildings are programmed according to a predefined geometry for each function (e.g. a villa is 10x10 meters square while a factory is 45x18 meters). Thus, given a number of residential buildings to be created during a given number of years, the implemented process consists of repeating each year the following steps:

- Creating proportional number of low or high density residential buildings,
- Creating other function buildings according to the new population: schools, offices, health institutes, shops, factories, churches, etc.
- Deleting buildings reaching end of life.

In order to create new buildings, the method consists of searching for the free cell of best satisfaction and required place. To create other functions, each function carries a population threshold corresponding to the need, e.g. 2000 for school. Thus the rule is: *IF population>2000*(1+number_of_schools) THEN create School (probability 0.9)*. This rule is identical for each function, modulo the population threshold.

Results are a series of 2D images captured at each transition (creation or deletion of a building) which prove a Flash animation.

Fig. 4 below shows a result of the effect of the introduction of an important program (e.g. a train station). Residences of high density are in yellow, villas are clear yellow, factories in black, schools in clear blue and shopping centres in deep blue. It clearly demonstrates that the station reorients the urban development.

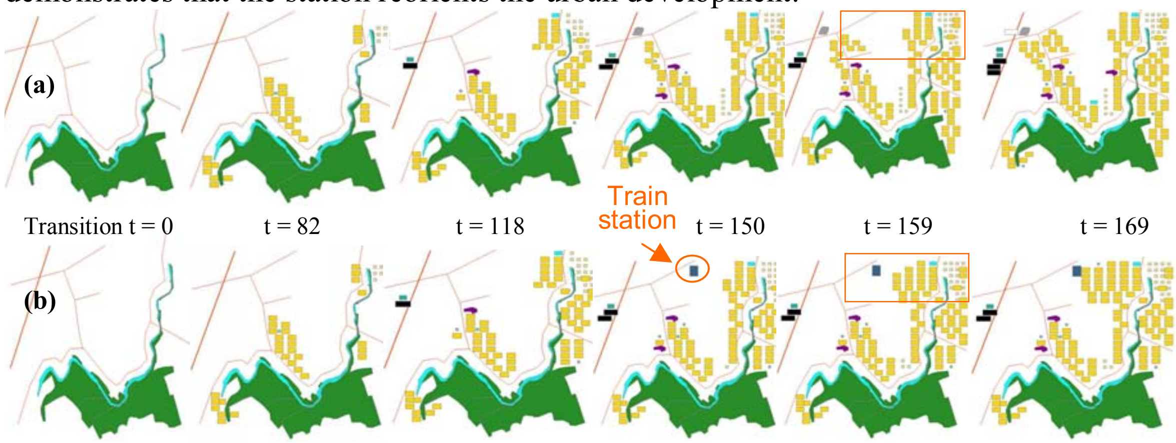

Figure 4. Example of effect of the localization of a program: (a) without any event; (b) apparition of a new train station.

5. Towards multi-scale vector agent approach

We are currently developing an agent engine in collaboration with the COGIT laboratory of the French National Mapping Agency (IGN-France), which has a strong experience in Multi-Agent implementation (Duchêne and Regnauld, 2002) and which has developed *GeOxygene* open source OGC/ISO compliant platform (http://oxygene-project.sourceforge.net/), enabling Java & PostGIS programming.

Cognitive vector agents communicate between hierarchical levels for collective behaviour and interact with their physical natural and built environment. Micro agents have a local perception, whereas macro agents have a global perception, meaning that they can communicate with every agent composing the metropolis. Below fig. 5 shows an example of sequence diagram for the creation of new residences in a building. Cognitive vector agents communicate between same as well as hierarchical level.

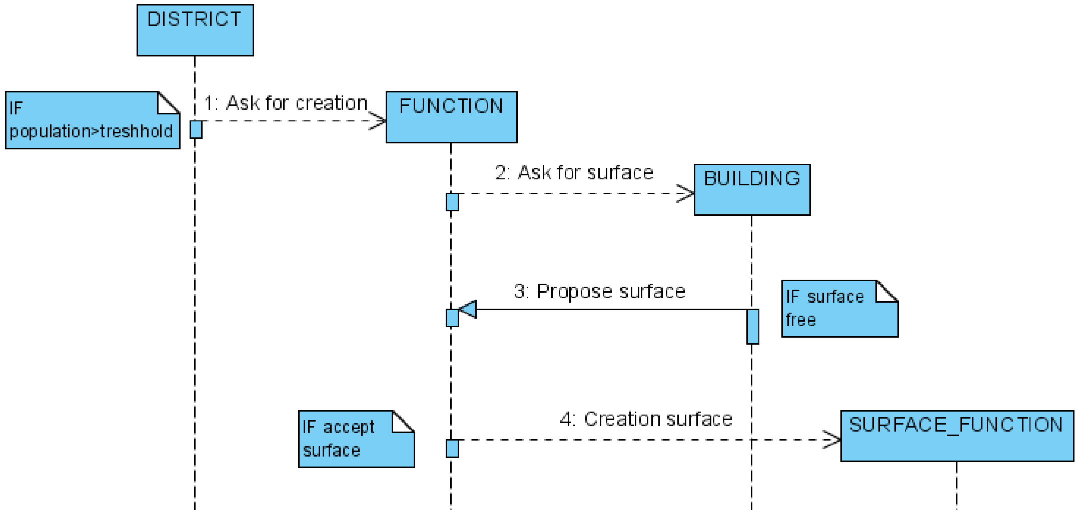

Figure 5. An example of sequence diagram.

Finally calibration and validation of the model will be done from historical data that we have on west Lausanne from 1900 to 2005, enriched by students' terrain survey and Swiss Federal Office of Statistics data.

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