between a high-density polymeric liquid and a low-density molecular fluid[11]. New IXS measurements of the local density fluctuations and dynamic heterogeneities will allow us to decipher the complex set of liquid–fluid transitions within this and other apparently chemically simple but often complex elements or compounds owing to their bonding, and extend the studies to the wide range of systems that might exhibit liquid–liquid and liquid–fluid polyamorphism. ❐

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COMPLEX NETWORKS

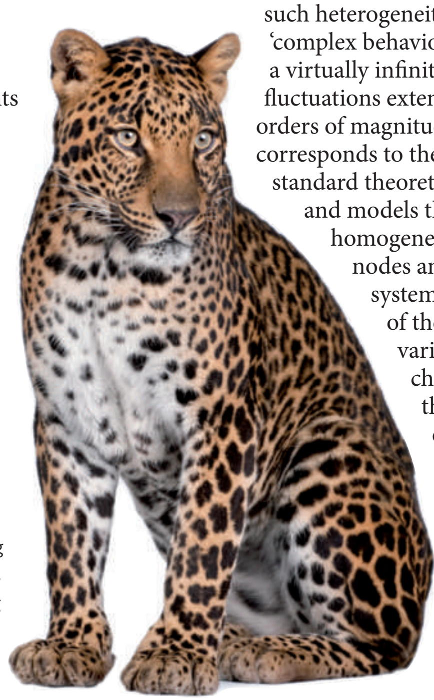
Patterns of complexity

The Turing mechanism provides a paradigm for the spontaneous generation of patterns in reaction–diffusion systems. A framework that describes Turing-pattern formation in the context of complex networks should provide a new basis for studying the phenomenon.

Romualdo Pastor-Satorras and Alessandro Vespignani

We live in the age of networks. The Internet and the cyberworld are networks that we navigate and explore on a daily basis. Social networks, in which nodes represent individuals and links potential interactions, serve to model human interaction. Mobility, ecological, and epidemiological models rely on networks that consist of entire populations interlinked by virtue of the exchange of individuals. Network science, therefore, is where we can expect answers to many pressing problems of our modern world, from controlling traffic flow and flu pandemics to constructing robust power grids and communication networks. But there is more than nodes and links. An important development of recent years has been the realization that the topology of a network critically influences the dynamical processes happening on it[1]. Hiroya Nakao and Alexander Mikhailov have now tackled the problem of the effects of network structure on the emergence of so-called Turing patterns in nonlinear diffusive systems. With their study, reported in *Nature Physics*[2], they offer a new perspective on an area that has potential applications in ecology and developmental morphogenesis.

In the past decade the physics community has contributed greatly to the field of network science, by defining a fresh perspective to understand the complex interaction patterns of many natural and artificial complex systems. In particular, the application of nonlinear-dynamics and statistical-physics techniques, boosted by the ever-increasing availability of large data sets and computer power for their storage and manipulation, has provided tools and concepts for tackling the problems of complexity and self-organization of a vast array of networked systems in the technological, social and biological realms[3–6]. Since the earliest works that unveiled the complex structural properties of networks, statistical-physics and nonlinear-dynamics approaches have been also exploited as a convenient strategy for characterizing emergent macroscopic phenomena in terms of the dynamical evolution of the basic elements of a given system. This has led to the development of mathematical methods that have helped to expose the potential implications of the structure of networks for the various physical and dynamical processes occurring on top of them.



A complex beast. The markings on leopards and other animals might be a manifestation of Turing-pattern formation during morphogenesis[8,9]. A new framework for studying the Turing mechanism on complex networks should deepen our understanding of the process and its consequences. Image credit: © iStockphoto / Eric Isselée

It has come as a surprise then to discover that most of the standard results concerning dynamical processes obtained in the early studies of percolation and spreading processes in complex networks are radically altered once topological fluctuations and the complex features observed in most real-world networks are factored in[1]. The resilience of networks, their vulnerability to attacks and their spreading-synchronization characteristics are all drastically affected by topological heterogeneities. By no means can such heterogeneities be neglected: 'complex behaviour' often implies a virtually infinite amount of fluctuations extending over several orders of magnitude. This generally corresponds to the breakdown of standard theoretical frameworks and models that assume homogeneous distributions of nodes and links. Therefore systematic investigations of the impact of the various network characteristics on the basic features of equilibrium and non-equilibrium dynamical processes are called for.

The work of Nakao and Mikhailov[2], in which they study the Turing mechanism in systems with heterogeneous connectivity patterns, is just such an investigation. And an important one at that — the Turing mechanism[7,8] represents a classical model for the formation of self-organized spatial structures in non-equilibrium systems. In its simplest setting, Turing patterns can develop in reaction–diffusion systems, in which an activator enhances its own production while an inhibitor suppresses the activator. In 1952, Alan Turing showed that such an activator–inhibitor system can be destabilized when the inhibitor is more mobile than the activator[8]. This diffusion-driven dynamical instability leads then to the development of stable spatial patterns, formed by activator-rich and activator-depleted regions. Applications of the Turing mechanism reach from ecology to developmental morphogenesis, where it has been proposed as an explanation of the development of the pigment patterns in animals[9] (Fig. 1).

In their study, Nakao and Mikhailov[2] consider a specific example of an activator–inhibitor system, known as the Mimura–Murray ecological model. They place this model on top of heterogeneous networks and perform a linear stability analysis, which reveals the presence of the Turing instability for a given ratio of the diffusive constants of the activator and inhibitor. However, the instability is not, as one might expect and as other models assume, localized in the hubs (that is, in the most connected nodes of the network), but in a set of vertices in which the degree of connectivity is inversely proportional to the characteristic scale of diffusion. The segregation leading to the Turing patterns therefore takes place mainly in vertices with a low number of connections. The process proceeds by a differentiation of vertices with high and low concentration of activator, until a steady-state, stable pattern is achieved, leaving behind a non-homogeneous distribution of activator and inhibitor throughout the network.

Whereas Nakao and Mikhailov[2] do not provide any direct experimental evidence of their model, the study of Turing patterns in complex networks has potential practical applications in the field of theoretical biology. The reactions taking place at the early stages of development can be modelled more accurately using a network as a substrate, instead of a continuous parameter space. A handle on Turing patterns in networks may thus lead to a fuller understanding of basic issues in morphogenesis and early development. Furthermore, reaction–diffusion systems are also capable of describing the evolution of populations in an ecological environment, and the Turing mechanism could provide an understanding of the diverse distribution of species in ecological niches. Given that biological ecosystems can be most naturally represented in terms of complex networks, the work of Nakao and Mikhailov should open the path to new insight into this fascinating issue, as well as to the possible development of controlled experiments capable of checking the validity of their results. ❐

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ASTROPHYSICS

Magnetic bubble wrap

The orientation of the magnetic field wrapped around a galaxy cluster has been measured for the first time, through a previously unexplored combination of traditional astronomy and computer simulations.

Ian Parrish

Galaxy clusters are the largest objects in the Universe, and contain the largest galaxies and black holes. Only 3% of the mass of galaxy clusters is in the familiar form of stars, however: the majority (84%) is composed of dark matter, and the remaining component is a hot dilute plasma, known as the intracluster medium or ICM, that emits copiously at X-ray wavelengths. Yet despite their size and importance in the pantheon of cosmological objects, galaxy clusters still hold many mysteries. In particular, the interplay of heating and cooling in the clusters is poorly understood, as is the role of magnetic fields.

In astronomy, magnetic fields are one of the trickiest things to measure. Yet, as they report in *Nature Physics*, Christoph Pfrommer and Jonathan Dursi[1] have succeeded in making the first measurements of the orientation of magnetic fields in a galaxy cluster, for the nearby Virgo galaxy cluster. As well as being a measurement first, their technique — using computational simulations to complement observations — is a promising direction for progress in astrophysics.

Why do we care about magnetic fields in galaxy clusters? A major unsolved problem lurks near the centres of these objects, where the cooling time in the 5,000,000 K X-ray-emitting plasma is 100–1,000 times shorter than the age of the galaxy clusters. This would not be an issue except that we don't observe any gas cooling below 1,000,000 K (ref. 2). Therefore, something must be heating the ICM to prevent what is known as a cooling catastrophe, or cooling flow, from occurring. The two most obvious possibilities are black-hole feedback through energetic jets and bubbles, or thermal conduction from the hot plasma outside the core. The plasma is strongly magnetized and magnetic fields are amazing conduits of heat, having high thermal conductivity along magnetic field lines and nearly perfect insulation across magnetic field lines — but this means we need to know the magnetic geometry to assess the efficacy of heating by thermal conduction.

Magnetic fields, however, are notoriously difficult to measure remotely in space.