CSH WORKSHOP ABSTRACT BOOK

Cities as Complex Systems

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COMPLEXITY SCIENCE HUB VIENNA
PALAIS STROZZI
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The growth and statistics of urban populations

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Abstract:
Modelling the population evolution of cities is at the core of urban science. The most fundamental problem is to understand the hierarchical organization of city population and the statistical occurrence of megacities. This was first thought to be described by a universal principle known as Zipf's law. However, the validity of this model has been challenged by recent empirical studies. In addition, we also observe empirically the relative frequent rise and falls of cities. I will present here a model able to explain and reconciliate these various aspects of urban dynamics. More precisely, I will discuss a stochastic equation recently proposed for modelling population growth in cities, constructed from an empirical analysis of recent datasets (for Canada, France, the UK and the USA). This model reveals how rare, but large, interurban migratory shocks dominate city growth, and that the distribution of city populations has a complex shape that is not described by Zipf's law.

Finite-size scaling of population distributions over fixed-size cells, multifractality, and unfulfillment of Zipf's law over clusters of populated cells

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Abstract:
Using demographic data of high spatial resolution for a region in the south of Europe, we study the population over fixed-size spatial cells. We find that, counterintuitively, the distribution of the number of inhabitants per cell increases its variability when the size of the cells is increased. Nevertheless, the shape of the distributions is kept constant, which allows us to introduce a scaling law, analogous to finite-size scaling. The scaling of the moments of the distribution is found to be related with the multifractal properties of the spatial pattern formed by the population. Further, we are able to define cities (human settlements) in an natural way by aggregating cells to form connected populated clusters. The resulting cluster-population distributions show a smooth decreasing behavior covering six orders of magnitude. However, we observe that a power-law description of the high population tail, characteristic of Zipf’s law, has a rather limited range of applicability.

A. Corral and M. Garcia del Muro (in preparation).
A. Corral, F. Udina and E. Arcaute, Phys. Rev. E 101, 042312 (2020).

Synthetic population generation and application to studying spatial inequality

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Abstract:
An increasing number of microsimulations produce synthetic spatial microdata to attempt to solve public health, climate change and transportation (e.g.) issues that may impact local communities in a variety of ways. Synthetic data is being used as an answer to a variety of problems, such as privacy concerns. With multiple challenges - such as air pollution, the energy crisis (with unequal impacts on the cost of living), and climate change - synthetic population datasets are needed to feed other models that attempt to represent the complex interactions and characteristics of a population.
We present a new microsimulation tool, the Synthetic Population Catalyst (SPC), which addresses the challenge of providing researchers with a spatially enriched synthetic population, with a particular focus on daily activities and social interactions. It is based on an earlier model coded to study the spread of the COVID-19 pandemic. It has fast runtimes (about 30 seconds for a population of 2 million individuals), contains a variety of socio-economic indicators (including a model of salaries), and simulates daily trips to geolocated schools, retail, and workplaces, and their durations. It is meant to be the first founding element in a series of multi-level and multiscale intertwined urban models that will represent the city in a constant state of evolution. We discuss the on-going projects that derive from the SPC. We review the methods, including multifractality, to quantify and analyse emerging spatial inequality patterns in the synthetic population. The SPC is also particularly well suited to study social interactions beyond simple physical proximity. It can be used to analyse hidden patterns of segregation by identifying a lack of meaningful interactions, even among people living in a common neighbourhood. This can be the basis, for example, to map a network of interactions and use complex network analysis.

Resilience and transitions of global complex urban systems

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Abstract:
In the context of the climate change and energetic and political crises, new tendencies in the long/medium term evolution of urban systems, together with new data and methods, require that existing theoretical assumptions and conceptualizations be challenged as global urban hierarchies are reconfigured. The connection between urban systems at different levels of organization becomes more and more relevant for understanding urban systems and their transitions. But the current inter-urban perspective is not sufficient to encompass these dynamics. The evolution of power distributions inside and between cities reshapes the world organization of central/peripheral cities and the complexity of the global urban system. Actors as multinational firms, or high-level innovation centers, participate actively in these reconfigurations that concentrate wealth, control, innovation, and attractiveness in a few cities. In the complexity of this multi-level system, how is regionalization of the world reshaping in a multipolar urban world? How does the multi-level perspective highlight some resilience properties? The methodologies derived from complex systems sciences bring new forms of intelligibility to worldwide urban transitions.

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Central and intermediate cities in Africa

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Abstract:
Due to their centrality, some cities may have a strategic position in the urban network. We construct Africa's urban network obtained from OpenStreetMap road data. City centrality is measured using two indices: by the degree of cities, Dk, so the number of roads that connect it, and by the intermediacy, Ik, or the number of journeys that pass through it [1]. The number of trips between cities is approximated using a gravity model based on city size and time travel. The additional time for crossing an international border is used as a model parameter to proxy the cost of political barriers in the connectivity and trade of cities and countries. Results show that city degree Dk scales sublinearly with population, meaning that larger cities tend to be better connected to the network. Also, the observed scaling extends beyond the city's limits in the form of regions of influence [2]. Results show that city degree scales sublinearly with population, meaning that larger cities tend to be better connected to the network. Based on the urban network, it is observed that large cities tend to be surrounded by many small towns for small distances [2]. Based on the urban network, it is possible to classify cities based on their degree Dk, counting the number of roads connecting them. Most small cities are isolated corridors (a degree of two) or terminals (a degree of one). However, small cities may have a high level of intermediacy if they have a high degree and proximity to large urban areas. There is a phase transition where the level of intermediacy of cities with less than one million depends on the size and degree. For cities above one million inhabitants, intermediacy depends mostly on city size. The intermediacy of cities, mainly those near international borders, is highly sensitive to border delays. Some countries are also susceptible to border delays. In countries like Benin and Togo, a one-hour wait at a border corresponds to a decrease of 30% of their trade.

[1] Prieto Curiel, R., Schumann, A., Heo, I., & Heinrigs, P. (2021). Detecting cities with high intermediacy in the African urban network. arXiv e-prints, arXiv-2110.
[2] Prieto Curiel, R., Cabrera-Arnau, C., & Bishop, S. R. (2022). Scaling Beyond Cities. Frontiers in Physics, 10.

Integrating urban models and theories

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Abstract:
Urban systems are highly multi-dimensional and complex, and thus studied from various perspectives and disciplines. To reach sustainable urban and territorial policies, we suggest that an integrative approach is needed. We propose in that context a theoretical and methodological framework, focused on the coupling and integration of simulation models. A first application example is then given, developing an urban dynamics model at the macroscopic scale coupling cities population dynamics with innovation diffusion. This simulation model allows investigating trade-offs between sustainable development goals in synthetic systems of cities, in particular emissions and innovation. Work in progress includes further model layers for economic exchanges and infrastructure, increasing the dimension of the SDG space in which Pareto compromises are found. The second example corresponds to the chapter of the Compendium discussed during this workshop. We review multiple models aiming at explaning regularities of city growth, including Gibrat‘s law of proportional random growth, Simon‘s random growth model, and more recent contributions. These models can be benchmarked against empirical evidence for multiple systems of cities, suggesting that a multi-modeling approach is more appropriate to cover the diversity of historical and geographical contexts observed for systems of cities.

Urban road networks: Geometric characteristics and generative models

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Abstract:
Road networks provide the spatial backbone for the development of urban agglomerations. Their practical relevance as the key substrate for private and public transportation of people and goods at the urban scale has made them becoming important subjects of studies employing complex network theory. While initial works in this field have mainly concentrated on topological (graph) characteristics (primarily exploiting different concepts of node or link centrality) that have been closely related to traffic efficiency, it has soon become apparent that the associated geometric characteristics also carry important information contributing to a better understanding of urban development from a two-dimensional spatial perspective. In my presentation, I will first review the results of some key studies investigating different aspects of the geometric structure of urban road networks, including the distributions of size (length, area), shape (cellular forms) and orientation characteristics, and discuss their role in shaping urban space. Subsequently, I will demonstrate the development of a new generative model that attempts to not only mimic the size distributions of road segments and two-dimensional cellular structures formed by them, but also their shape and orientation properties, primarily the wide-spread orthogonality of intersecting road segments. The presented model provides a potentially useful benchmark for investigating different pattern formation mechanisms in "naturally grown" cities by allowing for the generation of ensembles of surrogate urban spaces. As a possible future extension of this model, I will finally outline the explicit incorporation of the ease or difficulty to utilize available space according to geographic properties like slope, soil conditions, or topographic obstacles such as rivers in terms of a spatial potential function promoting or inhibiting the construction of new buildings and road infrastructures.

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Physicist's approach to public transportation networks: between data processing and statistical physics

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Abstract:
I aim to discuss how physical perspective enriches statistical analysis when dealing with a complex system of many interacting agents of non-physical origin. To this end, I consider urban public transportation networks viewed as complex systems. In such studies, a multi-disciplinary approach is applied by integrating methods in both data processing and statistical physics to investigate the correlation between public transportation network topological features and their operational stability. These studies incorporate concepts of coarse graining and clusterization, universality and scaling, stability and percolation behavior, diffusion and fractal analysis.

R. de Regt, C. von Ferber, Yu. Holovatch, M. Lebovka. Public transportation in UK viewed as a complex network. *Transportmetrica A* **15** (2019) 722-748

Yu. Holovatch, R. Kenna, S. Thurner. Complex systems: physics beyond physics. *Eur. Journ. Phys.* Vol. 38 (2017) 023002

C. von Ferber, B. Berche, T. Holovatch, Yu. Holovatch. A tale of two cities. Vulnerabilities of the London and Paris transit networks. *Journ. Transport. Security* **5** (2012) 199-216

C. von Ferber, T. Holovatch, Yu. Holovatch, V. Palchykov. Public transport networks: empirical analysis and modeling. *Eur. Phys. J. B* **68** (2009) 261-275.

B. Berche, C. von Ferber, T. Holovatch, Yu. Holovatch. Resilience of public transport networks against attacks. *Eur. Phys. J. B* 71 (2009) 125–137.

Cities and their workers

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Abstract:
Cities are exceptional in terms of their capacity to make their inhabitants more productive. At the same time, people and the urban labor markets they operate in determine what economic activities a city can participate in. This talk will cast cities as places that coordinate the efforts of large numbers of people with different skill sets and discuss how this coordination affects the workers in a city and how these workers shape the development path of the city.

On the relation between transversal and longitudinal scaling in cities

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Abstract:
Empirical evidence has shown that some urban variables scale non-linearly with the city population size. More specifically, some socio-economic variables, such as the number of patents, wages and GDP, show a super-linear behaviour with the city's population. On the other hand, infrastructure variables, such as the number of gas stations and length of streets, scale sub-linearly with the city population, generating a scale economy. However, do these scaling properties observed in a system of cities (transversal scaling) also work for individual cities in different stages of their growth process (longitudinal scaling)? The answer to this question has important policy implications, but the lack of relevant data has so far hindered rigorous empirical tests. The work that will be presented was developed by looking at the evolution of two urban variables, GDP and water network length, for over 5500 cities in Brazil. It will be shown that longitudinal scaling exponents are city-specific; however, they are distributed around an average value that approaches the transversal scaling exponent, provided that the data is decomposed to eliminate external factors and is valid only for cities with a sufficiently high growth rate. This result adds complexity to the idea that the longitudinal dynamics is a micro-scaling version of the transversal dynamics of the entire urban system.

[1] Ribeiro, F. L., Meirelles, J., Netto, V. M., Neto, C. R. & Baronchelli, A. On the relation between Transversal and Longitudinal Scaling in Cities. PLoS One 1–20 (2020). doi:10.1371/journal.pone.0233003
[2] Ribeiro, F. L., Joao Meirelles, Ferreira, F. F. & Neto, C. R. A model of urban scaling laws based on distance-dependent interactions. R. Soc. Open Sci. 4, (2017).
[3] Meirelles, J., Neto, C. R., Ferreira, F. F., Ribeiro, F. L. & Binder, C. R. Evolution of urban scaling: evidence from Brazil. PLoS One 10, 1–15 (2018).

Urban Scaling of Carbon Emissions

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[2] Complexity Science Hub Vienna, Josefstädterstrasse 39, A-1090 Vienna, Austria

Abstract:
There is considerable interest in the question to what extent urbanization drives or alleviates climate change and a series of papers have been published on urban scaling of carbon emissions. However, there is no general consensus on whether large cities are emission efficient in comparison to smaller cities. Here I give an overview of related work and focus on three approaches to the problem. (i) Recent results indicate a development dependence according to which less (economically) developed countries exhibit super-linear scaling and more developed ones exhibit sub-linear scaling. This finding could explain contradictions found in the literature so far. (ii) I present the urban Kaya relation. It can be used to attribute non-linear emissions scaling to GDP and energy scaling. (iii) Production functions combine urban population scaling with area scaling – and thereby, reconcile urban scaling and density scaling. The Cobb-Douglas model represents a simply extension of conventional urban scaling and can be extended to the transcendental logarithm model (translog) model as well as the constant elasticity of substitution (CES) model. All three have implications how population and area can substitute each other. I resume with caveats and perspectives.