Emergence of complexity in urban morphology: building distributions and transportation networks

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Social systems have recently attracted much attention, with attempts to understand social behavior with the aid of statistical mechanics of complex systems. Among them, the city is a representative system, where interactions between individuals give rise to emergent collective properties in its morphology. Among various collective properties, criticality is known as a characteristic property of a complex system, which helps the systems to respond flexibly to external perturbations. This work considers the criticality of the urban morphology, specifically, of the building distributions and transportation passenger flows. Analyzing the big data on every building in Seoul City, we specify the relevant interactions among constituents and probe the emergence of complex land use patterns. In particular, based on the empirical observations, we illustrate that interactions between land uses are frustrated, which serves as a basic postulate of the theory of urban morphology. We examine this conjecture with the help of a layered Ising-type model and disclose that the actual land use pattern emerges at the criticality of the system in the presence of heterogeneously distributed fields. In addition, we consider the mass transportation network and examine passenger flows, entailed in the massive smart card data on the Seoul transportation network. Observed are skew distributions and criticality manifested by power-law correlations. Such criticality is probed by means of the scaling and renormalization analysis of the modified gravity model applied to the system. Here a group of nearby (bare) bus stops are transformed into a (renormalized) block stop and the scaling relations of the network density turn out to be closely related to the fractal dimensions of the system, revealing the underlying structure. Specifically, the resulting renormalized values of the gravity exponent and of the Hill coefficient give a good description of the Seoul bus system: The former measures the characteristic dimensionality of the network whereas the latter reflects the coupling between distinct transportation modes. It is thus demonstrated that such ideas of physics as scaling and renormalization can be applied successfully to social phenomena exemplified by the passenger flow.

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