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The Cultural Convergence of Korean Immigrants in Hawaii: An Empirical Test of a Mathematical Theory

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Introduction

The second law of thermodynamics states that a physical system cannot be stable if it is not in equilibrium, and therefore it must adjust itself to an equilibrium state. While simple in principle, applying this law to matter on the level of atomic structure proved very difficult, because of the very large number of particles involved. Ludwig Boltzmann's (1844–1906) atomic model of a gas postulated a very large number of atomic particles, of the order of 10^{24} in 22 liters at room temperature and atmospheric pressure. How could it be possible to determine the positions of such a large number of particles at some initial time, and then solve a set of 10^{24} coupled equations to predict their future motions? Boltzmann solved this dilemma by finding average values for the properties of a gas in terms of a distribution function. In this manner he discovered that "the temperature of a gas is nothing more than an expression of the average kinetic energy of its constituent atoms" (Sachs, 1973, p. 13).

In other words, different temperatures of a gas correspond to particular average velocities of its constituent molecules. Thus, a gas in a nonequilibrium state "corresponds to the assertion that the distribution of the constituent atoms in the nonequilibrium gas, with respect to their speeds and positions, at any time, must correspondingly approach a most probable distribution" (Sachs, 1973, p. 14). If all of the gases in a closed container were squeezed into one corner, or if a proportion of the gas molecules were moving at a greater velocity, then over time the molecules would redistribute themselves evenly throughout the container, and eventually the molecules

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would converge on the average velocity corresponding to the most probable distribution. This most probable distribution corresponds to the minimum amount of order in the system of molecules, or maximum entropy.

Boltzmann's theoretical conclusion agreed with the experimental facts, and provided a fundamental explanation for the second law of thermodynamics. More importantly for the present purposes, his use of temperature as a measure of the average values of the properties of a gas extended the range of phenomena to which the principles of thermodynamics could be applied.

Encouraged by the success of Boltzmann's statistical thermodynamics for large, complicated systems, some communication theorists have been hopeful of applying the same principles to human communication systems. Several statements of the second law of thermodynamics appropriate to human communication systems have been offered, of which the following is typical (Kincaid, 1982, p. 14):

> In a closed social system with no communication among its members, the system as a whole will tend to diverge over time toward a collective pattern of thought of greater entropy.
>
> In a closed social system in which communication is unrestricted among its members, the system as a whole will tend to converge over time toward a collective pattern of thought of lower entropy (or greater negentropy and order).

Such law-like applications of thermodynamic principles to human communication systems are frequently greeted with suspicion and alarm, since they tend to convey the image of a "dead" system, drifting toward a static state of cold, unmoving structure—a picture quite the opposite of living human communication systems. At least in part, these objections may result from a misunderstanding of the "ideal" sense in which such principles are offered. As is typical of science, such principles are meant to refer not to systems as they exist, but to ideal systems in artificial isolation which serve only as templates against which existing situations may be gauged.

In fact, human communication systems are never completely closed (for very long, at least), and so the tendency of any communication system to move fully toward static equilibrium can never be realized. In fact, the principle does not say that systems *must* move toward equilibrium, but rather that "... the spontaneous tendency of a system to go toward thermodynamic equilibrium cannot be reversed *without at the same time changing some organized energy, work, into disorganized energy, heat*" (Morse, 1969, p. 43, emphasis added).

Since human communication systems are always in communication with their physical environments, they are always benefitting or suffering from the change of some "organized energy, work, into disorganized energy, heat". Communication as a process requires that work be done and energy be expended. Consequently, communication systems are never at, and perhaps seldom near, equilibrium.

Prigogine and Nicolis (1977) have reported progress toward extending the application of the thermodynamic model to chemical, biological and perhaps social systems. The cornerstone of Prigogine's advances is his consideration of "... systems where exchanges with the environment exist, i.e., non-isolated systems" (Prigogine and Stengers, 1977, p. 326). As Prigogine and Stengers suggested, "in non-isolated systems, the decisive magnitude is no longer entropy, but *entropy production*, i.e., the variation in unit time of the entropy linked to the processes *inside* the system" (Prigogine and Stengers, 1977, p. 327).

In these "dissipative structures", as Prigogine termed them, it is no longer the case that the system moves spontaneously to a state of maximum entropy where it remains, but rather, interaction with the environment maintains the system in a nonequilibrium state. In these cases, the second law, which Prigogine termed the "theorem of minimum entropy production", requires "... that the system is moving towards a stationary state where it remains as long as its interaction with the environment continues to take place" (Prigogine and Stengers, 1977, p. 327). In essence, in the case of interaction with the surroundings, the second principle requires the system to produce the minimum quantity of entropy consistent with the interaction. Prigogine and others see promise in the new "nonequilibrium thermodynamics" for comprehending not only, as heretofore, physical systems, but also biological and social systems.

While this may be true, progress in including biological and social systems within the range of thermodynamics has so far been limited largely to the level of mathematical but nonquantitative principles, since a conceptual framework for *describing* these processes which is at once informative and subject to a quantitative metric has not yet become available. Indeed, Prigogine and Stengers even seem to have suggested that such concepts should be provided by the human disciplines: "What we wish to learn from biology and the human sciences is which kind of concepts have been found to be particularly fit to the understanding of their object: an evolving and self-organizing being" (1977, p. 650).

It is our belief that a new conceptual model developed principally by human-communication researchers may well provide a description of human cultural and cognitive processes which is at once useful, informative, quantitative and compatible with the newly emerging thermodynamic models of nonequilibrium processes. By "compatible" is meant not only that the epistemologies of the two systems be logically consistent; more importantly, it is hoped that the measurement model contained within human communication theory will provide quantitative empirical data which may be input directly into the equations of Prigogine and his associates. In the present article we provide descriptions of such a model, together with a worked-through example involving actual empirical data, in order to show (a) how data may be fitted to the elementary equations, and (b) how well early efforts fit data to theory. Empirical results of a survey of Korean immigrants in Hawaii are used to illustrate a mathematical theory of cultural convergence as described by Woelfel (1980), Woelfel and Fink (1980) and Barnett and Kincaid (1983).

Convergence Theory and the Second Law of Thermodynamics

The most recently developed paradigm treats human communication as a process that unfolds over time and which focuses on the mutual relationships between participants (especially groups of participants), rather than on what one individual does to another individual or to a mass audience (Kincaid, 1979; Rogers and Kincaid, 1981). The new orientation envisions a flow of information through a network of communication which is shared by those who participate in the process, and in which effects occur among members of the network. The results are indicated by changes in the relative position between two or more participants over time, and in the structure of the network which they comprise. It is expected that local regions of greater communication density will be characterized by movements toward decreasing variance (or differences) at a greater rate than regions of less dense communication.

From this perspective, communication is defined as a process of sharing information in which two or more participants reach a more mutual understanding of each other and the world in which they live. Mutual understanding is approximated successively by the sharing of additional information, or what is commonly known as feedback. Usually several cycles of such information exchange are required to correct initial divergences or differences of understanding. The convergence model of communication posits mutual understanding (reduced within-group variance) to be the primary function of the communication process, and a prerequisite for collective action and the achievement of social goals.

Theoretically, the process of divergence, or movement toward increased within-group variance, corresponds to movement toward the position of maximum entropy as described above in the context of thermodynamics: i.e., toward the most stable equilibrium point for members of a closed social system with no information flow among its members. In this situation no differences among the system's members can be detected by its members, no communication takes place among the system's members, and hence no energy is required from the system's physical environment for purposes of communication. Over time, members of such a system would be expected to become more different from one another, and the system as a whole would reach a state of greater entropy or disorder.

The process occurs in the opposite direction when communication is unrestricted among the members of the system. The process of convergence, or movement toward reduced within-group variance, corresponds to movement toward the position of maximum negentropy: i.e., toward the most stable equilibrium point for members of a closed social system with unrestricted information flow among its members. Differences among the system's members can be detected by its members by means of communication and subsequently reduced through the cyclical feedback process described above. Energy is required for this communication process, however, and ultimately this energy must be drawn from outside the system. Because external energy supplies are limited and information processing requires time, the social system would be expected to converge toward, but not necessarily reach, the equilibrium point of maximum negentropy. In other words, the social system moves toward a stationary, nonequilibrium state where it remains as long as the necessary internal information flow and corresponding energy exchange with the external environment continue to take place.

Thus, the spontaneous tendency of a social system to move toward greater entropy can be reversed by changing some organized energy—work, in the form of communication—into disorganized energy, heat. These principles describe the production of negentropy by a social system by means of communication.

The convergence model of communication enables cultural processes to be subsumed within the laws of thermodynamics. Together, these models predict that the members of a social system (participants within the same subregion of a communication network) who share information with one another about a given topic will over time develop more similar conceptions of that topic (Woelfel, 1972; Kincaid, 1982). Although considerable divergence may at times exist within a subgroup or local network, the system as a whole will tend over time to define and to conceptualize matters more similarly than other systems that have not shared the same information.

It should be obvious that it would be impossible to test this theory using equations that account for the relative positions and changes of all the potential ($N(N-1)/2$) dyadic pairs of individuals in a given, naturally occurring social system of any substantial size. Fortunately, this is not necessary if the perspective proposed by Durkheim (1951) is assumed. Culture may be taken to be the collective cognitive state of a social system's members, its "collective consciousness". This average representation of a social system has the emergent properties of the society as a whole. It is an important part of the culture of the whole social system which is made possible through the interactive pocesses (communication) of society's members. In fact, the members' interactions curtail deviant conceptualizations and provide the impetus toward the central, sacred zeitgeist which constitutes society's culture (Woelfel, 1972; Barnett and Kincaid, 1983).

Thus, together with the second law of thermodynamics, the convergence model of communication would predict that all participants in a closed system will converge over time on the mean collective pattern of thought if communication is allowed to continue indefinitely. Unlimited and unrestricted communication between subcultures would lead to a reduction in the total number of possible states, to a lower level of entropy or disorder, and to a greater similarity of beliefs and values tending toward the collective mean. The cultural convergence that would result from such communication can be delayed or reversed only by the introduction of new information from outside or inside the system, and/or by the formation of boundaries that restrict the flow of information. Relatively bounded, isolated subcultures would be expected to experience greater convergence toward their own local subsystem means than toward the mean of the larger intercultural system, even though the net convergence of the whole system would continue to increase.

Of course, no human system is ever isolated from its surroundings, and such convergences are not expected to become complete. Quite the contrary: consistent with the notions of nonequilibrium thermodynamics of Prigogine and others, it is instead expected that complex and varying "dissipative structures" will be found which produce entropy at the minimum rate consistent with their interaction with the environment.

This view evolves directly from earlier work (Woelfel and Haller, 1971), which showed that the educational and occupational aspirations of high-school students tend to converge on the average of the educational and occupational expectations held by their "significant others". This work was repeated and extended in first explicit statements of the theory as applied to cultures in general; these statements, together with the equations from which those given here have been generalized, may be found in Woelfel (1972). Elaborations of this model can be found in Woelfel (1980), Barnett and Kincaid (1983) and Woelfel and Fink (1980).

The Measurement of Cultural Processes

Construction of the way in which a given culture thinks about a subject requires a determination of the concepts that members of that culture use to understand the subject in their own minds. It may be assumed that the concepts that people use to define a topic correspond to the words they use to discuss it. The interrelationships (differences) among the most commonly used set of concepts can be measured in a questionnaire or interview by the methods of complete pair comparisons and direct magnitude estimation, which yield ratio-level scales of well-tested accuracy and precision (Stevens, 1975; Kincaid, 1980; Woelfel and Fink, 1980). The meaning of this set of concepts is represented by an $N \times N$ symmetric dissimilarity (distance) matrix. The psychological configuration of a group or a culture is represented by the average matrix $\bar{S}$, where any entry $s(i, j)$ is the arithmetic-mean conception of the dissimilarity between objects i and j as seen by all members of the group (Woelfel, 1972). Each vector of the matrix represents the definition of a concept in terms of its relationship to all other concepts.

If the concept of "me" or "yourself" is included among the set of concepts, then the aggregate self-concept of the group is defined by the row and column of the matrix which represent the measured relationship of the self to all of the other concepts in the set. Empirical research has shown that the behavior of a group toward an object is inversely related to the measured distance between the aggregated self-concept and the concept corresponding to that object (Barnett et al., 1976; Barnett, 1980; Barnett and McPhail, 1980).

The processual nature of culture may be represented by a series of matrices, $\bar{S}(t_0)$, $\bar{S}(t_1)$, $\bar{S}(t_2), \ldots, \bar{S}(t_n)$, whose elements represent the distances among the concepts at times $t(i)$. Cultural change is constituted simply by the differences between the $\bar{S}(t_i)$. Using sufficiently frequent measures, it is possible to describe cultural processes by calculating the velocities and accelerations of the individual elements of culture, as well as the overall cultural change over time. The velocities and accelerations are necessary to describe the convergence among a number of different subcultures toward the mean collective culture, or, for that matter, the convergence of different world cultures toward a global mean.

This conceptualization may also be applied to compare a number of different societies at one point in time. The difference between two cultures $\bar{S}(1)$ and $\bar{S}(2)$ at any one point is simply the degree of discrepancy $\bar{S}(1) - \bar{S}(2)$.

While these matrices provide accurate representations of a social system's culture, they are not in convenient mathematical form. By calculating the eigenvalues and eigenvectors of the scalar products of these matrices, however, the points representing beliefs may be projected onto the axes of a multidimensional Riemann space. This process is mathematically equivalent to converting a matrix of distances among cities into a graphic representation, such as a map. In this special case, an $N \times N$ table of cities can be described with no loss of information in a three-dimensional Euclidian space. In the case of culture and other cognitive domains, the spatial manifold is usually of higher dimensionality, and often several of the eigenvectors will be imaginary (the eigenvalues for these dimensions will be negative), indicating that the spaces are general Riemann spaces rather than Euclidian.

In fact, this representation is remarkably similar to the statistical mechanics of Boltzmann, since the location of each "idea" or concept for a culture is given by a vector which is itself the average of many—perhaps millions—of individual such vectors at any point in time.

After a series of Riemann spaces have been generated at separate points in time (or among a set of groups), they may be rotated to a solution which minimizes the squared distances between the equivalent concepts across the spaces. The differences between cultures may then be determined simply by subtracting the position vectors of the concepts in one space from the equivalent vectors in another. These differences, and the trajectories of the points over time, are again *averages* in the same sense as used for molecules in Boltzmann's statistical model. A computer program, Galileo™, performs conveniently all the calculations described above.

A Mathematical Theory of Cultural Convergence

The capacity to compute differences between the conceptual spaces of cultural groups makes it possible to measure displacement from an equilibrium position. This would describe the case of the spatial configuration (thought patterns) of a subgroup within a culture compared to the average spatial configuration for the total group, that is, the culture as a whole. Another example would be the input of immigrants from one national culture to another. If communication between the immigrants and the host culture were unrestricted, then the convergence theory would predict that the mean conceptual configuration of the immigrant subgroup should converge over time toward the equilibrium position for the host society, measured as the average conceptual configuration of the whole culture.

Mathematically, this situation can be modeled in the same way as can a particle or block of mass m attached to a spring with a specified stiffness k and suspended at some distance from the equilibrium point a, its stable resting position (Fowles, 1970). Any divergent subgroup, such as constituted by recent immigrants, would be considered as displaced from the equilibrium position a for the new society as a whole by some quantity x, where $x = y - a$ (the distance from the equilibrium position). Accordingly, immigration of a new culture increases the energy of the system as a whole in the same way as stretching a spring beyond its resting position is a source of stored (potential) energy in a physical system. If cultural systems behave according to the law of convergence, then, like the particle suspended by an extended spring, the divergent subculture will tend to converge over time toward the position of maximum negentropy, which is the average (equilibrium) position for the society as a whole. The main purpose of this paper is to test this fundamental hypothesis.

In its simplest form, this process may be modeled by the mathematical equation

$$m\ddot{x} + C\dot{x} + kx = 0 \tag{1}$$

where m is the concept's mass, C is a velocity-dependent linear damping force, k is a linear restoring force, x is the position of the concept measured from the equilibrium position, and $\dot{x}$ and $\ddot{x}$ are respectively the first and second derivatives with respect to time of the displacement; these correspond to the velocity and acceleration of the concept.

This equation is of homogeneous form (equal to 0). It represents a closed system with no forces acting upon the converging system, and may be treated as the mechanical analogy of a linear harmonic oscillator, such as constituted by a spring, a mass and a dashpot.

In the case where it is necessary to assume an open or nonconservative system, that is, one with additional forces from outside the system altering the expected pattern of convergence, the differential equation becomes

$$m\ddot{x} + C\dot{x} + kx = F \tag{2}$$

where F is the external (impressed) force. The additional force may thus operate either to increase or to decrease the rate of convergence. It is important to note that the theory does not postulate that all cultures will converge, but only that convergence is predicted in the absence of external forces.

This formulation is the most general. It includes four terms: the first and second derivatives, the linear term and the generalized residual. In specific cases any of these terms may vanish or be constant.

Equation (1) may be rewritten in its characteristic form as

$$m\lambda^2 + C\lambda + k = 0 \tag{2a}$$

Setting $m = 1$ and solving for λ gives

$$\lambda = -C/2 + (C^2 - 4k)^{-1/2}/2 \tag{2b}$$

The solution to eqn. (2b) results in three distinct structural versions of the differential-equation model depending on the relative values of m, C and k (Kaplowitz et al., 1980).

Each of the coefficients m, C and k has substantive meaning within the theory. The linear damping force k, for example, represents the tendency of the system to return to equilibrium. Other factors being equal, higher values of k will lead to a more rapid return to equilibrium. The velocity-resistant force C represents dissipative forces within the system. These forces may be thought of as random losses to the environment. They tend to resist velocity in the system. In physical systems, C generally represents losses due to friction, heat, viscosity and such factors. However, mass, represented by m in these equations, offers no resistance to velocity, but resists acceleration. Other factors being equal, the greater the mass of the cultural concepts, the greater the force required to achieve a given rate of acceleration. (While these forces are represented in the equations, their existence is not assumed by the theory. Since their values are determined from measurements, however, it is possible to discover whether or not they exist and take substantively meaningful values.)

The main theoretical importance of these coefficients is due to the fact that they determine whether and in what manner communicating systems will move toward equilibrium. The three structural equations mentioned by Kaplowitz et al. (1980) represent three distinct ways in which such systems may approach equilibrium.

In the case where

$$C^2 > 4mk \tag{3a}$$

damping forces are large relative to the mass and to restoring forces in the system (as in the case of a light particle dragged through a thick, resistive medium by a weak spring). In this case, the curve representing the position of the converging system relative to the equilibrium value as a function of time is one of damped exponential decay. Such an "overdamped" system (Fig. 1(a)) will not oscillate about the equilibrium value.

The second case has

$$C^2 < 4mk \tag{3b}$$

In this case, damping is small relative to the mass and to restoring forces in the system (as in the case of a heavy particle attached to a strong distended spring in a thin and nonresistive medium). Here the curve of the system's distance from equilibrium as a function of time (Fig. 1(b)) shows the system oscillating about the equilibrium value with a phase angle θ. Systems which fit this model are "underdamped".

When the values of the coefficients are related according to

$$C^2 = 4mk \tag{3c}$$

the system returns to equilibrium at the fastest possible rate without oscillation (Fig. 1(c)). This mathematical model and each of the three conditions can be tested using an appropriate measure of some aspect of a culture's

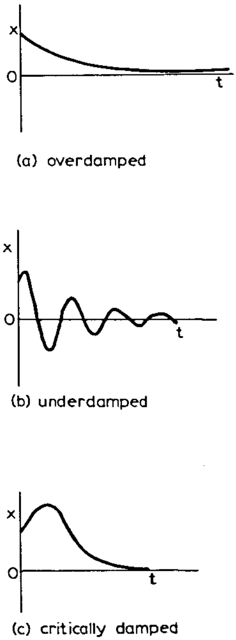

Fig. 1. Oscillating Systems with Three Levels of Damping (after Haberman, 1977, pp. 35–40).

conceptual pattern compared to the pattern of one or more of its subcultural groups, where the total difference (or distance) between the relative positions of all the measured concepts (after the rigid-body rotations described above have been performed) is treated as the scalar quantity x, the displacement from equilibrium at a specified time t. The remainder of this paper presents the results of a test of this theory using data from immigrant groups and members of the host society in Honolulu, Hawaii.

Research Design and Methods

The principal hypothesis is tested using cross-sectional survey data collected in Hawaii during 1978 and 1979 from independent-probability samples of first-generation immigrants from Korea, the Philippines and Samoa; and from resident Japanese Americans and Caucasian Americans who were born in Hawaii or migrated there from Japan or the United States mainland *.

* This study was funded by the East–West Communication Institute, Honolulu, HI 96848, U.S.A., and by a grant from the Hoso Bunka Foundation, Tokyo, Japan.

The Korean sample was designated as the subculture of interest for comparison to the host society. A surrogate host society was created by combining all of the five ethnic samples, weighted by their respective proportions in the total population on the main Hawaiian island of Oahu (referred to hereafter as the host society or equilibrium culture).

According to the 1980 census, there are now over 350 000 Koreans in the United States, and 17 949 in Hawaii, dating back to 1903. The Korean sample was selected randomly from an exhaustive list of the 249 Korean surnames found in the 1978 Honolulu Telephone Directory. Face-to-face interviews were conducted at residences after a brief telephone interview to screen out disconnected numbers and non-Koreans. Interviews were completed with 62% of the original Korean sample ($N = 401$). The Korean sample was selected as the focal subculture because 94% of those interviewed had been in the United States for 15 years or less, which allowed a comparison of the results for immigrants who had arrived in the United States during each of the 15 years before 1978. Koreans have been in Hawaii for an average of 3.3 years, compared to 8.4 years for Samoans and 22.0 years for Filipinos.

The Caucasian American ($N = 200$) and Filipino ($N = 208$) samples were selected by means of a three-stage cluster technique, beginning with census tracts selected randomly in proportion to the known probability of members of those ethnic groups residing within them. Then households were selected systematically from random starting points following a serpentine path through the tracts. Finally, each household selected became the starting point for clusters which were identified by means of the Hawaii Telephone Cross-Reference Directory for Oahu. Potential respondents were then telephoned for screening according to the following eligibility requirements: resident of Hawaii, at least 18 years of age, member of the required ethnic group (for Filipinos, only Ilocanos born in the Philippines), and willingness to participate in the study.

The Japanese American sample ($N = 98$) was selected according to the same procedure followed for the Korean sample: Japanese surnames selected randomly from the 1978 Honolulu Telephone Directory were prescreened by telephone for eligibility and willingness to participate. The Samoan sample ($N = 199$) was selected first by random selection of known Samoan surnames from the Honolulu Telephone Directory. Each name drawn was visited at home and if the person met the eligibility requirements and was interviewed, then he/she was asked to identify up to 15 other Samoan households in the same neighborhood for interviewing before moving on to the next neighborhood cluster. Although the Samoan sample represents the major subgroups of Samoans on Oahu, it does not qualify as a probability sample.

All data were collected in face-to-face interviews by native-language speakers from the same ethnic group as that interviewed. In addition to other questions not reported here, respondents were asked to complete a separate printed Galileo^{TM}-type complete-pairing comparison instrument (Gillham and Woelfel, 1977; Woelfel et al., 1980), which asked them to estimate the differences in meaning among the following 11 concepts:

1 Success
2 Happiness
3 Americans
4 Koreans, Filipinos, Samoans, Japanese or Caucasians (Haoles)
5 Me
6 Individual freedom
7 Saving face
8 Sense of authority
9 Family
10 Children
11 Divorce

These concepts represent some of the most important values common to both the United States and Asia. They were selected from a preliminary list of 25 value concepts which were identified by means of open-ended interviews with Asian and American students at the East–West Center in 1977. The 11 concepts required 55 paired-comparison judgments per respondent, according to the following instructions: "if Love and Hate are 100 units apart, how far apart are ____ and ____?". The criterion pair (Love and Hate at 100 units apart) was selected as a result of the Korean pretest. Respondents were instructed to keep this standard measure in mind as a guide for making direct magnitude (ratio) estimates of the distances among the 11 value concepts.

All of the questions in the interview required an average of 1 hour. Another 15 minutes were required near the end of the interview to fill out the separate Galileo^{TM} instrument for the value concepts. For reasons of fatigue and/or difficulty this separate instrument was not completed by all respondents. It was completed by 93% of the Caucasian American sample, 86% of the Japanese sample, 80% of the Samoan sample, 75% of the Korean sample, and 67% of the Filipino sample.

The statistics option of the Galileo^{TM} program was used to compute standard errors of measure for the 55 mean paired comparisons for each of the ethnic subgroups and the percentage relative error (that is, the standard error as a percentage of the mean). There is an ~ 68% likelihood that the true mean score lies within one standard-error unit, assuming normal distributions. The average relative error is 7.0% for the 55 mean scores of the Korean subgroup, 8.2% for the Japanese American group, 5.6% for the Caucasian Americans, 7.7% for the Filipinos, and 5.5% for the Samoans.

A preliminary analysis of the test–retest reliability of five paired comparisons out of the 55 indicated that the reliability increases as the level of aggregation increases (Kincaid, 1980). The average coefficient of reliability computed at the individual level for all five samples together is 0.61 (median = 0.82). When computed for groups according to their numbers of years in Hawaii (ranging from 30 to 48 members), the reliability coefficients across the five ethnic groups range from 0.90 to 0.97. The aggregated responses for each ethnic group as a whole have reliability coefficients ranging from 0.975 to 0.996.

The value concept data for each intact ethnic group were entered into the Galileo™ version 5.2 computer program at the State University of New York at Albany. The maximum-value option was set at 999 to eliminate missing data (coded as 99999) and extreme values (1000 or above). This level of filtering reduced the average cell sizes by 1.5% for the Korean means, 2.4% for the Caucasian American means, 0.1% for the Filipino means, and 1.9% for the Samoan means.

The value configuration for the equilibrium culture was computed by taking the average of the mean distance matrices for all five ethnic groups weighted by the relative proportions of the same ethnic groups in the total population of the island of Oahu, Hawaii: 42.8% for Caucasian Americans, 37.7% for Japanese Americans, 15.6% for Filipinos, 2.3% for Koreans, and 1.9% for Samoans (which sums to 100% for the equilibrium means). Thus, the Korean value configuration also contributes to the computation of the host society's equilibrium-value configuration, though by only a small amount. The equilibrium culture to which the Korean subculture is compared is dominated by the value patterns of Caucasian Americans and Japanese Americans. All of the ethnic-group conceptual patterns were compared to this equilibrium cultural pattern by means of the computer routine for rigid-body rotations using a least-squares criterion, allowing the two reference concepts—ethnic identification (which differed from group to group) and personal self-concept—to remain free of constraint.

In order to test the main hypothesis, the Korean sample was divided into separate data sets according to the respondents' numbers of years in Hawaii. Including groups of two or more respondents allowed analysis of Korean subgroups that had been in Hawaii for 1 year or less up to 15 years, which included 94% of the entire Korean sample. The sizes of the subgroups ranged from 2 to 73 respondents, with a mean of 27, with the larger groups between 1 and 9 years. These Korean subgroups were compared to the weighted-average data set for the equilibrium culture by means of the rotation procedure in order to test the degree to which the summed distance/difference across all the concepts (excluding ethnic identity) decreases as the number of years in the host society increases from 1 to 15 years. This provided the data to evaluate the models which follow.

Results

A visualization of the results is presented in Fig. 2. The spatial configuration of the values of the host-society equilibrium is shown in the first two dimensions, located at the points closest to the arrowheads. The value configurations of two groups of Korean immigrants are superimposed on this configuration (after rigid-body rotations to best least-squares fits). The points at the location of the concept labels in the diagram indicate the value configuration of the most recent Korean immigrants, those resident in the United States from 1 to 7 years. The points in between the recent immigrants and the host society indicate the value configuration of earlier Korean immigrants, resident in the United States from 8 to 15 years. The dashed arrows indicate the distance remaining between the value locations of the early Korean immigrants and the host society. The diagram presents a clear picture of the convergence of values that is occurring as length of residence in the United States increases. The mathematical theory of convergence was tested by dividing the total Korean immigrant group into 15 groups corresponding to each of the 15 years of residence in the United States, and then comparing their quantitative distances from the host society's value configuration.

However complicated the operationalization, the complete theory is sim-

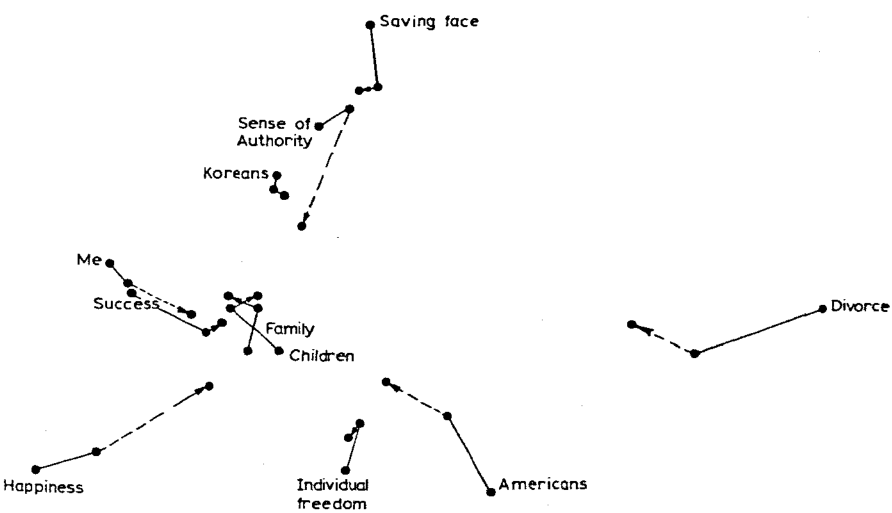

Fig. 2. Value Convergence of Korean Immigrants Toward Host-Society Equilibrium over Two Time Periods: Labels or Concepts given for Recent Immigrants (1–7 years); Terminal Points (ends of dashed arrows) represent Beliefs of Host Society; Dashed Arrows represent Distances from Equilibrium Point of Early Immigrants (8–15 years).

ply represented in eqn. (1) above. This equation describes the motion of a particle oscillating about an equilibrium position and should apply regardless of the nature of the particle to which it refers, even if that "particle" is a culture converging toward an equilibrium point. In this equation, m, C and k are constants whose values must be measured empirically in each instance. The system mass m represents the extent to which the culture resists acceleration, or changes in the rate at which it moves toward the equilibrium point. Since we are dealing with only one system here, the value of its mass may be conveniently set at 1. The constant C represents a linear damping force (like the resistance of air or water, or due to friction, on a moving body), and represents random losses from the system. In a cultural system, such forces may represent random failures of information passage through the system, random memory losses, and so forth. The linear restoring force k represents the strength of the forces pressing the system toward equilibrium. If the subculture is visualized as drawn toward the equlibrium point by a distended spring, then k represents the amount of force produced by extending the spring by one unit.

Depending on the relative values of these constants, eqn. (1) has three different solutions. If the value of C is great relative to m and k (see eqn. (3a)), the system is said to be overdamped, and the solution to eqn. (1) is

$$Y = C_1 e^{\lambda_1 t} + C_2 e^{\lambda_2 t} \tag{4a}$$

If the model is stable, λ_1 and λ_2 are negative. C_1 and C_2 represent the amplitude of the oscillation.

When the product of mass and restoring force is large relative to the linear damping force c, the system is said to be underdamped, and has the solution

$$Y = e^{\lambda t} C_1 \cos \theta t + C_2 \sin \theta t \tag{4b}$$

If λ is smaller than 0, the oscillation damps out over time and a stable equilibrium is reached. Again, C_1 and C_2 represent the amplitude and θ is the phase angle in radians.

When the linear damping force and the product of mass and restoring force are "balanced", that is, when the damping force is just strong enough to prevent oscillation (see eqn. (3c)), the system is said to be critically damped, and its solution is given by

$$Y = e^{\lambda t} C_1 + C_2 t \tag{4c}$$

Since these equations all assume that measurements have been made as deviations from the true equilibrium position, and since these positions have only been estimated from the data, it is appropriate to represent the possible deviations from the true equilibrium by adding a constant term C_3 to each equation.

The resulting six equations were tested against the data at Renssalaer Polytechnic Institute using a nonlinear curve-fitting program, APPL: SSQFIT. The program estimates nonlinear functions from discrete data by minimizing the sum of squared errors from the data.

Evaluation of the three equations without the intercept term C_3 produced the following results. In the overdamped case, $\lambda_1 = -0.07$, $\lambda_2 = -5080935$, $C_1 = 198.97$ and $C_2 = 9438057$. The implausibility of these coefficients, particularly λ_2 and C_2, together with the fairly poor fit of the resulting curve ($r^2 = 0.32$), leads to a fairly clear rejection of the overdamped model (at least without an intercept) for these data.

In the underdamped condition, $\lambda = -0.28$, $C_1 = -520$ and $C_2 = 102$, with $\theta = 1.65$. These coefficients are much more plausible, but the fit of the curve is poor, accounting for only 28% of the variance. The critically damped solution provides $\lambda = -0.20$, $C_1 = 132$ and $C_2 = 61$.

The tests of the three cases with the intercept C_3 included generally produce a better fit to the data. The exception is the overdamped model, which fits even more poorly in this case. The underdamped model accounts for 40% of the variance, with $\lambda = -0.38$, $C_1 = 50$, $C_2 = 121$ and $\theta = 1.48$, and with the intercept $C_3 = 65$. These coefficients seem reasonable, and the amount of variance explained is within what might be expected given the other factors known to be operating (which have been ignored in the present study).

The critically damped model also accounts for 40% of the variance in the data, with $\lambda = -0.41$, $C_1 = -42$, $C_2 = 151$ and $C_3 = 68$. Although these coefficients differ from those for the underdamped model, both models are within reason, given the little that is known about the behavior of these systems, and both fit the data equally well and within encouraging limits at this state of investigation. Figure 3 shows the best-fitting curve for these data.

Once these values have been calculated, it is possible to solve for the values of m, C and k in the original equation. It must be recalled, however, that the numerical values of these parameters depend upon scaling decisions of an arbitrary nature. Since there is no international standard unit of cultural distance, the size of such a unit was set arbitrarily at 1/100 of the distance between Love and Hate in this study. Values of these same parameters determined in other studies will need to be rescaled to this unit before comparison with the present results if a different standard is chosen.

A further restriction is the unavailability of either a standard unit of mass or even a table of relative masses for various cultural domains, so it is appropriate to set the mass of the system considered here at 1.

Given these qualifications, the relations among the coefficients should nonetheless remain comparable across studies. Within these restrictions, we stipulate $m = 1$, and calculate C and k as follows. First, eqn. (1) is expressed in its characteristic form

$$m^{\lambda^2} + C\lambda + k = 0$$

and solved for λ:

$$\lambda = -C/2 + (C^2 - 4k)^{-1/2}/2$$

inserting the appropriate value of λ from the above. For the critically damped case, $\lambda = -0.20$, and so $C = 0.4$ and $k = 0.04$. For the underdampled case, $\lambda = -0.28$, and so $C = 0.56$ and $k = 2.8$.

Although the metric is arbitrary, it is nonetheless the same for both the underdamped and critically damped cases, and so the values computed for C and k may be compared directly. They are, of course, substantially different in the two cases, showing that both equations can be made to fit the data equally well given a suitable choice of values for these coefficients. Basically, the figures show that approximately the same results can be obtained with relatively high damping and a small restoring force, or with less damping and a stronger restoring force. The present data, however, do not provide a basis for choice between the two equations.

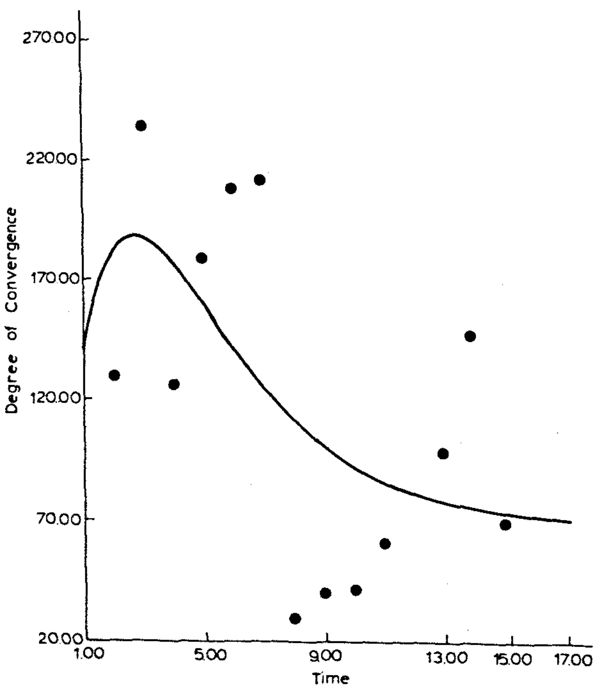

Fig. 3. Degree of Convergence according to Time in United States.

Discussion

As does any study, the present research has many limitations. Chief among these are the relatively small sample sizes, the limited number of time periods, and the absence of positive measurements of factors known to affect rates of assimilation (some of these variables were measured in the present study, but a complete analysis is beyond the scope of this report). In spite of these problems and omissions, however, the theory in its present operationalization accounts for the observed data within useful tolerance. Without much further development, present measurements and equations can provide useful predictions of socialization trajectories for different immigrant groups. These may in turn relate in important ways to large-scale social stability and change.

On a theoretical level, the most interesting aspect of the research is that a highly general model of behavior applies as precisely to cultural processes as does traditional theory in the social sciences. The theoretical advantage, of course, lies in being able to unite human and "physical" nonequilibrium processes in a single general theory.

Further research in this area may well be directed into two areas. First, denser sampling in time, that is, measurements at once more closely spaced in time and extending over greater overall time-spans, will improve the resolution with which the trajectory of cultural convergence can be pictured. This will make it possible to determine more precisely the exact form of the equation which describes this trajectory.

Secondly, survey work of the sort reported here might well be supplemented by a program of experimental and time-series studies, in which positive efforts to influence trajectories are examined.

Finally, although research of all types can be invested usefully in the study of this model, the comparative nature of the measurement system which underlies it makes intercultural studies of extra value. Unlike more tradiational scaling devices, the ratio-type devices used in the present study allow stipulation of standards of measure useful in enhancing cross-cultural comparative studies.

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