Колеге из Народне републике Кине, **HongGuang Sun, Yingjie Liang** ће дана 14.07.2016 године, четвртак, одржати следећа предавања са почетком у 10 часова у сали 211, под насловом

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Anomalous diffusion: fractional derivative equation models and applications in environmental flows

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Structural derivative, implicit calculus equation, differential operator on fractal, and their applications

У прилогу су дати и одговарајући апстракти предавања.

Срдачан поздрав, У Београду, 21.06.2016

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Anomalous diffusion: fractional derivative equation models and applications in environmental flows

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Abstract:

Heterogeneity embedded in natural media and flow field challenge the application of Fick's 1st Law in anomalous diffusion well documented in many disciplines. Anomalous diffusion is one of the major topics in theoretical physics and statistical mechanics, and it is also the fundamental physical process with good potential application in environmental and hydrologic sciences and engineering. As a novel modeling tool in mathematics and physics, the fractional-order derivative diffusion equation models characterize anomalous diffusion with history-dependence and spatial non-locality, accurately describe the tailing in breakthrough curves of solute transport. We summarize the recent progresses and discuss the key challenges of fractional derivative diffusion equation models including the existed research and current development, fractional derivative modeling, numerical algorithms, and related applications in the field of environmental fluid mechanics. Here also made some preliminary discussions on issues of fractional derivative diffusion equation model, such as statistical description, model parameter determination and dimensional analysis, which may contribute to the further study of anomalous diffusion.

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Abstract:
This survey paper summarizes the latest advances of the first author’s group on the three new methodologies of fractional and fractal derivatives modeling to meet the increasing and challenging demands in scientific and engineering communities. Firstly, the structural derivative approach was proposed as a significant extension of the global fractional calculus and the local fractional derivative approaches to tackle the perplexing modeling problems. The classical derivative describes the change rate of a certain physical variable with respect to time or space, which rarely takes into account the significant influence of mesoscopic time-space fabric of a complex system on its physical behaviors. The structural function plays a central role in this new strategy as a kernel transform of underlying time-space fabric of physical systems. Secondly, we employed the fundamental solution or probability density function of statistical distribution which can describe the problem of interest to construct the implicit calculus governing equation. The “implicit” suggests that the explicit calculus expression of this governing equation is difficult to derive and not required. The fundamental solution or potential function of calculus governing equation and corresponding boundary conditions are sufficient to do numerical simulation. We call this strategy the implicit calculus equation modeling. Thirdly, based on the implicit calculus equation modeling approach, we introduced the concept of fundamental solution on fractal and consequently defined the fractal

differential operator to describe various mechanical behaviors of fractal materials. Fractal calculus operator significantly extends the application scope of the classical calculus modeling approach under the framework of continuum mechanics. This is also a step-forward advance of the fractal derivative proposed earlier by the first author. To demonstrate the structural derivative application, we applied the inverse Mittag-Leffler function as the structural function to model ultraslow diffusion of a random system of two interacting particles. On the other hand, this paper uses the fractional Riesz potential as the fundamental solution to establish the implicit calculus equation of fractional Laplacian modeling the power law behaviors of steady heat conduction in multiple phase material. Finally, by using the singular boundary method, we made numerical simulation of the fractal Laplacian equation for phenomenological modeling potential problems in fractal media. Numerical experiments show that all the three new methodologies are feasible mathematical tools to describe complex physical behaviors.