Communication Theory and Multi-Element Physical Systems

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Children are fascinated by *assemblages* of things. Marbles bounce off one another, gears mesh in a clock movement, an electric motor runs by magic, droplets slide, coalesce and slide again down a window pane, and any number of living creatures walk, crawl, cooperate and battle – providing hours of entertainment and pondering. What is the mechanism of interaction? How do the parts affect one another? Can the future evolution of the system be predicted through careful observation? Though the questions are framed from the perspective of an adult, they are those of any curious child. As scientists and engineers, the systems we consider are often more complex, but the basic structures and questions remain in some sense the same. We study systems of *interacting elements* be they electrical circuit components, finite-element volumes, fundamental particles, chemical species in reaction kinetics, computers in a network, or biological organelles and organisms.

Interaction is often defined in terms of empirical observation about outcomes and relationships – reactants move toward some equilibrium, momentum and energy are conserved, elements of an organism "signal" each other chemically, mechanically and electrically. These observations are mathematically framed and the resulting equations often have great predictive power – which is the whole point of science. However, any interaction is a communication and communication implies some sort of information exchange, in essence a quantification or even digitization of what is knowable about systems and their elements. So, to any communication theorist trained in the physical sciences, a basic question comes immediately to mind – *what are all these interacting elements saying to one another, how are they saying it and can I listen in?*

We are carefully examining multi-element physical systems under a formal communications theory lens. By casting systems usually represented by differential equations in a communication-theoretic framework we produce an implicit quantization of element states and interactions which allows various powerful analytic concepts and tools to be applied. We can thereby explore ways by which systems can be observed and/or actively probed to obtain information about their structure or behavior. How precisely such information can be conveyed is subject to information-theoretic bounds based on available energy. Furthermore, these bounds are *mechanism-blind* – energy constraints place inviolable limits on how much information can be reliably conveyed. Thus, energy constrains communication possibilities and thereby gross behavioral possibilities as well.

Overall, our research goals are to:

- Recast multi-element physics at a variety of scales in terms of communication theory
- Explore the conceptual and computational implications of information-based descriptions.
- Quantify and understand information flow across size scales in multi-element systems.
- Identify practical uses of "physics/biology as communication theory."