A set of physical macroscopic observables for communities

P. Fraundorf
*Physics Department, U. Missouri-StL (63121), St. Louis, MO, USA**

(Dated: June 28, 2008)

Information theory has been applied successfully, in the fields of thermodynamics and statistical mechanics, to studies of the collective behavior of atoms and molecules. A similar information theory approach to the study of our most complicated living systems, communities of individuals, remains an oft touted but elusive goal. It is the thesis of this paper that the key macroscopic observables appropriate to such a theory are the sustained patterns of constrained behavior (i.e. in physical terms: the dynamical states; in biological terms: the niches) associated with individuals, provided that the communities are examined over time scales comparable to or longer than the lifetime of the individuals making them up. Sustained constraint patterns or niche categories actually observed in human and animal communities generally involve the welfare of either an individual, a pair bond, a family, a social hierarchy, a cultural belief systems, or a field of specialized literacy. This niche structure is a tangible, and in fact extremely important, physical part of the world we live in. Its explicit recognition provides insight into some themes of popular and traditional culture, puts some old questions from the social and biological sciences into a new light, and provides a set of macroscopic observables which could serve as basis for construction of a physical paradigm[1].

PACS numbers: 05.70.Ce, 02.50.Wp, 75.10.Hk, 01.55.+b

CONTENTS

I. INTRODUCTION

This article stems from a desire to find simple conceptual approaches which are well informed to constraints imposed by reality[2] in the study of communities of individuals. The specific goal is to identify (qualitatively at least) a fundamental set of physical observables for such systems. Following the success of statistical mechanics in elucidating the behavior of macroscopic observables in liquids, gases and solids[3], this may provide a starting point for a better understanding of communities and the relationship between macroscopic and microscopic observables fundamental to them. Goals of this sort have been expressed in the literature on numerous occasions[4–7]. We propose that progress toward their attainment has been hindered by lack of an appropriate set of observables with which to begin.

Inspiration for the dynamical state paradigm used by us to identify appropriate observables also comes from the physical sciences. The usefulness in general of physical science tools in applying these constructs to the social systems for which they are designed, however, is limited because communities of individuals differ in fundamental ways from the systems usually targeted for application of such tools. We've examined application of the dynamical state formalism discussed here, in various contexts during the past decade. Our observations suggest that it has promise as a unifying paradigm, even though the task of appropriate quantification remains formidable. This note has been assembled so that researchers, in diverse fields of potential impact, might consider the match between this dynamical state paradigm and their own observations.

Because we address phenomena which are in Kuhn's "pre-paradigm" state as far as physical theory is concerned, the emphasis here is on established facts viewed in the context of a new frame of reference, rather than on new data about issues arising within an established frame of reference. The objective is to provide elements of a framework for asking new questions, and thus to help focus, as well as to explain, the enthusiasm expressed by other authors for the potential of information theory concepts in the study of our most complicated systems.

TABLE I: Niche or constraint types

1.	individual
2.	pair bond
3.	family
4.	social hierarchy
5.	cultural belief system
6.	field of specialized literacy

II. STRATEGY

The basic idea is simple. Communities of individuals can be looked upon as physical systems, albeit ones which are very complicated. The challenge is to find a set of patterns in the behavior of these systems that will serve as macroscopic observables in the information theory sense. Since there must be an objective basis for recognizing these patterns if we are to share perceptions, the strategy was to step back and consider behavior of these systems over time scales comparable to or longer than an individual life. Following well-worn tradition in the physical sciences, we then considered the nature of the various dynamical "states" occupied by the individuals making up these systems.

III. OBSERVATIONS

In stark contrast to the comparatively black and white worlds familiar in theoretical physics, we find in animal and human communities that individuals occupy dynamical states of bewildering diversity, irreproducibility, and extent. The common assertions that "all electrons are alike" while "all individuals are different" highlight nicely the underlying difference between elementary systems from whose study we glean inspiration, and the complicated systems in which we seek insight. Nevertheless, patterns exist. If we think about our understanding of the behavior of individuals in a social system, the constraints to which their actions are informed can be classified loosely into six classes (Table 1). Empirically, we might say that individuals buffer (look after, or act in ways informed to) constraints associated with each niche type with varying ability, motivation, and persistence.

The niche concept itself is hardly new. It is applied in human communities, for example, each time someone asks: if their acquaintance can look out for his or her self, if their colleague can be counted on as a friend, if they themselves are playing the role of a good parent, if a regular voting record is in their case prerequisite to being a good citizen, if stealing would constitute betrayal of their belief system, and if they are living up to their own professional standards. The assertions specific to this paper are instead: (i) that these niche structures constitute macroscopic observables appropriate for a physical theory, and (ii) that this state structure of a community, following information theory principles, may be represented by a set of six non-negative numbers, one for each of the constraint types listed in Table 1.

The information theory argument is elementary. Let $I = S_o - S$ be the information in structure associated with a system comprised of N subsystems. Here, S_o and S are information-based uncertainties (entropies) for the state of the system, of the sort generalized from thermodynamic entropy by Shannon[8] and Jaynes[3] to take into account information on arbitrary macroscopic observables. In particular, S_o is some reference uncertainty for the system which assumes: (A) a minimum of information about the subsystems, and (B) that the state of the subsystems is uncorrelated. In the case of a community of individuals, for example, S_o might assume that the individuals are all humans, and nothing more. S is defined as the uncertainty (fine-grained entropy) associated with the state of that system, given all that we know. We can then write the information in structure (i.e. net surprisal) as:

$$I = \sum_{i=1}^{N} I_i + C. \tag{1}$$

Here, I_i is the microscopic information associated with the state of the ith subsystem, and C is the correlation information. The I_i are non-negative by assumption (A), while C is non-negative by assumption (B) and equal to zero if and only if there is no evidence for correlated subsystem states[9]. Protocols for general application of information-in-structure concepts have been discussed recently by Lloyd and Pagels[10], where the quantity I is there referred to as thermodynamic depth. In thermodynamic ("energy-type" work) systems this measure is closely related to the well-known free-energy measures for potential work[11–13].

We here focus on the information in structure associated with a community (system) of individuals (as subsystems). In that case, C can be rewritten as a sum of positive correlation terms C_j (j=2,6) associated, respectively, with the five (often overlapping) correlated-behavior state types listed as 2 through 6 in Table 1. The assertion that we may legitimately assign non-negative numbers with some additive significance to each of the entries in Table 1, based on our knowledge of a given community, is thus established.

One of the reasons that we do not address quantitation here is that it has a long history of informal consideration, in contexts such as those mentioned in the paragraph before last. Any original solutions to the general problem are likely to be difficult to find. Another reason is that simple schemes for assigning numbers are going to pale beside the rich detail and diversity inherent in a real living example. As much as a physicist may long for elegant equations which summarize all that we know in a specific case, this will not be. Immediate prospects for quantitative application seem to lie instead in the contribution of foundation-related insights to strategies for quantification already under development in the many social and biological science areas on which these observations bear.

The primary thesis is that this occupied niche structure, however difficult to quantify, is tangible physical structure. In much the same way that the state of an electron might not be apparent at all if we were able to take a snapshot of it at a single instant of time, so the niche structure of a community is not apparent if we take a snapshot of the community on time scales short compared to an individual life. But these structures nevertheless fit the definition adopted here for a dynamical state, i.e. they indeed are sustained patterns of constrained behavior.

As a simple example, consider the community role for behavior associated with the classical dance discipline of ballet. Conventional wisdom in human communities (the empirical source that we cite here) is likely to recognize a lifelong commitment to the discipline of ballet as an important element of structure. A lifetime's worth of transient commitment to one discipline after another, by comparison, is unlikely to offer a contribution of the same magnitude. This observation can be made not only for other specialized literacy niches, but for patterns of constrained behavior in the other areas listed in Table 1 as well.

In general, it appears that the noble passions of individuals (e.g. sustained commitments to be a good companion, friend, spouse, parent, citizen, manager, parishioner, chaplain, professional, or scholar) give rise to the lifelong patterns of constrained behavior that we discuss here. In special cases, a subset of these states endure over periods of time longer than the physical lifetime of individuals in a community. The oft-spoken desire to "leave a positive mark on society" in one way or another is empirical evidence of the importance attached to patterns of constrained behavior which outlive the individual giving them a start.

IV. DISCUSSION

The foregoing seems to establish sustained patterns of behavior, informed to one or more of the constraint types listed in Table 1, as legitimate macroscopic elements of physical structure in communities. We would also like to argue that these dynamical states represent in some sense a complete set of such observables. This feeling is supported by our recognition of niche structure as the primary macroscopic observable in more spatially and temporally microscopy communities (e.g. those of ants, bees, and termites). If such long term niches do represent a complete set of macroscopic observables associated with community structure (however unique and irreproducible these niches appear to us when we view them in human communities), then it is in the relationship between these macroscopic observables and the microscopic variables of any specific field (e.g. economics, psychology, geography) that physical insights in the information theory sense area likely to arise. The first area of needed work, therefore, is in methods with which to inventory these dynamical states. An immediate practical application for such monitoring methods, of course, would lie in the provision of means to assess the effect, over and above "body count", of natural and man-mediated disaster.

A more day-to-day need for explicit awareness of the details of dynamical state structure in communities arises because the familiarity that individuals have with disparate parts of the niche structure, and in particular with what works and what does not work, is sometimes limited. For example, one finds in places a difference in perception between workers in industry and university (regardless of whether their mandate is applied or basic, experimental or theoretical) in which the former take pride in their ability to solve problems posed from without, while the latter take pride in their ability to solve problems posed from within. The difference in emphasis stems from valid insights into what often works, in the former case in context of a specialized literacy niche.

Since an understanding of both types of niche is important in both types of job assignment, explicit awareness of the insights underlying these differences has proven useful for each type of job. This understanding is useful in communication between different job assignments as well. The result, in short, is behavior informed to constraints pertaining to both types of niche. The balance sometimes brings tangible advantage. For example, externally imposed problems have repeatedly brought into our lab an influx of information. This has in turn injected life into internal programs which would have languished under more sheltered conditions. Since externally imposed problems are a distaction as well, the optimum lies in a balance between extremes.

Recognition of the niche structure as physical also puts some old questions into new context. Some of the questions concern emergence of these niche structures in the organization of life on earth. For example, there appears to be evidence in the literature that, in addition to worrying about their individual survival, animals commonly buffer niches in the pair, family, and social hierarchy categories[14,15]. However, belief system (cultural/religious) and specialized literacy (professional/scholarly) niches of responsibility might be found only in human communities. Questions concerning the role of developments in human communication (e.g. speech and typography)[16] in creating these two niche types take on new light, since their answers in this context bear on physical requirements for activation of such dynamical modes in any community of individual life forms, regardless of the biological detail.

A second question which is given novel perspective concerns the mechanism underlying utility for the concept of freedom in American culture. The concept of freedom historically does not center around the right to cast off constraints associated with participation in the human community. It centers instead (rather neatly) around the right of individuals to choose the object of their passion in the matters of friendship, marriage, government, religion, and profession outlined in Table 1. If individuals are as unique and full of surprises as we (as individuals) like to think, then who will be better informed to decide on the object of those passions (in the interest of the community) other than the individual who is their source. A mechanism, ground in information theoretic constructs, to explain the workability of a tradition is thus hinted at by the formalism. Of course, the impact of this mechanism on the survival of communities, like the impact of mechanisms underlying survival of individuals, will never be possible to evaluate in any general terms (save in this handwaving and subjective manner), because of the role of an unspecified and changing environment in their success.

V. CONCLUSION

The formalism proposed above has potential as a unifying physical paradigm, in the biological and social sciences concerned with the behavior of individuals (e.g. ethology and political science) as well as in popular and traditional culture. We make a case that the niche types discussed are physical states whose structure is well-defined when examined over time scales comparable to or longer than the lifetime of an individual. Their recognition as part of the physical structure associated with a community, or collection of communities, is therefore legitimate.

Consideration of this insight concerning information-in-structure in specific application areas in the next step. In recent decades diverse authors have argued that properly informed physical theories, in particular those grounded in information theory, are capable of non-mechanistic approaches that may be helpful with systems of this sort. The simple-minded observation here, of a limited set of dynamical state types observable over time scales on order of an individual lifetime or longer, will hopefully stimulate some cautious and constructive thinking along these lines.

ACKNOWLEDGMENTS

This research has been supported in corollary fashion by diverse funding agencies over the past decade. We thank especially G. Keefe for critical readings of the manuscript, and E. T. Jaynes for inspiration.

REFERENCES

* Monsanto Report MSL-8857 (Monsanto Information Services, St. Louis MO, 1989)
[1] T. S. Kuhn, *The structure of scientific revolutions* (U. Chicago Press, 1970), 2nd ed.
[2] R. P. Feynman, R. B. Leighton, and M. Sands, *The Feynman Lectures in Physics* (Addison-Wesley, Reading Massachusetts, 1963).
[3] E. T. Jaynes, Phys. Rev. **106**, 620 (1957).
[4] L. von Bertalanffy, *General systems theory: Foundations, development, applications* (G. Brazilier, New York, 1968).
[5] W. M. Elsasser, *Atom and Organism* (Princeton U. Press, Princeton NJ, 1966).
[6] E. Schrodinger, *What is Life?* (Cambridge U. Press, 1944).
[7] I. Prigogine, in *Theoretical physics and biology*, edited by M. Marois (North Holland, Amsterdam, 1969), p. 23.
[8] C. E. Shannon and W. Weaver, *The Mathematical Theory of Communication* (University of Illinois Press, Urbana, IL, 1949).
[9] L. Brillouin, *Science and information theory* (Academic Press, New York, 1962), 2nd ed.
[10] S. Lloyd and H. Pagels, Annals of Physics **188**(1) (1988).
[11] E. L. Knuth, *Introduction to statistical thermodynamics* (McGraw-Hill, New York, 1966), original ref had "cf." before it, and p. 200 specified.
[12] R. B. Evans, PhD dissertation, Dartmouth College, Hanover, NH (1969).
[13] M. Tribus and E. C. McIrvine, Scientific American **224**(3), 179 (1971).
[14] K. Lorenz, *King Solomon's ring: New light on animal ways* (Crowell, New York, 1952).
[15] R. Chauvin, *Ethology: The biological study of animal behavior* (International Universities Press, New York, 1977).
[16] M. McLuhan, *Understanding media: The extensions of man* (McGraw-Hill, New York, 1964).