

Extending the Reach of Info-Metrics to Dynamics and Non-Hierarchical Complex Systems

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A Joint Info-Metrics and Santa Fe Institute Working Group

AHA, WATSON! YOU CAN SEE FROM THE ARRANGEMENT OF THE ROOM THAT THERE HAS BEEN A GREAT INCREASE IN ENTROPY. THIS SUGGESTS THAT THE MURDER OCCURRED SOME TIME IN THE PAST.



Fortunately, Sherlock Holmes never studied physics.



The Questions (two interdependent questions – both related to our understanding of complex systems):

Q1 - 'Hierarchical Organization' of a system:

- Can those same info-metrics tools (that also include the tools of information theory and the maximum entropy principle) provide insight into the properties of complex systems for which discrete hierarchical scales are not readily resolvable?
- Is there a distinction (and if so, what it is) between complex systems that are organized into discrete hierarchical levels and those for which no such delineation of discrete hierarchies is possible?
- Are systems of the second type in some practical sense more complex than those of the first type?

Q2 - Systems far away from equilibrium.

- Is the failure of information-theoretic approaches when applied to far-from-steady-state systems (such as in ecology) true across complex dynamic systems in general?
- Can the inferential tools of information theory and info-metrics be modified and extended to provide insight into the dynamics of rapidly changing complex systems?
- Does the answer depend in any way on whether or not the system has discrete hierarchical levels of organization?
- Will the introduction of additional uncertainty about the constraints (information) be useful in that case?

Info-Metrics – The Very Basic Idea:

The available information (for modeling, inference and decision making) is most often insufficient to provide a unique answer or solution for most interesting decisions or inferences for problems across all disciplines.

Implication:

There is a continuum of solutions (models, inferences, decisions) that are consistent with the information (most often ‘circumstantial’ evidence/data) we have.

Therefore:

We can impose many different requirements on the data. These requirements/information can be correct or not. Regardless, they force the data to ‘confess’ too fast. Different requirements (‘tortures’) will result in different solutions (confessions), most are untrue.

Classical methods:

Impose too much structure. They torture the data to confess too fast.

Info-Metrics:

Uses minimally needed information (minimal/no torture)

Info-Metrics: Definition

info-metrics is the science of modeling, inference, and reasoning under conditions of noisy and insufficient information.

- It deals with the question of how to model effectively, draw appropriate inferences, and make informed decisions when dealing with inadequate or incomplete information.
- It also deals with the complementary question of how to process the available information while imposing minimal assumptions (or structures) that cannot be validated.

The Suggested Solution/framework:

A Constrained Optimization Framework

- Information as constraints – or stochastic constraints;
- Objective function defined simultaneously on the entities of interest and the uncertainty surrounded the information/model.

The info-metrics framework combines the tools of information theory and statistical inference within a constraints optimization framework

More precisely:

All inferential (and modeling) problems can be converted to optimization problems:

Optimize a **Certain** Decision Function

Subject to

Constraints (Information; 'conservation laws')
(normalization)

The issues:

- What **certain** function to optimize? (Entropy)
- Constraints (what constraints? How to specify? Validate? Uncertainty?)
- Priors (from where?)
- Soft information (validate? Quantify? Measure?)

Info-Metrics Framework for Modeling and Inference

The Info-Metrics Framework:

- Allows us to accommodate for all types of uncertainty about the system we model (including model uncertainty).
- Allows us to derive 'approximate theories' and inference for evolving and/or complex systems
- Under traditional approaches accommodating for these uncertainties demands imposing more information – information and structure that we usually don't know and most often cannot validate. We 'Torture' the information (or data) – making it 'Confess' too fast
- Info-metrics provides a framework that can be used for modeling, inference, and problem- solving across all the scientific disciplines. It is a complete framework for modeling and inference rather than a model for solving a specific problem.

The info-metrics framework also creates synergies between distinct scientific fields and create a common scientific language, bridging disciplines while allowing us to incorporate discipline- specific and problem-specific information.

Now, to John and the Questions!



Thank You!!