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# Reduced Order Modelling of Complex Systems

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## ABSTRACT

One of the major challenges in today's Science and Engineering fields is how to handle complex systems. Reductionist principles have helped the scientists and engineers to develop uncanny understanding of universe range from mechanical to electro-magnetic properties and phenomena. Ever since that famous quote from Albert Einstein, "God does not play dice," people often wonder what happened to seemly obvious uncertainties in nature. What would have happened if the Asteroid missed the Yucatan Peninsula in Mexico and the Earth 65 million years ago? The research in chaotic nonlinear systems seems to point us in a direction that even the deterministic nonlinear system can produce unpredictable results. Is it possible that when a large number of factors or entities interact with each other, they eventually yield a completely different system quantifiable with an entirely different set of phenomenological rules? Of course, the intermediate stage is characterized with a so-called positive Lyapunov exponent. It is not difficult to imagine that a large or infinitely large positive Lyapunov exponent will lead us to a stochastic or random system. In this work, we will explore and explain such complex systems.

The accurate description of physical, chemical, and biological phenomena over a wide range of spatial and temporal scales is extremely difficult. The intricate nature of turbulence poses seemingly insurmountable challenges to scientists and engineers. In practice, various hierarchical modeling techniques have been explored. However, the concurrent coupling which is more relevant and ubiquitous in biological systems has not yet been fully understood. It appears that various modeling techniques eventually depend on the singular value decomposition, a common method to identify rank, left null space, column space, right null space, and row space for any rectangular matrix. Using the singular value decomposition, it is possible to identify the hidden spatial and temporal correlations and patterns between variables and material properties. It is hopeful that based on the singular value decomposition a computational protocol for complex dynamical systems can be established to handle complex biological materials. In an example published earlier in Refs. [1] [2] [3], normal and sickle red blood cells were studied at molecular and cellular levels.

## REFERENCES

[1] T. Wu, S. Wang, B. Cohen, and H. Ge, "Molecular Modeling of Normal and Sickle Hemoglobins," *International Journal for Multiscale Computational Engineering*, 8, pp 237-244, 2010.

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[3] S. Wang, "Immersed Methods for Compressible Fluid-Solid Interactions" in *Multiscale Simulation and Mechanics of Biological Materials*. Chapter 12, Wiley, 2012.