

Exploring geographical modal and its implication to support geographical integration

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Abstract: The balance of human-nature interactions is increasingly destabilized by climate change, urbanization, and socioeconomic shifts. These complex and dynamic processes constitute a regional complex—a holistic geographical system characterized by interacting elements within specific spatiotemporal contexts. A regional complex exhibits diverse states and behaviors across multiple spatiotemporal scales, posing significant challenges for regional governance, particularly in managing cross-scale interactions and system interdependencies. Effective regional governance requires modeling the regional complex and identifying its pivotal components (including key drivers and critical interactions), as accounting for all components is resource-intensive and impractical.

To address this challenge, an integrated modeling framework is essential to define a regional complex and identify the key drivers and interactions that shape regional dynamics. Such a framework should employ structured quantitative modeling of complex systems to ensure that the identification and characterization of critical components are evidence-based and generalizable across diverse regional contexts. Identifying these pivotal components enables targeted interventions that address main constraints on regional development. Furthermore, understanding the comprehensive characteristics of these components, such as their formation mechanisms, thresholds, and evolutionary patterns, is crucial for forecasting future trends, identifying critical tipping points, and assessing policy impacts to support sustainable regional development.

Influenced by reductionism, existing methods often overlook the interconnections among system components and the physical, biological, and socioeconomic processes that govern them. This limitation renders the identification of key components and their spatiotemporal characteristics incomplete or biased, undermining the ability to predict system behavior and formulate effective governance strategies. This situation highlights the need to combine structured quantitative modeling of regional complex with extraction of integrated characteristics from the pivotal components to enhance understanding of complex regional systems.

Across several disciplines, the foundational concept of “modal” has already shaped the understanding of system characteristics through system modeling. Building on the concept of “modal”, we propose GeoModal to extend its implication to regional complex. GeoModal refers to the spatiotemporal state, spatiotemporal behavioral, and cascading response characteristics of the pivotal components in a regional complex across different spatiotemporal contexts. These three characteristics are derived through the structural and quantitative modeling of specific regions of the Earth’s surface—including analysis of their constituent elements, spatiotemporal context, spatial patterns, evolutionary processes, and underlying mechanisms. The atmospheric modes and climate modes represent specific subsets in spatiotemporal behavioral characteristics. Beyond these concepts, GeoModal provides a broader, integrated representation of a regional complex by synthesizing its spatiotemporal state characteristics, behavioral characteristics and cascading response characteristics, derived through consideration of the system’s tipping elements, to inform comprehensive governance.

Over the past five years, GeoModal has been applied to uncover synergies and trade-offs among sustainable development goals at China’s provincial level, identifying key drivers, and to inform optimized pathways and policy recommendations for 66 countries along the Silk Road under diverse future scenarios. Deriving GeoModal requires thorough modeling of the interactions among the pivotal components within the regional complex. Thus, GeoModal provides a more adaptable and optimized approach for studying complex regional systems and supporting comprehensive geographical analysis.

Keywords: *Geographical Integration, Regional Complex, Geographical Modal*