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The Use of Negentropy as a Measure of Democracy

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Key Words--Entropy; second law of thermodynamics; information theory; negentropy; political system; democracy; media access allocation.

Abstract--This article develops and illustrates the hypothesis that key tenets of information theory, in particular the mathematical equations for the discrete noiseless communication channel, can be applied by analogy to measure the level of human freedoms (i.e., degree of democracy) of a political system and to allocate access to political communication channels. Application of these equations provides a basis for maximizing negentropy, ~~strengthening democratic institutions,~~ and in general countering the natural tendency for entropy to increase and for order in the universe to be transformed into disorder, but [illegible] 7

1. INTRODUCTION

The still largely unrealized potential application of general systems research to the political process has been recognized for decades by researchers such as Wiener [26, 27], Bertalanffy [4], Deutsch [7], Easton [9], Ericson [11], and Miller [18]. The purpose of this article is to use a general systems approach in applying selected concepts from engineering systems, specifically information theory and the mathematical theory of communication (as first developed by Shannon [22] and Weaver [23]), to measure the level of democracy and allocate media access in a political system.

This article is addressed in part to the relatively recent and growing political opportunities and problems presented by the "Information Era" (sometimes also known as the "Communications," "Computer," or "Microchip" Era or Age, see Ericson [12], Wood [9, 32]). During the present "Information Era," the dominant technologies are information processing and intelligence amplifying technologies such as the transistor, integrated circuit, computer, broadcast and cable television, electronic mail and bulletin boards, and the like. The diversity of media available for political communication is itself an opportunity but presents problems in terms of: the potential for information overload (too many channels, too much information), the allocation of access to the most heavily used channels, and, in general, the balancing of diversity and centrality in the political process necessary to maintain a democratic and stable society.

[illegible]

The central hypothesis of this article is that several key tenets of the communication theory that work for the design and implementation of physical engineering systems can also be applied to political systems in order to maximize the negentropy of the communication (and political) systems and thus counteract the tendency of physical (and social) systems to run down or deteriorate (increase in entropy) over time.

This article first develops in some detail the theoretical underpinnings of the central hypothesis, and then illustrates its application to measuring the level of democracy in city or nation-states and to the allocation of media access for political communication. The article concludes with a brief discussion of the implications for possible use of entropy-like measures in the conduct of domestic and foreign policy.

2. THEORETICAL CONSIDERATIONS

The theoretical basis for the proposed general systems approach to measuring the level of democracy and allocating media access in a political system includes the concepts of entropy, information theory, negentropy, and the discrete noiseless communication channel model.

The concept of entropy was first developed by Clausius in about 1850 when he synthesized the work of Mayer, Joule, and Helmholtz with the work of Carnot and Claperyon to form a well organized theory of thermodynamics [1, 8]. The concept of entropy was initially used by engineers and scientists in understanding and developing the steam engines of that era, for example, how to design an engine with ideal efficiency when working between two given temperatures [1, 3, 8]. In general, entropy has been defined as a measure of the unavailable energy or disorder of a closed thermodynamic system or, in mathematical terms, a constant multiple of the natural logarithm of the probability of occurence of a particular molecular arrangement. Thus, as a closed thermodynamic system uses energy and "runs down," the entropy of the system will increase since the diversity of molecular arrangements will decrease and the probability of the remaining molecular arrangements will increase.

The second law of thermodynamics can be stated quite simply that: a closed system always evolves spontaneously toward the most probable state of matter and energy within itself. An alternative statement of the law is that, within any closed system, the direction of spontaneous change is always from order to disorder, with a maximum of disorder and entropy as the ultimate equilibrium state [1, 3, 8].

The implications of the second law have led some scientists to suggest the need to counteract the natural tendency toward disorder. For example, R.B. Lindsay has proposed a "thermodynamic imperative" as follows: "All men should fight as vigorously as possible to increase the degree of order in their environment, i.e., consume as much entropy as possible, in order to combat the natural tendency for entropy to increase and for order in the universe to be transformed into disorder, in accordance with the second law of thermodynamics" [16]. This is consistent with the view of physicist E. Schroedinger who, as early as 1945, suggested that life processes represent local reversals of the degradation processes predicted by the second law and that biological evolution can be related to increasing negative entropy [21].

We are proposing a modified thermodynamic imperative which uses the concepts of entropy and negentropy to link the physical world of thermodynamics with the political world of information. As early as 1928, the astronomer A.S. Eddington identified entropy as a potential link between empirical science and humanistic values [10]. And in 1929, the Hungarian physicist L. Szilard pointed out more clearly the relationship between entropy and information. Szilard used a hypothetical "Maxwell's demon" to illustrate how information is gained (or lost) as the entropy of a gas decreases (or increases) [24]. And in 1948, C. Shannon developed the mathematical theory of communication, which became known as information theory, and defined information negentropy (negative entropy) as a measure of the average number of bits of information in messages on a communication system that convey information not already known to the receiver or, in other words, the level of diversity of information [22]. In information theory, negentropy is also referred to as communication entropy. In order to avoid confusion, we use only the term negentropy (see also Brillouin [5], Tribus and McIrvine [25], Cherry [6], Bell [2], and Pierce [20]).

In mathematical terms, thermodynamic entropy can be defined as:

$$S = k \cdot \ln(P) \qquad \{1\}$$

where S is entropy, k is the Boltzman constant, ln means natural logarithm, and P is the number of elementary states of the system.

The information negentropy of a discrete noiseless communication channel can be defined as:

$$H = -[P_1 \ln(P_1) + \ldots P_k \ln(P_k) + \ldots P_n \ln(P_n)] \qquad \{2\}$$

where H is information negentropy, ln means natural logarithm, and P_k is the probability of occurrence of message k over the communication channel.

Our general systems hypothesis is that, if we take the formula for information negentropy of a set of messages over a discrete communication channel (e.g., over a telephone line) and substitute a set of political freedoms, the probabilities of occurrence of the respective political freedoms assumes a role analagous to the probabilities of occurrence of the set of messages. Stated more formally, the hypothesis is that: the negentropy of a political system can be approximated by calculating the negentropy of a set of messages that might be sent over an equivalent pair of wires such that the political system corresponds to the discrete noiseless communication channel in information theory, and that the set of freedoms in the political system corresponds to the set of messages sent over the isomorphic electrical communication system. The mathematical formula for this hypothesis is obtained by replacing H in equation {2} by D and P_k by G_k, as follows:

$$D = -[G_1 \ln_2(G_1) + \dots G_k \ln_2(G_k) + \dots G_n \ln_2(G_n)] \qquad \{3\}$$

with the restraint that

$$G_1 + G_2 + \dots G_k + \dots + G_n = 1.00 \qquad \{4\}$$

where D is political negentropy, $\ln_2$ means logarithm to the base 2 (use of $\ln_2$ instead of ln is arbitrary to facilitate computation), G stands for the probability of occurrence of a particular political freedom (or set of freedoms), and the subscript k refers to a single individual or group or class of invididuals with a similar freedom (or set of freedoms). Equation {4} must sum to 1.00 because it expresses the entire range of probabilities of political freedoms held by the individuals or classes of individuals within a given society, with the probability of each freedom (or set of freedoms) calculated by dividing the population holding that freedom by the total population. The so-called political negentropy of equation {3} provides an estimate or measure of the diversity or distribution of political freedoms in a society (e.g., a city or nation-state) which we call its degree of democracy.

In sum, then, the theoretical basis for this paper is the development of entropy-like properties of political systems (and, more generally, social systems) such that mathematical equations from thermodynamics and information theory can be applied to the analysis of political systems, using negentropy as a primary measurement tool. This assumes that the political system can be represented at least in part by mathematical equations designed originally for physical (e.g., energy-matter and electrical communication) systems. When a mathematician, physicist, or engineer represents a physical system by a mathematical model, a completeness theorem can be specified. The theorem can be used to prove if the mathematical model does in fact represent the physical system with less than a specified error (see Margenau and Murphy [17]). However, it is difficult if not impossible to prove a completeness theorem for political (or, in general, social) systems. As noted by D.T. Ingle, "[i]t is one of the implications of a review of cause-and-effect relationships that it is theoretically as well as practically impossible to prove the completeness of any mathematical or physical model of a living or social system" [15]. As an alternative to a formal completeness theorem, a checklist could be developed that included other parameters besides negentropy. In this sense, negentropy, however important, must be viewed as only a partial and approximate indicator or measure of a political system.

An approach for testing such hypotheses in the absence of a formal completeness theorem is to compare the hypothesis against the results of a range of deductive, inductive, empirical, and experimental tests. This is the approach used for testing the validity of hypotheses such as the special theory of relativity where a formal completeness test is not possible (see

Panofsky [19] and Holton [14]). In the following sections, the political negentropy hypothesis is illustrated through its application to a variety of hypothetical situations.

3. POLITICAL NEGENTROPY OF CITY-STATES

The first example illustrates an application of negentropy as a measure of democracy in a city or nation-state. For this illustration, negentropy will be calculated for six hypothetical city-states (i.e., political systems) of 100,000 population each with six different forms of government: ideal democracy, democracy with 10 percent underprivileged, partial democracy with class discrimination, oligarchy with a 12 person ruling elite, caste system, and dictatorship.

The different forms of government are defined in terms of 10 assumed components of human freedom. These could vary, but for purposes of illustration, the 10 freedoms are:

- freedom of speach
- freedom of religion
- freedom of the press
- freedom to form a family
- freedom to obtain an education
- freedom from job discrimination on account of race, religion, sex, or national origin
- freedom to rent, buy, or build a home
- freedom to vote
- freedom to have a trial by jury
- freedom to establish a small business or farm

Recall that in equations {3} and {4}, G stands for the probability of occurence of a particular freedom or set of freedoms. In order to obtain a quantitative measure of freedom that behaves like a probability function, a normalized variable G_i is defined as:

$$G_i = F_i/n \qquad \{5\}$$

where F_i is a measure of freedom, n is the population of the city-state subsystem (individuals or a group within the city-state), and subscript i stands for each subsystem within the city-state. The total F_i is the sum of F_f for each of the 10 freedoms listed above. For an ideal democracy, F_f is assumed to equal 0.1 for each of the 10 freedoms and for all members of the city-state, and $F_i = 1.0$. Thus, for each person in a city-state with a population of 100,000, $G_i = F_i/n = 1.0/1.0\text{x}10^5 = 1.0\text{x}10^{-5}$. For other forms of government, the values of F_f are assumed to vary, with values greater than 0.1 indicating a greater level of a specific freedom and values less than 0.1 indicating a lesser level of a specific freedom.

Thus, for example, for a hypothetical partial democracy, 10 percent of the 100,000 total population is assumed to be underprivileged with a measure of freedom F_i =0.34, 80 percent of the population is assumed to have $F_i = 0.1$, and 10 percent is assumed to be overprivileged with $F_i = 1.66$. Treating the lower and upper population groups as classes and the middle group as individuals and then normalizing (dividing by the class size as a percent of the total or by the number of individuals) yields G_i values of 0.034, $1.0\text{x}10^{-5}$ (for each of 80,000 persons), and 0.166 respectively. Remember that according to equation {5}, the G_i values must sum to 1.0, which they do.

Once the normalized probabilities of freedom are calculated, equation {3} can be used to calculate the political negentropy of the distribution of freedom for each of the hypothetical city-states. The assumptions and calculations for the hypothetical partial democracy are shown in Fig. 1. The results of the negentropy calculations for all six hypothetical city-states are shown in Fig. 2, and range from a high of 16.61 entropy units for the hypothetical ideal democracy to a low of 3.10 entropy units for a dictatorship. The results are consistent with expectations, since the democratic forms of government accomodate a much higher level and broader diversity of freedoms among the population, and thus higher negentropy, while the dictatorial forms of government accomodate a high level of freedoms for only a very few persons and result in lower diversity and negentropy.

[illegible] the [illegible] measure.

[Fig. 1 and Fig. 2 About Here]

While the above calculations were carried out for hypothetical city-states of 100,000 population, similar calculations can be carried out for different populations. Fig. 3 shows the negentropy for two forms of government, ideal democracy and dictatorship, for various populations and with all other assumptions unchanged. As expected, the negentropy values increase as population increases, due to the increase in the size of the probability distributions. But the relative differences between the negentropy for democracy and dictatorship remain about the same, whether the analylsis is for a city-state of 100,000 or one million or a nation-state of 100 million or one billion persons.

[Fig. 3 About Here]

4. NEGENTROPY AS A BASIS FOR ALLOCATING MEDIA ACCESS

The second example illustrates an application of political negentropy to the allocation of access to political communication channels. The channels could range from physical bulletin boards and "op-ed" newspaper space to broadcast and cable television time. Cable television has been selected for this example because cable TV is a medium that generally has the channel capacity for public access. This example assumes that a local cable television station has designated one channel for public access, including discussion of political issues and candidates. The illustrative question facing the cable system operator is how to allocate time to candidates for a hypothetical public office.

One possibility is to allocate cable television access so as to maximize the negentropy of the communication channel. In other words, time would be allocated so that the probability distribution of the different political messages conveyed would maximize the negentropy. The approach suggested here is to weight the allocation of access time by multiplying the total available time by the negentropy of each candidate's message divided by the total negentropy of all messages. Expressed mathematically, the equation is:

$$T_i = T_t(D_i/\S D_i) = T_t[P_i\log(P_i)/\S P_i\log(P_i)] \qquad \{6\}$$

where T_i is the cable access time allocated to candiate i, T_t is the total time available for allocation, D_i is the negentropy of the message of candidate i, P_i is the probability of that message, log stands for logarithm, and § stands for sum. P_i can be calculated several different ways, such as by the percentage vote of the candidate's party in the last election or, if an independent candiate, by the candidate's support as measured by polling results or the number of nominating petition signatures collected.

Fig. 4 illustrates the results for seven hypothetical candidates--two major party candidates, one third party candidate, one minor party candidate, and three independents--with a total of 10 hours of cable television access time to be allocated. The message probabilities (P_i) are based on the results of hypothetical voter preference polls. The weighting factors are $P_i\log(P_i)$ or D_i, and the weighted probabilities are $D_i/\S D_i$. And the hours allocated are calculated using equation {6}.

[Fig. 4 About Here]

The resulting allocation of cable access time illustrates the use of negentropy for weighting the allocation. The two candidates with the largest support receive somewhat less than the allocation that would be based strictly on their level of support in the polls, but still more than the other candidates. The candidates with lower support received a somewhat greater than proportional allocation. This is because maximizing negentropy in this illustration translates into maximizing the diversity of the messages being communicated by the candidates. Although not illustrated here, it would also be possible to allocate communication channel access by some combination of direct proportional measure and weighted probability (negentropic) measure (see Wood [31] for an illustration).

5. CONCLUSIONS

The use of negentropy as an approximate measure of political freedoms or level of democracy and for allocation of access to political communication channels has a ~~strong~~ theoretical basis in information theory. Negentropy provides a tool for linking the modified thermodynamic imperative with practical political reality. In other words, if one wants to take actions to increase negentropy and counter the natural tendency of entropy to increase and diversity to decrease, the mathematical equations for the discrete noiseless communication channel provide a means to measure the negentropy of a political system (in terms of diversity of freedoms) or a political communication channel (in terms of diversity of messages). [illegible]

The two illustrations show how negentropy could be applied. Further research and experimentation are needed, of course. For example, the values assigned to various human freedoms in equation {5} and alternatives for calculating message probabilities (P_i) in equation {6} need careful scrutiny and refinement by political scientists as to [illegible]. But the potential applications are broad and range from foreign policy and international human rights activities to allocation of bulletin board space in public and private locations to electronic media access allocation. The degree of democracy for various countries could be measured in negentropic terms, and could be used as an additional input into the development and implementation of foreign policy strategies (by the United States or other countries) and by international organizations that monitor human rights. The relative increase (or decrease) in the degree of democracy in specific countries could be monitored for changes over specific periods of time. [illegible]

Applications of other equations from information theory, such as those for a continuous communication channel with limited average power, also warrant exploration. The negentropy calculated by equations {3} and {4} provides an estimate of the diversity of political freedoms in a city or nation-state but does not give an indication of the country's political stability, that is, its ability to withstand threats from internal and external forces and thus protect whatever political freedoms it has. The continuous channel model may be useful in maximizing negentropy for different combinations of political democracy and political stability--the latter measured, for example, by electric power production as a surrogate indicator (see Wood [29, 30] for further discussion).

In the broadest sense, it is hoped that the kinds of applications of information theory discussed in this article will help strengthen democratic institutions around the world and that entropy-like properties of political systems can be used to help steer a course toward a democratic and peaceful world future (also see [13, 28, 29]).

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Fig. 1. Assumed values for the measures of freedom
and calculations of F_i, G_i, and D,
hypothetical partial democracy (population 100,000).

	Assumed Values for Measures of Freedom		
Freedom	Lower Class (lower 10%)	Middle Class (middle 80%)	Upper Class (upper 10%)
speech	0.05	0.1	0.15
religion	0.10	0.1	0.10
press	0.05	0.1	0.15
family	0.05	0.1	0.15
education	0.01	0.1	0.19
job	0.01	0.1	0.19
home	0.01	0.1	0.19
vote	0.01	0.1	0.19
jury	0.03	0.1	0.17
business	0.02	0.1	0.18
	Calculated Values of F, G, D		
F by class	0.34	1.0	1.66
n by class	10% of total	80,000	10% of total
G by class	0.034	1.0×10^{-5}	0.166
D by class	0.166	13.3	0.431
D total		13.90 entropy units	

Note: D is calculated using equation {3} as follows:

$$D = -[1.0(0.034)\ln_2(0.034)+80,000(10^{-5})\ln_2(10^{-5})+1.0(0.166)\ln_2(0.166)]$$

$$= [0.034(4.88) + 0.8(16.61) + 0.166(2.59)]$$

$$= [0.166 + 13.3 + 0.431] = 13.90$$

Fig. 2. Political negentropy for six hypothetical city-states of 100,000 population each.

Type of Government	Negentropy	Negentropy as % of Ideal Democracy
Ideal democracy	16.61	100.0%
Democracy with 10% underprivileged class	16.52	99.5%
Partial democracy with class discrimination (10% lower, 10% upper)	13.90	88.6%
Oligarchy (12 person ruling elite)	6.31	38.0%
Caste system (10 castes)	3.25	19.5%
Dictatorship	3.10	18.7%

Fig. 3. Political negentropy of city or nation-states with democratic or dictatorial form of government and population 100 thousand to 1 billion.

	Negentropy by Form of Government	
Population	Democracy	Dictatorship
100,000	16.61	3.10
1,000,000	19.92	3.52
10,000,000	23.24	4.10
100,000,000	26.56	4.60
1,000,000,000	29.88	5.10

Fig. 4. Illustrative use of negentropy
to allocate cable television access.

Hypothetical Candidate	Message Probability*	Weighting Factor	Weighted Probability	Hours Allocated
A--major party	0.45	0.518	0.269	2.69
B--major party	0.325	0.531	0.275	2.75
C--third party	0.10	0.332	0.172	1.72
D--minor party	0.08	0.292	0.151	1.51
E--independent	0.03	0.152	0.079	0.79
F--independent	0.01	0.066	0.034	0.34
G--independent	0.005	0.038	0.020	0.20
Totals	1.000	1.930	1.000	10.00

*Based on the results of hypothetical voter preference polls.