Condensed Matter > Statistical Mechanics

Information Symmetries in Irreversible Processes

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(Submitted on 12 Jul 2011)

We study dynamical reversibility in stationary stochastic processes from an information theoretic perspective. Extending earlier work on the reversibility of Markov chains, we focus on finitary processes with arbitrarily long conditional correlations. In particular, we examine stationary processes represented or generated by edge-emitting, finite-state hidden Markov models. Surprisingly, we find pervasive temporal asymmetries in the statistics of such stationary processes with the consequence that the computational resources necessary to generate a process in the forward and reverse temporal directions are generally not the same. In fact, an exhaustive survey indicates that most stationary processes are irreversible. We study the ensuing relations between model topology in different representations, the process's statistical properties, and its reversibility in detail. A process's temporal asymmetry is efficiently captured using two canonical unifilar representations of the generating model, the forward-time and reverse-time epsilon-machines. We analyze example irreversible processes whose epsilon-machine presentations change size under time reversal, including one which has a finite number of recurrent causal states in one direction, but an infinite number in the opposite. From the forward-time and reverse-time epsilon-machines, we are able to construct a symmetrized, but nonunifilar, generator of a process---the bidirectional machine. Using the bidirectional machine, we show how to directly calculate a process's fundamental information properties, many of which are otherwise only poorly approximated via process samples. The tools we introduce and the insights we offer provide a better understanding of the many facets of reversibility and irreversibility in stochastic processes.

Comments:	32 pages, 17 figures, 2 tables; this http URL
Subjects:	**Statistical Mechanics (cond-mat.stat-mech)**; Information Theory (cs.IT); Statistics Theory (math.ST); Chaotic Dynamics (nlin.CD)
Cite as:	**arXiv:1107.2168 [cond-mat.stat-mech]**
	(or **arXiv:1107.2168v1 [cond-mat.stat-mech]** for this version)

Submission history