SOE 15: Focus Session: Cities as complex systems

Cities form complex systems exhibiting nontrivial statistics and dynamics. Not only the scaling of city sizes, but connectivity, infrastructure usage and spatial densities can be analyzed for scaling laws. Urban growth is steered by decisions of individuals and companies where to settle and sell. Efficiency of transport and trade networks are essential for sustainable development of cities. The Focus Session provides an overview of current research and future trends in this area. (Focus Session organized by Diego Rybski)

Time: Wednesday 15:00–18:15 Location: GÖR 226

SOE 15.1 Wed 15:00 GÖR 226

Urban Economic Development: Agriculture, Industry, and Services — •Diego Rybski, Prajal Pradhan, and Jürgen P. Kropp — Potsdam Institute for Climate Impact Research – PIK, Member of Leibniz Association, P.O. Box 601203, 14412 Potsdam, Germany

With the purpose of analyzing the sectoral composition of cities' gross domestic product (GDP) we consider US Metropolitan Statistical Areas (MSA) and the partitioning into agrarian, industrial, and service GDP. In order to characterize the transfer of GDP shares between the sectors in the course of economic development we explore a simple system of differential equations which has previously been proposed for countries. Fitting the model to more than 90 MSA we find that according to the obtained parameters the majority belongs to 5 of 8 groups. The purely consecutive transfer is not representative for the set of MSA.

SOE 15.2 Wed 15:15 GÖR 226

The city in 2 and 3 dimensions: monocentric analysis and scaling of land use and population density — •Rémi Lemoy and Geoffrey Caruso — University of Luxembourg, Maison des Sciences Humaines, 11 Porte des Sciences, L-4366 Esch-Belval, Luxembourg

In this work we study the profile of land use and population density in European cities with respect to the distance to the city centre. We use the GMES Urban Atlas database, providing a precise description of land use at 5m resolution in the 300 major European urban areas (more than 100.000 inhabitants). We combine this dataset with population density from the Geostat population grid, which covers the whole of European Union with a 1km^2 resolution. Population is allocated proportionally to surface and weighted by soil sealing and density classes of the GMES data.

We analyse the evolution with distance to the city centre of population density and of the share of artificial land. We analyse the scaling of these curves with respect to city population. We find that land use curves tend to scale (in 2 dimensions) like the square root of city population. Population curves tend to scale (in 3 dimensions) like the city population to a power close to 1/3.

These results allow us to propose a simple intra-urban description of a representative European city, whose size can be defined based on the scaling relationships we obtain. This is useful for the calibration and validation of monocentric urban economic models. Further, our analysis provides a coherent definition of cities of different sizes and hence a new way to interrogate inter-urban scaling laws or Zipf's law.

SOE 15.3 Wed 15:30 GÖR 226

Zipf's Law for Australia: An outlier? — Somwrita Sarkar[1] and •Peter Alexander Robinson[2] — [1]Faculty of Architecture, Design and Planning, The University of Sydney, Australia — [2]School of Physics, The University of Sydney, Australia

Various studies of city size distributions across the planet have shown what is now known as Zipf's law, which says that the distribution of city sizes fits a power law: the number of cities with populations greater than N is roughly proportional to 1/N. We explore this relationship and its historical evolution for city size distributions in Australia (from 1922 to 2015), and find that Zipf's Law does not hold for Australia. Rather, a different organization emerges with (a) the Zipf exponent close to 0.7, suggesting a 'flatter' distribution with the biggest cities having larger sizes, and (b) a 'missing middle' with no middle-sized cities (of approximately 500,000 to 1 million). Curiously, when the five largest cities (Sydney, Melbourne, Brisbane, Perth and Adelaide) are removed and the analysis re-performed for the smaller cities, the exponent is close to unity, maintaining itself as stable from 1922 to 2015. These empirical findings will be presented and some preliminary thoughts on this outlier behavior will be discussed. Two hypotheses will be considered: (a) the possibility that smaller (regional) and larger cities in Australia are following different growth processes, and (b) the possibility that each state in the country could be behaving as a 'country'. Relationships of these hypotheses with Australia's colonial history and relatively young urban settlement will be discussed. Implications for urban and regional development will also be discussed.

SOE 15.4 Wed 15:45 GÖR 226

Discovering the laws of urbanisation — •Filippo Simini and Charlotte James — Department of Engineering Mathematics, University of Bristol, UK

In 2012 the world's population exceeded 7 billion, and since 2008 the number of individuals living in urban areas has surpassed that of rural areas. This is the result of an overall increase of life expectancy in many countries that has caused an unprecedented growth of the world's total population during recent decades, combined with a net migration flow from rural villages to urban agglomerations. While it is clear that the rate of natural increase and migration flows are the driving forces shaping the spatial distribution of population, a general consensus on the mechanisms that characterise the urbanisation process is still lacking. Here we present two fundamental laws of urbanisation that are quantitatively supported by empirical evidence: 1) the number of cities in a country is proportional to the country's total population, irrespective of the country's area, and 2) the average distance between cities scales as the inverse of the square root of the country's population density. We study the spatio-temporal evolution of population considering two classes of models, Gravity and Intervening Opportunities, to estimate migration flows and show that they produce different spatial patterns of cities. Moreover, both models suggest that the formation and growth of cities is possible only if the migration rate is sufficiently higher than the rate of natural increase.

SOE 15.5 Wed 16:00 GÖR 226

Urban systems rank diversity — •Roberto Murcio, Clementine Cottineau, Michael Batty, Elsa Arcaute, and Robin Morphet — University College London, London, UK

Digest the complex temporal dynamics of hierarchical communities is hard to attain in a way that capture the changes in rank and size of its members. Particularly, in urban systems, scaling laws and rank clocks approaches have proved to capture much of this dynamic at macro and micro scales respectively, summarizing the variation of urban attributes with city size. Here we argue that examining the behaviour of the rank itself, measuring the number of cities occupying that rank over time, could give some insights about the self-organization process these urban hierarchical structures experience as the system evolves in time. We applied this distribution, namely rank diversity, to three different urban systems: UK and USA (1900 to 2010) and former Soviet Union cities (1840 to 2010). Our findings point out the profound differences between the UK and the USA/Soviet Union urban structures, reinforcing the notion that there is no rank-size universality to be found in cities. Exploring the moments of the distribution and applying classical Zipf's law corpus analysis, we clustered cities in three categories: "seed", containing cities that practically do not change their rank in time; "epoch-dependant", comprising those [cities] which fluctuation in rank is considerably and finally, if a city exhibit a limited change in rank, we labelled as a "content bearing" city. The size of the seed set is similar in all urban systems while the tail is more similar between USA and the Soviet Union than with the UK.

SOE 15.6 Wed 16:15 GÖR 226

Statistical issues in scaling laws' estimation — •Jose M. Miotto[1], Jorge C. Leitão[2], Martin Gerlach[3], and Eduardo G. Altmann[4] — [1]Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany — [2]iCourts, University of Copenhagen, Copen-

hagen, Denmark — [3]Department of Chemical and Biological Engineering, Northwestern University, Chicago, USA — [4]School of Mathematics and Statistics, University of Sydney, Sydney, Australia

One of the most celebrated findings in complex systems in the last decade is that different indexes y (e.g. patents) scale nonlinearly with the population x of the cities in which they appear, i.e. $y \sim x^{\beta}$, $\beta \neq 1$. More recently, the generality of this finding has been questioned in studies that used new databases and different definitions of city boundaries. We investigated the existence of nonlinear scaling, using a probabilistic framework in which fluctuations are accounted for explicitly. In particular, we show that this allows not only to (i) estimate β and confidence intervals, but also to (ii) quantify the evidence in favour of $\beta \neq 1$ and (iii) test the hypothesis that the observations are compatible with the nonlinear scaling. We employ this framework to compare five different models to 15 different datasets and we find that the answers to points (i)*(iii) crucially depend on the fluctuations contained in the data, on how they are modelled, and on the fact that the city sizes are heavy-tailed distributed.

15 min. break

SOE 15.7 Wed 16:45 GÖR 226

Formulae of urban attractiveness — •Stanislav Sobolevsky[1], Iva Bojic[2], Alexander Belyi[2], and Carlo Ratti[2] — [1]New York University — [2]Massachusetts Institute Of Technology

Scientific studies investigating the laws and regularities of human behavior are nowadays increasingly relying on the wealth of widely available digital information produced by human social activity. In this paper, we leverage big data created by three different aspects of human activity (i.e., geotagged photographs and tweets as well as bank card transactions whenever available) in Europe and the US for quantifying city attractiveness for the foreign visitors. An important finding is the strong superlinear scaling of city attractiveness with its population size. The observed scaling exponent stays around 1.5 - nearly the same for different ways of defining cities, different data sources and different geographies, emphasizing the robustness of our finding. In contrary to cities, exponents for country attractiveness are less than one, indicating sublinearity. Finally, scaling exponent for the foreign attractiveness of the US states, which are smaller, but still composite areas similar to countries, fells somewhere in between values of exponents for city and country attractiveness, but still tend to be slightly sublinear similar to the case of countries. After getting those results, we propose and evaluate a possible explanatory mechanism for the observed effects based on a simple discrete choice model.

SOE 15.8 Wed 17:00 GÖR 226

Scaling of professional connections and urban performance — •Stanislav Sobolevsky[1], Iva Bojic[2], Lyndsey Rolheiser[2], Anthony Vanky[2], Homgmou Zhang[2], and Vijayragunath Aruswamy[3] — [1]New York University — [2]Massachusetts Institute Of Technology — [3]LinkedIn Corporation

Recent studies have shown that many aggregate socio-economic characteristics of the city do not grow proportionally with population, but scale superlinearly with city size. This means larger cities see a bigger increase of various features of socio-economic activity per capita. In this research we consider an additional important quantity - connectivity of the professional population (as measured by the amount of LinkedIn connections). We analyze this connectivity in relation to city population and its economic performance. Consistent with previous findings, our results show that professional connectivity across the US cities scales superlinearly with the city size. Furthermore, this superlinear relationship is quite significant with a scaling exponent of roughly 1.3. We find this exponent being mitigated by industry: the lowest for manufacturing, transportation, construction and the highest for media, arts and design. Similar patters are also observed in European countries - Spain, Germany and France. Finally, with respect to an overall scaling trend, individual cities can be characterized by the relative coefficient of connectivity versus the trend expectation. We highlight the strong relationship between this relative connectivity and city-level income and unemployment; a finding that can potentially lead to using connectivity as an indicator of economic health.

SOE 15.9 Wed 17:15 GÖR 226

Predicting the response of urban real estate markets to socio-spatial dynamics — •Aike Alexander Steentoft and Markus Schläpfer — ETH Future Cities Laboratory, Singapore

Cities connect people and create opportunities for exchanges which promotes social and economic enrichment. In this work, we present a complementary perspective on how social life in a city interacts with its economic environment. More specifically, we analyze the gentrification phenomenon where urban migration boosts the real estate market. To that end, we use Twitter and Foursquare data to track the interconnected network of people and places in New York City from 2012 to 2016. Following the approach of Hristova, the socio-spatial dynamics are quantified using "four metrics of the social diversity of places which relate to their social brokerage role, their entropy, the homogeneity of their visitors and the amount of serendipitous encounters they are able to induce" [Hristova et al. 2016]. At the same time, we use Zillow data for New York City neighborhoods to track the dynamics of the residential real estate market where we define adjusted price and value indices to overcome biases caused by exogenous influences. We correlate these indices with the social diversity measures, contributing to the understanding of an adaptive economic environment, and ultimately providing early warning signals of escalating real estate prices.

SOE 15.10 Wed 17:30 GÖR 226

Spatial scaling behaviour of an optimized highly renewable European electricity system — •Jonas Hörsch, Tom Brown, and Stefan Schramm — Frankfurt Institute for Advanced Studies (FIAS), Goethe-Universität, 60438 Frankfurt am Main, Germany

Techno-Economic investment planning of electrical energy systems is mostly based on optimizing large-scale spatial Linear Programming (LP) problems that find the spatial distribution of generation and transmission capacities for minimal capital and operating costs. The tractable spatial resolution of this type of problem is strongly limited by computational complexity, so that many studies of renewable energy integration have reduced the network to representative nodes with as few as one node per country. In this study a clustering algorithm is used to reduce the number of nodes and lines of a high resolution network-solution while preserving the most important transmission corridors. Preliminary results are presented that quantify the effects of the spatial scale on the operation of the electrical network and the threshold to a necessary scale invariance of the energy flows.

SOE 15.11 Wed 17:45 GÖR 226

Spatial correlations, clustering and percolation-like transitions in homicide crimes — •Haroldo Ribeiro — Universidade Estadual de Maringa, Maringa, Brazil

The spatial dynamics of criminal activities has been recently studied through statistical physics methods; however, models and results have been focused on local scales (city level) and much less is known about these patterns at larger scales such as at a country level. Here we report on a characterization of the spatial dynamics of the homicide crimes along the Brazilian territory using data from all cities (˜5000) in a period of more than thirty years. Our results show that the spatial correlation function in the per capita homicides decays exponentially with the distance between cities and that the characteristic correlation length displays an acute increasing trend in the latest years. We also investigate the formation of spatial clusters of cities via a percolation-like analysis, where clustering of cities and a phase transition-like behavior describing the size of the largest cluster as a function of a homicide threshold are observed. This transition-like behavior presents evolutive features characterized by an increasing in the homicide threshold (where the transitions occur) and by a decreasing in the transition magnitudes (length of the jumps in the cluster size). We believe that our work sheds new lights on the spatial patterns of criminal activities at large scales, which may contribute for better political decisions and resources allocation as well as opens new possibilities for modeling criminal activities by setting up fundamental empirical patterns at large scales.

SOE 15.12 Wed 18:00 GÖR 226

Tracking urban evolution - a way to investigate allometric scaling over time? — Hendrik Herold, •Robert Hecht, and Martin Behnisch — Leibniz Institute of Ecological Urban and Regional Development Dresden, Germany

Studying cities as complex systems requires reliable data on their spatial structure and development. Available remote sensing-based datasets allow for following the urban growth since the 70ies on a global scale. However, most of the urban development in European and most of North American cites has taken place before this era. In this work, we present an approach for delineating the physical structure, in particular the city borders, from digitized historical topographic maps. This

includes a generic image analysis part as well as an uncertainty modeling component. Germany is the testbed for this study. The approach enables to track the urban evolution back to the era of the beginning of the trigonometric survey and hence back to the beginning industrialization. This data allows to measure the degree of urbanization and in particular urban sprawling on a long-term perspective. This could also form the basis for investigating the allometric scaling of cities over time.