EDITORIAL

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Mesoscale spatiotemporal structures: opportunities from challenges

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There are major challenges in resolving the ever-present complexity in nature, science and engineering. The difficulty in analysing complex systems, invariably featuring spatiotemporal dynamic structures, is attributed to revealing the origin of these structures and formulating their conditions of stability. Since this conundrum has remained unresolved for a long time, various coarse-graining approaches have to be adopted for approximate descriptions. The recent proposition of the concept of mesoscience, having as its basis the principle of compromise in competition, opens a promising route to crack such a recalcitrant problem.

In studying the complex world, different logics and landscapes gradually emerge in many systems, roughly featuring multilevel, each multiscaled and complex at the mesoscale transitioning between the scale of individual elements and the scale of the entire system. Current approaches focus mainly on either the element or the system scale of the relevant level. Reductionist approaches strive to understand the details at the element scale, while holistic approaches focus on the behavior at the ensemble or system scale. However, a grand challenge remains for these two methodologies as to how to correlate and connect the interactions between elements with the system behavior. Some research has already revealed that the inherent complexity of mesoscale structures usually appear in the mesoregimes lying between two limiting regimes (each dominated by only one mechanism; another mechanism might exist, but without dominance), which is always dominated jointly by at least two different mechanisms.

For any complex structures, the root of complexity is attributed to compromise in the competition between different dominant mechanisms. The structure is usually simple when it is dominated by a single mechanism while it will necessarily be much more complex when at least two mechanisms (e.g. *A* and *B*) strive to dominate. Thus, generally speaking, three regimes occur successively as the change in relative dominance of *B* over *A* takes place: ***A*-dominated**, ***A*-*B* compromising in competition**, and ***B*-dominated** (*Engineering* 2016; **2**: 276–85).

Current methodologies are generally reliant on single-objective variational principles, either minimum or maximum, which are applicable to the structures related to the limiting *A* or *B* regime. However, processes in the critical mesoregime—that of *A*-*B* compromising in competition—requires that a multi-objective variational formulation be involved. This arises since neither *A* nor *B*, can by itself, fully determine the system behavior, and they therefore have to compromise in competition. To a certain extent, the process of compromise between mechanisms *A* and *B* reflects their common interest, resulting in a system that is dynamically stable. In other words, the extremum of any mechanism can seldom be realized exclusively, but can be realized *only* relatively and alternately with respect to time and space, leading to inevitable spatiotemporal dynamic changes—a hallmark of *complexity*! In such cases, the blurring two mechanisms into a single-extremum function is usually difficult. Of course, it is a usual—and understandable—practice to attempt to transform a multi-objective problem into a single-objective one, but this is fundamentally different in nature from that based on a single dominant mechanism. Ignoring this critical difference is the reason why the definition of stability for complex systems is notoriously challenging.

The concept of mesoscience is based on the core principle of compromise in competition. Instead of looking for a single-objective variational function directly, different dominant mechanisms at the mesoscales in mesoregimes are first analysed. The resulting variational functions are then defined and their compromise in competition is analysed, mathematically, leading to multi-objective variational formulation. Physically, the origin of complexity is related to the alternate appearance of states dominated by different mechanisms. This shift in research strategy from single-objective to multi-objective variational formulation might offer a glimmer of hope for understanding the complex world in which nature exists. The solution of such a multi-objective variational problem represents a continuing grand challenge. However, in some cases the possibility to transform it into a single-objective problem, particularly based on physical analysis, should certainly not be excluded.

The proposition of mesoscience was developed primarily from case studies in chemical engineering; its universality needs further investigation and evidence from many vastly different fields. There are still many specific issues to clarify in studying specific systems, and some descriptions and perspectives could be found in recent publications on the subject of mesoscience. We hope that such a perspective can lead to a broader discussion of this subject in the academic community with the objective of gradually identifying the best way to interrogate spatiotemporal systems, so as to enable better understanding the dynamics of such mesoscale problems and the mesoregimes in which they operate.

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