Research Proposal

Title: CityEngine for Urbanity Vizualisation based on hypernetworks

Keywords: City engine, urbanity, hypernetworks, data science, smart city, Q-Analysis, simplicial homology (Algebraic topology), graph theory.

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1) Context and subject topic

Two distinct entities cannot occupy exactly the same point of a geographical scope. The distance is a key variable of any social space. Space has some attributes (scale, metric, topic…). Space is thus not absolute, it is relative and must be calculated. There are two methods to minimize the distance between two social realities which is the cost function to be optimized: colocation and mobility. Finally, space only fully exist if it is used by actor or involved in some activity (spatiality). Space and spatiality is a multi-dimensional complex network termed as assemblage.

Space and spatiality are also defined by a space value. The city illustrates the relevance of this model. In space term, the city is a spatial object which privileges the colocation: it gives access to a maximum of social realities in a minimum of time and cost. To search colocation aims to increase economic efficiency, development of social interactions or improvement of city management. In terms of spatiality, the city can be defined by its urbanity (Levy and Lussault, 2003), i.e. by the conjunction of two factors: density and diversity of the co-located objects. The search of colocation produces growth of density and increase of the diversity of the co-located objects. Conversely, the simultaneous increase in mobility (displacement, telecommunication) privileges connectivity compared to immediate contact and leads to urban sprawl, and thus to the weakening of densities and, often, diversity.

The city engine concept proposed in this research has the objective to calculate, for some specified urban situations (use cases), the space and spatiality hypergraph which minimizes the distance and optimizes urbanity, while taking into account mobility. Use cases could be: crime map, mobility management, improving cycling safety, smart elderly care system, smart commuting, personal emergency response, interactive street sensing, stimulating green behavior, etc.

2) Objective and challenges

Hypernetworks generalize the concept of a relation between two things to relations between many things. Relational simplices have multi-dimensional connectivity related to hypergraphs, simplicial complexes and the Galois lattice of maximally connected sets of elements. This structure acts as a kind of backcloth for the dynamic system traffic represented by numerical mappings, where the topology of the backcloth constraints the dynamics of the traffic. Simplices provide a way of defining multilevel structure. Multilevel hypernetworks provide a significant generalization of network theory and set theory, enabling the integration of relational structure that are likely to be necessary for a science of complex multilevel socio-technical systems. Theory of hypernetworks is based on previous work of Ron Atkin, following the ideas of Clifford Hugh Dowker, generalized by J. Johnson (2013).

Two main challenges are to be considered:

1. Tools for manipulating simplicial complexes and hypernetworks.

As hypergraphs are nowadays a mathematical tool used in all the fields where one uses the graph theory they are no really efficient industrial software that allows to do specific computations in algebraic topology. There exist some open algorithms libraries and modules which implements basic topological operations and indexing for abstract simplicial complexes in object-oriented language (see for example The Gudhi Library, Perseus, Dionysus, JavaPlex for persistent homology software or https://github.com/mikolalysenko/simplicial-complex for a simple basic tool). Some mathematical research teams (or projects like CHomP for Computational Homology Project) develop also classes, libraries and mathematical software, but they are generally not easy to use. Computational topology is thus an issue. The present project will have to present main algorithmic choices, the different components of the software, their interaction and the user interface.

2. Implement relational algebras to analyze massive heterogeneous data sets.

Hypernetworks theory is often presented as if it could handle important volumes of data. But because of dependence of this theory towards the set theory, it uses relatively short lists of elements and not so many dimensions. However, the model of urbanity is a complex system which has the following properties: many heterogeneous parts, complicated transition laws, network connectivity, multiple subsystem dependencies, and emergent dynamics from interactions of autonomous agents, discrete dynamics with combinatorial explosion, ill-defined boundaries, multilevel dynamics and misleading data. And thus we need massive volume of data to feed the system. Data acquisition, understanding and preparation challenge hypernetwork theory: we do not known today if simplicial complexes applied to spatial analysis support large-scale data processing.

3) Planning (provisional timetable for the project)

T0, T0+ 6 months: bibliography, algorithms state of the art, and identification of use cases

T0+6 months, T0+12 months: development of urbanity model

T0+12 months, T0 +18 months: data sets preparation based on Cross-industry standard process for data mining (CRISP-DM)

T0+18 months, T0+30 months: model implementation, CityEngine development and validation on real data

T0+30 months, T0+36 months: PhD report writing

4) Academic Requirements:

Persons with a Master's Degree or equivalent degree of higher education (Curriculum Vitae)

Algorithmic, Data Science, Machine Learning

Programming (Python, C/C++, Java)

Mathematical skills

Knowledge in probabilities and statistics