Biological and Cultural Evolution

Some Analogies and Explorations

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Since Darwin there has been much discussion pro and con as to whether profitable analogies can be drawn between the evolution of species and the development of different kinds of primitive and advanced human societies. This question is reviewed in this article by an interdisciplinary team. It is suggested that orientations and methods which have been employed to investigate biological evolution might also be used in the study of the evolution of society or culture. Perhaps these will throw light on the theoretical problem of the similarities and differences in the two sorts of evolution. Experiments are suggested in which small groups work together on problems under special constraints of customs and languages dictated by the experimenters. In addition to this experimental approach to the study of different cultures, and normal and abnormal behavior in them, the historical method of comparing biological and social evolution is employed in an examination of language.

INTRODUCTION: ON GENERALIZING

THIS paper gives a preliminary report on work initiated by an interdisciplinary group (anthropology, biology, mathematics, social psychology, and sociology were represented') at the Center for Advanced Study in the Behavioral Sciences during 1954-1955. We are quite conscious of the tentativeness and indeed the controversial nature of many of our suggestions; but are nevertheless persuaded that it may be useful both to our colleagues and to further work planned by us to share these points of view and some provisional findings.

The group began with little more than a general conviction that the question of similarities between biological and cultural change deserved re-examination from a somewhat fresh angle.' After some early unstructured discussion we decided that the carefully worked-out knowledge of population genetics might provide the most suggestive model from biology. We then turned to linguistics as representing the area in the cultural realm where—at least in phonology—fundamental units organized into a system have been firmly established, and examined phonological and phonemic theory and empirical data on phonetic evolution, searching for similarities with the processes demonstrated in Mendelian genetics. The third topic in our program, that of constructing experimental analogues to some aspects of the cultural process, is undoubtedly the most innovating development of the work group. How it arose out of group discussion and how its construction was influenced by consideration of the first two topics would become fully evident only to someone who read a complete record of our sessions. We believe, however, that careful readers of the

Besides the present authors, Alex Bavelas, R. Duncan Luce, and Louis Schneider participated in the group discussions. Bavelas contributed the key ideas of the experimental outline described below and took the lead in working them out. Only his modesty prevents his co-authorship.

[2] See, e.g., Gerard (5, 6).

present communication will catch interconnections and implications between the three topics which we cannot take the space to spell out in full, explicit detail.

Before reporting seriatim on our three major topics, it seems important to state explicitly two points of view which emerged in present form during our sessions and which guided our investigations. The first relates to the role of analogy in science. The second concerns our particular conception of interdisciplinary research.

The role of analogy in science

There is a certain organized necessity about generalizing or thinking across fields because all knowledge, indeed perhaps all perception, starts with the recognition of similarities. One advances, to the degree that the data make possible, from similarities to analogies to congruences to identities. Starting with a similarity between sound waves and water waves, or even between heat flow and electric flow, there is progressive likeness, to the congruence between light waves and radio waves (which differ only in wave length, as do red and orange). One may instance comparable chemical examples: rock and soil are similar; alcohols and other organic compounds are analogous; members of a series of alcohols are congruent; finally, the temporally interchangeable forms of a molecule, as in the keto-enol shift, are two tautologies or different forms of an identity and are actually called tautomers. The mathematical and logical tautologies which simply state a formal isomorphism between the variables of different phenomena—as the identical equations for mechanical and electric oscillators—carry formal identities across widely disparate content areas.

If by looking across the board, one achieves a new approach, a new way of viewing something and new insights result, there is a tremendous gain. If the particular universe under examination suddenly becomes part of a wider universe, if generalization can be extended to include new kinds of elements, new power results. In the behavioral sciences, in particular, there is need to be able, as it were, to add peanuts and elephants. Since arithmetic is not applicable, it is useful to generalize from simple numerical to abstract logical relations. In the latter is included set theory, for example, which does permit one to handle peanuts and elephants together.

Curiously, two extreme attitudes toward analogy both stem from a recognition of the nature of deductive method. One is epitomized in the well-known dictum, "Proof by analogy is not proof." The other is contained in a statement of the mathematician, E. H. Moore, who maintained that any similarity between two mathematical theories implies the existence of a more general theory of which the two are special cases. Stated in terms of formal logic, the first statement is a recognition of the fallacy of the all too common *non sequitur: A* implies *B; A* and *C* have elements in common; therefore *C* implies *B.* The second statement is, on the face of it, trivial. All it says is that if sets A and *B* have elements in common, there is a set *C* which contains them both. Set *C* can always be constructed so as to contain both *A* and *B.* However, self-evident as are both strictures from formal logic (or the equivalent algebra of sets), they are philosophically significant when applied to theory construction because they point both to the fruitfulness and the shortcomings of analogy.

To take an example from the history of physiology, the first tissue intensively studied for its chemical components and metabolic events was skeletal muscle, being the easiest to handle. Here it was found that during activity, sugar splits into lactic acid, which is partly burned to carbon dioxide, that certain phosphate compounds break down, etc. When work later extended to other tissue, as brain, liver, kidney, the same things were looked for and, to be sure, mostly found. Here the analogy of one tissue to another was useful and led to the expectation of common features in all living tissue. However, many workers rather thoughtlessly came to expect that all the chemistry of muscle would apply to, say, brain. This expectation is obviously unjustified, for if brain had exactly the same metabolism as muscle the two tissues would be identical. There must be some point at which similar metabolisms begin to diverge; and the divergences will ultimately teach us even more about tissues than the similarities. Nevertheless, great progress can be made by starting with the similarities.

Let us now look at the second statement, which, we said, was logically trivial, because in the realm of abstract sets (with which all purely deductive thinking is exclusively concerned) a set can always be constructed to include any two given sets. For instance, one could take the set "objects" to include the sets "peanuts" and "elephants." The task, however, is not merely to construct any theory (set) from which two given theories can be deduced as special cases (which includes two given sets), but rather to construct a simple and coherent theory (an easily recognizable set) which has this property. Thus "animals and their food" includes "peanuts and elephants" more significantly than "object"; "oxidation" relates to "respiration" and "combustion" more fruitfully than "process."

Indeed, the history of theoretical physics is the most impressive example of just such constructions. A linear mechanical oscillator behaves like an alternating current circuit, where the impressed potential difference of the latter corresponds to the impressed force of the former, the current to velocity, charge to displacement, ohmic resistance to frictional resistance, capacitance to the rigidity modulus, and inductance to mass. Different as the respective contents of the situations are, a single differential equation governs the behavior of both. The recognition of the unity of heat and mechanical energy, of light and electromagnetic waves, of mass and energy, all triumphs of theoretical physics, are directly traceable to the persistent search for general schemata to embody phenomena which exhibit analogous features.

In chemistry, the classification of compounds according to analogous properties led to the discovery of the primary classical building blocks of matter, the elements, so that analogous chemical properties of substances were revealed as manifestations of analogous structures of their respective molecules. Moreover, the classification of the elements themselves, according to their analogous properties, led to the construction of the periodic table and subsequently to the discovery of the structure of atoms.

In biology, one distinguishes between analogies (here "analogy" has a more restrictive meaning) and homologies of anatomical structures. Both concepts are exceedingly fruitful. The first points to similarities of adaptation to environment, the second to phylogenetie origins.

There is no question, then, of the fruitfulness of analogical thinking if it is pursued, not with the view of "proving" that two similar things are instances of the same thing, but with the view of inquiring what may be behind the similarity. At the same time, the tautological nature of Moore's "existence conjecture" should serve as a warning against letting a powerful generalization degenerate into an empty generality. It is probably of little consequence that key holes and tunnels are both "orifices" and that the Washington Monument and a pencil are both "oblong objects" (although both sets may appear in certain contexts in the significant set, phallic symbols). One should guard against the temptation of undisciplined and vague analogizing offered by such powerful general concepts as energy, homeostasis, stress, interaction, structure, system, libido, etc. Recent advances in the mathematical theory of communication and in cybernetics have introduced the terms: information, entropy, noise, channel capacity, feedback, servo-mechanism, stability, time series, etc., etc. Although defined with mathematical precision in their technical context, these terms are immensely suggestive of a vast variety of situations. Accordingly, well-meaning but often insufficiently informed enthusiasts, under the impression that the use of these terms renders metaphorical speculations "scientific," tend to use them promiscuously and thereby often obscure their real value.

In summary, we hold the recognition of analogies to be fundamentally useful in the construction of theory, the usefulness depending on the precision with which analogical entities and relations in two or more situations can be identified and on the nature of the questions which arise as a consequence of the comparison. Thus, the spread of excitation in a neural net, the spread of an epidemic, and the spread of information in a population are usefully analogous, because in all three cases we have (a) identifiable carriers (neurons and individuals), (b) identifiable relations among the carriers relevant to the spread (existence or nonexistence of a connection or contact), *(c)* an identifiable state (excited, infected, informed, and their opposites), and (d) nonconservative transfer of the state (extinction and proliferation possible in all cases). The analogy is fruitful to the extent that it is possible to treat all phenomena by equations of a similar type and to the extent that the parameters of the equations suggest further analogies, e.g., refractory state of a neuron and acquired immunity to a disease, frequency distribution of synaptic delays and the time course of infectivity, etc.[3] The ultimate fruitfulness of the analogy depends, of course, on extensive testing of the proposed equations under a variety of conditions and on the derivation through the observed divergences among the phenomena of the features characteristic for each phenomenon. Analogical thinking is thus in our view not so much a source of answers on the nature of phenomena as a source of challenging questions.

Interdisciplinary research

Our second point of departure, the interdisciplinary, stems to considerable degree from our faith in the fruitfulness of analogical thinking, properly controlled. The example just given connects, by apparent similarity of underlying structure, events which content-wise neurologists, epidemiologists, and sociologists had appropriated for their special studies. But, again, we hold no simplistic brief for all research dubbed "interdisciplinary." There is no dearth of conferences and symposia nowadays in which many disciplines are "represented." The joint outputs of such enterprises fall short of their mark, however, if they are little more than "mosaics" of gems, each carefully polished by its appropriate expert. The results of joint efforts should be more than additive or else the effort involved in talking across disciplinary boundaries is hardly justified. In the present instance, while no one of us would pretend to control of an additional field, we worked together long enough and intensively enough so that we think at least we all have some understanding of one another's biases. While the original drafting of the sections of this paper followed disciplinary lines to some extent, there is now scarcely a page which has not been reworked from the angle of at least one additional subject.

In concluding this introduction, we present a first sketch of our thematic analogy. The anthropological study of culture has shifted emphasis from the totality of artifacts and directly observable customs to the concepts and premises distinctive of each culture. These are held to constitute a system of least common denominators within a culture, of which the observables are the expressions. Thus it is possible to isolate more fundamental and therefore more stable units of analysis. Such units show empirically a remarkable stability, in spite of the fact that an entire population of culture-carriers is replaced within a few decades. On the other hand, cultures certainly change through time. These changes are in many respects systematic and cumulative. In other ways they resemble the "spontaneous" or "accidental" nature of genetic mutations. As a preliminary scheme of our basic analogy, we offer the suggested correspondences, shown in Table 1.

A major difference between species and cultures may rest in the relative biological isolation of breeding populations as against the extensive "cross-breeding" continually observed in the history of cultures. However, at least in the case of Homo sapiens, gene exchange among human beings has occurred on a scale comparable to that demonstrated between cultures and subcultures. Also, just as new species may result from isolation and adaptations of breeding populations, so new cultures evolve when subcultures develop through time in varying environments, either in relative isolation or in contact with cultures of different types than those which influenced the original culture that becomes

[3] See, e.g., Rapoport (19, 20) and Landau and Rapoport (16).

TABLE I

CORRESPONDENCES BETWEEN BIOLOGICAL AND CULTURAL EVOLUTION

Biological Evolution	Cultural Evolution
Distinct species and varieties	Distinct cultures and subcultures
Morphology, structural organization	Directly observable artifacts and customs distinctive of cultures
Physiology, functional attributes	Functional properties attributable to directly observable cultural characteristics.
Genetic complex determining structures and functions	"Implicit culture"*—i.e. the inferred cultural structure or "cultural genotype"
Preservation of species but replacement of individuals	Preservation of cultures but replacement of individuals and artifacts
Hereditary transmission of genetic complex, generating particular species	"Hereditary" transmission of idea-custom-artifact complexes, generating particular cultures
Modification of genetic complex by mutations, selection, migration, and "genetic drift"	Culture change through invention and discovery; adaptation; diffusion and other forms of culture contact; "cultural drift"
Natural selection of genetic complexes generally leading to adaptation to environment	Adaptive and "accidental" (i.e. historically determined) selection of ideas, customs, and artifacts
Extinction of the maladapted and maladjusted species	Extinction of maladapted and maladjusted cultures

*For an explanation of this concept, *see* Kluckhohn (15).

TABLE 2

CORRESPONDENCES BETWEEN CULTURES OR SUBCULTURES AND SUBSPECIES OF A SINGLE SPECIES

Culture or Subculture	Subspecies
Partial isolation of subspecies—"cellulation"	Partial isolation of cultures—"cellulation"
Cross-breeding through migration and limited interbreeding	"Cross-breeding" through diffusion of ideas, customs, artifacts
Hybrid vigor	Hybrid vigor?

modified. It would be possible to extend the analogy by comparing both cultures and subcultures to subspecies of a single species. We have then the correspondences shown in Table 2.

We suspect further that the "inner logic" of the organism is paralleled by the "inner logic" of a culture. The survival potential of a given biological characteristic must be evaluated not only in terms of its use in a certain external environment but also of the internal organization of the organism. The incisors of a horse would be of little use to a tiger, whose habits are attuned to hunting animal prey; fleetness is hardly called for in a tapeworm nourished in a pig's intestinal tract. Similar considerations apply to the fitness of a particular cultural trait in each distinctive cultural pattern. On the other hand, organisms and cultures may be "ready" for radical innovations so that when these come on the scene through biological or cultural mutation or diffusion, the evolution, whether of an organism or of a culture, may be greatly accelerated.

There are both historical and experimental models for the study of evolution. Earlier biological work was largely historical, but genetics now has an experimental base. Linguistics also has an experimental side. But we shall use linguistics as our historical analogue, returning in our final section to some suggestions for possible experimental procedures for investigating at least some essential particulars of the evolution of cultures.

GENETIC EVOLUTION

A great body of data exists concerning the evolution of biological groups, not only describing the phenomena of organic evolution but also analyzing the mechanisms. Organic evolution depends on the chemical structure and action of genes, including their arrangement; species appear and change as determined by the shifts in the gene pool of the population. We shall, therefore, first examine the gene and factors influencing the gene pool, and then look for cultural units and processes that may prove comparable.

The evolutionary factors to be considered are mutation, selection, migration, and genetic drift. Together they determine the genetic characteristics of a population, namely the genetic complex and the genetic distribution.

The genetic complex. The gene, a clearly defined unit of biological inheritance, was initially a hypothetical construct, invented to fit the results of breeding experiments, but is now a practically identified nucleo-protein molecule. A given gene may appear in the germinal cell from which the organism develops (a biparental zygote or a uniparental spore), in one of several variations, called alleles, and is then reproduced in that form in every cell of the organism (except for occasional "somatic mutations," which will not be considered here). A gene may be altogether absent from the germinal cell or represented by a completely inert allele. To subsume all cases, we shall speak of the presence or absence of a particular allele. An allele, then, is present or absent as an indivisible unit in an organism and is passed on to offspring in this all-or-none manner. The presence or absence of a given allele in a given individual is ultimately independent, when linkage and crossing over operate, of the presence or absence of other alleles in that individual. The genes interact with each other and with their environment, ranging from intracellular to extraorganismic, to produce an organism. The action is through a large series of steps, each dependent on the preceding and the current situation. The genes act largely as enzymes to catalyze the steps. The organism will thus be largely, though not entirely, determined by the particular combination of alleles present in the spore or zygote.

Since the number of genes is of the order of thousands for most organisms (20,000 to 40,000 for man) and there are commonly several alleles possible for each gene, the number of possible combinations is prodigious. With only two alleles and a thousand genes, this number is 2^{1000}, incomparably greater than the surmised number of atoms in the universe. A particular combination of alleles which characterizes an individual is called the *genotype.* The set of external characteristics determined by the genes and their interaction with the environment is called the *phenotype.* The totality of genotypes of a population is called its *genetic complex.* Just as the "fate" of the individual is to a large extent determined by its genotype, so the evolutionary "fate" of a population is to large extent determined by what happens to its genetic complex. Note, however, that the genotype of an individual is normally set in the zygote or spore, and subsequent mutations in the individual are unlikely to be of importance with respect to his phenotype (some somatic mutations, especially pathological ones, excepted) ; while the genetic complex of a population, on the other hand, may change drastically even in the absence of mutations, since it depends on the proportions within it of the various alleles, which proportions can change radically through differential selection of genotypes from generation to generation.

The genetic distribution. Consider each gene as either present or absent in an individual. This can be done, even when there are many alleles (there are, for example, over 80 at the B locus "red cell antigen" in cattle), by simply considering the gene as represented by one of its alleles, the so-called normal or "wild type," so that the presence of any other allele or the absence of the gene altogether is counted as an absence. Having thus defined a gene as either present or absent, in an individual, one can define the frequency of the gene in a population by the fraction of the population in which the gene is present. In general, this fraction q will vary from generation to generation. The several factors contributing to the variations fall into two classes: The *systematic drift* includes changes in frequency due to mutation, selection, migration, and other "pressures," which can be considered constant over many generations; the *random drift* includes the random fluctuations in the coefficients which characterize the systematic drift and, especially, *sampling variance* (see below).

Over many generations, a gene will be represented in a given fraction of the population with a certain relative frequency. One can thus speak of the "probability frequency distribution of the gene frequencies." This distribution of gene frequencies is a mathematical function, whose independent variable q is a fraction of the population (ranging, of course, from 0 to 1), and whose dependent variable *co(q)* is the probability that in a given generation the gene in question is represented in the fraction q of the population.

It is shown in the mathematical theory of evolution[4] that the distribution of gene frequencies is given by the following expression:

$$\varphi(q) = \frac{C}{\sigma^2_{\delta q}} \exp \left\{ 2 \int^{q} \frac{\Delta q}{\sigma^2_{\delta q}} dq \right\}. \quad [1]$$

Here Aq is a function of q representing the effect of the systematic drift factors (selection, migration, and mutation pressures) and *crL* is the variance in q representing the random drift factors. The lower limit of q in the integral is immaterial, since it is absorbed in the normalizing constant C, chosen so as to make $\int \varphi(q)\, dq = 1$.

The form of this frequency distribution indicates how the representation of the gene in question varies from generation to generation, and so the character of the function $\varphi(q)$ indicates the variability in time of the genetic complex of the population. Thus, when the distributions of all genes are strongly bunched around their respective average values, the representation of each gene remains almost constant from generation to generation, that is, the genetic complex remains constant. When, on the other hand, the individual distribution functions are spread out (in the extreme case being bunched around the values $q = 0$ and $q = 1$) the representation of individual genes fluctuates wildly, and so the genetic complex undergoes large fluctuations. As we shall see, the evolutionary fate of a population depends on the extent and the character of these fluctuations. The latter depend in specific ways upon the parameters of the gene frequency distributions Aq and cr!,, which, in turn, depend on the above-mentioned evolutionary factors and on population size. This chain of dependence constitutes the current theory of population genetics. Let us consider the evolutionary factors in turn.

Mutation. Genes mutate, that is, pass abruptly from one allele to another. On the basis of existing evidence, the overwhelmingly dominant view is that mutations occur at random. Certain environmental factors may change the rates of mutation, but no systematic correlations have been unequivocally established between environmental factors and the direction of the changes. Each gene has certain constant probabilities of mutating from one of its alleles to each of the others, which probabilities may, however, depend on the presence of other alleles. If a gene has a probability u of mutating in a generation, and if the probability of mutating back to the original allele is v, the contribution of mutation pressure to the parameter Lq will be

$$-uq + v(1-q) \quad [2]$$

Selection. Each genotype, as manifested in its phenotype, is characterized by a "survival potential," a reflection of the degree of adaptation to environment and of fecundity. Greater survival potential or survival advantage of a genotype is manifested in its increased representation in the next generation, because of its favorable differential in birth and death rates as compared to other genotypes. No matter how slight (numerically) is the relative increase of representation, eventually the genotypes possessing such advantage would inevitably replace the others, were it not for the operation of such other factors as mutation and migration pressures, which insure the replenishment of deviant genes in the population. Since selection works on individuals (actually on larger units also) rather than on genes, any selection coefficient should be a function of the entire genotype. For simplicity, however, a selection coefficient has been taken to

[4] The mathematical theory presented here has been developed largely by Sewall Wright (14, 26, 27).

mean that alleles a and A of a gene tend to be reproduced in ratio (1 — *s):1* per generation. Then the distribution (1 — *q)a* *qA* becomes

$$\frac{(1 - s)(1 - q)a \quad qA}{1 - s(1 - q)}$$

The change of frequency of A is the contribution to *q* by selection pressure. It is given by

$$\frac{q}{1 - s \quad sq} \quad q$$

$$\frac{sq(1 - }{1 - s(1 - q)} \quad sq(1 - q) \qquad [3]$$

if *s* is small.

Migration. If a population is not completely isolated from other populations with which it can interbreed, there will be an inflow and a leakage of genes through migration. Migration pressure thus operates in the same way as mutation pressure on a partially isolated population. If the average frequency of a gene in the entire cellulated population (consisting of partially isolated subpopulations) is *q,,,,* the contribution to zq due to migration will be

$$-m(q - q_{,,}) \qquad [4]$$

where m is the excess of inflow over the outflow of the gene in question.

The random drift. The genetic complex is determined to a large extent by the mutation, selection, and migration pressures. However, there enter also random elements. To begin with, the coefficients of the abovementioned components of systematic drift may themselves undergo random fluctuations, which (except possibly in the case of mutation rates) may be considerable. Another source of random fluctuations is the so-called sampling variance. Each reproducing generation is only a sample of all the individuals born into the entire generation. If the population is large, the successive samples will not show large deviations with respect to their genetic complex; but if the population is small, the random fluctuations of the sample may be considerable. Thus, the components of systematic drift, by determining *Aq,* and the components of random drift, by determining 01,, in Equation **1,** determine the gene frequency distribution co(q).

Let us now see how the evolutionary fate of a population can be inferred from the gene frequency distribution. For simplicity, we will consider just migration and sampling variance and examine their effects on the variation from generation to generation in the representation *q* of some gene. Suppose, also for simplicity, that *q,,,,* the average frequency of that gene in the entire population (of which we are considering a subpopulation) is The contribution of migration to *Aq* is given in Equation 4. The contribution to cri$_g$ by sampling variance is given by the well-known formula

$$= q(1 - q)/2N. \qquad [5]$$

Substituting Equations 4 and 5 into 1, using *q$_n$, = IA,* and simplifying, gives

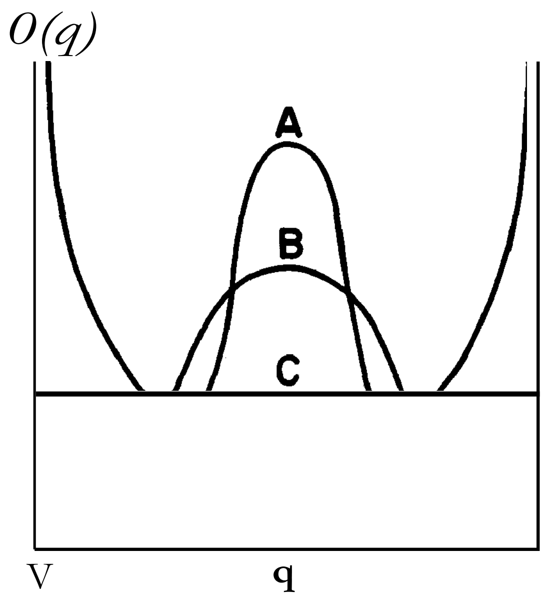
$$co(q) = \frac{1'(4Nm)}{(2Nm)]^2} q \quad q)^{2Nm-1}. \qquad [6]$$

Here r is the well known "gamma function" defined by

$$r(x) = \quad 1(s\text{-}ne\text{-}t \; dt.$$

Curves for various values of *Nm* are shown in Figure 1 (cf. Wright 1932). Note that for both m and *N* large, the spread of the genetic distribution is small, and vice versa. Other things being equal, therefore, a large migration pressure and a large population favor small fluctuations in the representation of a gene, hence a small drift effect; while a small migration pressure (isolation) and a small population favor a large drift effect. Similar conclusions hold for the effects of selection pressure, and analysis has covered the combined effects of selection, migration, and population size.

The landscape of adaptation. A genotype can be viewed as possessing an over-all degree of adaptation to its environment, a magnitude represented by a real number. The genotype itself, having thousands of components, cannot be represented by a real number but only by a vector having thousands of dimensions. Thus the domain of the variable representing the genotype is a space of thousands of dimensions. For qualitative discussion of the situation, however, consider



Fm. 1. The Frequency Distribution Curves of a Gene for Various Values of Nm
A : Nm >> ; B: Nm > C: Nm = D: Nm <

this space as having only two dimensions, the smallest number which can be associated with a "region," and the population as occupying such a region in the genotype space. The area of the region is the greater, the greater the genetic diversity of the population. Moreover, because of the drift effect, the population wanders more or less rapidly over the region, depending on the strength of the drift.

If we think of the degree of adaptation as a third dimension, our two-dimensional genetic complex space becomes a "landscape," in which the regions of high adaptation are peaks and those of low adaptation, valleys. Natural selection of the genotypes of high adaptation guides the population to the peaks of the landscape, but the random drift enables the population to leave them. Moreover, because of changes in environmental conditions, the landscape itself is shifting, so that peaks may change into valleys, and vice versa. The evolutionary fate of the population is now seen to depend: first, on the ability of the population to find an adaptive peak; second, on its ability to cling to its peak; third, on its ability to readapt as the landscape shifts because of changes in environmental conditions; and finally, on ability to find other, perhaps higher, peaks of adaptation even if the environment remains constant.

Mathematical considerations, similar to the above, of the effects on the genetic distribution of the various evolutionary factors and of population size lead to the following conclusions:

1. Under stable environmental conditions, a large, randomly mating population (i.e., where the migration pressure is so large that the entire population can be said to interbreed freely) will remain situated around the particular relative maximum of adaptation it happens to have reached, its "niche." If selection pressure decreases, say under a milder environment, or mutation pressure increases, or both, the area occupied will increase; if converse changes occur, it will shrink; but the population will not wander away from its peak.

2. Under changing environmental conditions (where the relative survival advantages of the several genes change and hence where there is a shift in the peaks and valleys of the "adaptation landscape"), a large, randomly mating population will shift its position *adaptively,* i.e., to the nearest available new peak. Given sufficient heterogeneity (insured by a large population and random mating), the chances of finding a new peak are good; hence there is insurance against extinction.

These two results can be summarized as follows: A large, randomly mating population, having reached an adaptive peak, tends to remain there under stable environmental conditions. It is a safe but "conservative" population. It stands a good chance of surviving, but will not, in general, evolve by finding distant, possibly higher, peaks of adaptation.

3. A small homogeneous population occupies a small area on the adaptive landscape. Under changing environmental conditions, it may find itself entirely in a valley; that **is,** without a pool of genes adapted to new conditions, and so can easily become extinct. Moreover, such a population is subject to considerable random drift, and so will wander over the landscape, even without en-

vironmental change. Hence, even under constant conditions, a small strongly inbred population may, in fact must, eventually become extinct. Such populations are "adventuresome," they wander; but they are not safe, they are more likely to end in a valley than to find another peak.

4. A "cellulated" population, consisting of several relatively small and relatively weakly interbreeding subpopulations, occupies several small areas of the landscape. The subgroups, because of their smallness and relative homogeneity, do wander over the landscape, even in the absence of environmental changes; but, being interconnected by migration and interbreeding, the total group enjoys the safety of a large heterogeneous population. If one such subgroup wanders into a valley, it can be "rescued" by the others, since the good genes of the other subgroups are available to it. Moreover, such a population is not hemmed in by the conservatism of the randomly mating population; for subgroups are able to wander and explore the landscape for new peaks, while the interbreeding insures the entire population against extinction. Such a population is thus both "adventuresome" and safe; as emphasized by Sewall Wright, it is endowed with the greatest evolutionary potential.

LINGUISTIC EVOLUTION

If by evolution we mean the cumulative process of small changes, it is a truism that this term can be applied not only to the history of organisms but equally to many other histories of development. One speaks of evolving institutions, evolving languages, evolving ways of thought. Often the history of an artifact presents a striking similarity to that of an organism: witness the changing appearance of the automobile, in which we can trace "vestigial parts," such as the whip stands in the earliest models and the gradually disappearing running boards in the later ones.

In the realm of culture we decided to examine phonetic change, partly because of precision and some good documentation in this field, partly because phonological evolution best parallels the "unconscious,"[5] "automatic," and "spontaneous" aspects of biological evolution ; partly because language is the best approximation of pure culture; but most of all because, of all aspects of the study of culture, linguistics has not only the most distinctively cultural methods but also the best defined concepts. Linguistics has, mainly within the past generation, grown out of philology. Philology is a humanistic discipline with an interest in endless particulars, of and for themselves; linguistics is a science interested, like all other sciences, in discoverable regularities. The discovery of such regularities presupposes standard fundamental entities like the chromosome and the gene. There are such in linguistics and especially in phonology.

Any humanly produced sound is a "phone." The number of phones is limited only by the anatomy and physiology of the human speech organs as these operate in varying environmental situations. But every language has a limited number (the known range at present is between 11 and 67) of distinctive sound-classes known as "phonemes." Most phonemes have one or more alternative forms (more often than not positional), which are called "allophones." A brief sketch of phonemic theory is now essential to our purposes.

The human vocal apparatus allows the making of a great variety of sounds. But children in each different group soon learn to make, with small variations, a particular set of sounds that has been selected by their culture out of a vast number of biological possibilities. Every sound system has a number of structure points, the phonemes. Each language, in other words, consists of discrete units of short duration which meet certain physical requirements. A phoneme is variously defined, technically, as "a minimum same of vocal features" or as "the class of all segments and spans containing a givers feature." The meaning of these (to the nonlinguist) cryptic utterances will become clear if

[5] Edward Sapir speaks of language as "the mountainous arid anonymous work of unconscious generations." The facts that *(a)* most phonetic change is little complicated by purposive and value factors and (b) that it is massive in comparatively short time periods, give phonological evolution at least certain superficial similarities to biological evolution.

we turn to concrete illustrations from familiar material.

Take the English word "pin." There are three irreplaceable sound units here. Each occurs in other combinations: the first occurs, for instance, in pip, pill, and pocket; the second in pip and pill but not in pocket; the third in tan, run, and hen. But these three units cannot be analyzed by further partial resemblances. In the case of "pin," the three phonemes are represented by three letters of our alphabet. Our conventions of writing, however, are far from a trustworthy guide. In "thick" the first phoneme is represented by two letters, "th," and the third phoneme by two more letters, "ck." The linguist represents the first of these phonemes by a Greek letter (theta), the second by simple "k."

Phonemes are types or classes of sounds which are treated by speakers of that language as units. Thus the "p" sounds in the words pin, spin, and nip, which we English speakers react to as if they were the same, are, from the standpoint of an acoustic engineer, quite different. But they are all *allophones* of the same phoneme, "p." In English, "t" has five allophones. The English phonemes "p" and "t" are conventional or cultural, not natural, categories. Nature, as reflected in the sound waves recorded with oscilloscopes, reveals the three distinct sounds for "p" indicated above and the five for "t." But, where the natural world presents nothing but an indefinite number of contingent varieties, the intervention of culture creates a bundle of *distinctive features* that have a minimum sameness and are treated as a unit. In one language, a sound made with the two lips, voiceless, strongly articulated, and with stopped breath is bundled together and contrasted with another sound that is otherwise identical but made with vibrations of the vocal chords (voiced); while in another language, sounds are contrasted on the basis of force of articulation rather than of voiced-voiceless. Lip rounding in the production of vowels occurs in many languages; but it is phonemic in some (e.g., German and Hopi), nonphonemic in others (e.g., English and Shawnee).

Phonology, with its demonstration of ultimate significant entities (phonemes and their distinctive features), thus converges with modern physics, which has revealed the granular structure of matter and the elementary particles which compose it, as well as with biology, with its particulate genes and chromosomes. The number of contrasts (binary oppositions; compare these with the diploid state) of distinctive features in the languages studied this far runs approximately from six to twelve. (This includes only "inherent" features; "prosodic" features would add another three or four.) In the French phonemic system (13), for instance, the indispensable binary oppositions are:

vowel-consonant
nasal-oral
saturated-diluted
grave-acute
tense-lax
continuous-intercepted

Sound change. Although sounds and phonemes are rather more characterized by inertia than the rest of culture, there is constant variation in detail just as there is in all biological behavior. No two speakers of the same language or dialect utter "the same" sounds in precisely identical ways. Indeed, the self-same speakers vary in their production of a phoneme in fixed position, depending in part on the social situation and on their biological state at the moment of utterance. Not all of these variations, of course, can be compared to mutations. Many are perhaps crudely comparable to nontransmitted, somatic mutations or to modifications in gene effects induced by the environment; but some sound changes, like the germinal cell mutations which do spread by inheritance, may become durably established in a population. In fact the striking degree of established regularity requires emphasis here. Grimm's Laws on sound shifts in Western European languages were the first proof of statistical uniformities in human behavior. Since then there have been massive documentations of orderliness in linguistic change. Two illustrations must suffice. In Latin, between 450 and 350 B.C. the consonant "s" was changed to "r" wherever it came between two *vowels—genesos,* the possessive singular of *genus,* became *generis; meliosem* ("better") became *meliorem.* In Hausa, an African language, during the eighteenth century "s" changed to "sh" whenever followed by one of four particular vowels. Much of the regularity in sound change is due precisely to the fact that we have to do with phonemic *systems.* If one phoneme alters radically, there will be compensatory alterations in others, particularly those made in the same region of the mouth or produced by similar mechanisms. If, for instance, a new "back" phoneme "crowds" the "back" series, then a germ of instability is introduced into the whole system. And the introduction of a new principle ("distinctive feature") or the dropping out of an old one will gradually produce changes spreading across all the relevant areas of the sound system.

There are, however, regularities other than those deriving from the systematic nature of phonemics. Some of these are analogous to the ecological factors, such as location, radiation, and the like, that have proven so significant in biology. It has been shown (2), for example, that the following principles generally hold:

1. Isolated areas (such as islands' or mountainous regions) conserve older linguistic features than others.

2. Lateral areas preserve older linguistic features than central areas.

3. Of two forms, the older one is spread over the larger, the innovation over the lesser, area; provided the latter area is not either the isolated one (norm 1) or the sum of both lateral areas (norm 2).

4. Of two forms, the older one is preserved in a territory later occupied *(area seriore)* or colonial. . . .

Some analogies. Though we shall make appropriate arid necessary qualifications at points, our purpose, in general, is to press the biologic-linguistic analogies as far as seems possible, perhaps further. Note the following, as a beginning:

1. There appears to be almost as much order and regularity in linguistic evolution as in biological evolution.

2. In both cases, "internal necessity" (genetic and linguistic systematic "drift"); selection to meet adjustive and adaptive needs; and external pressures (migration, location, contact) seem to be supremely relevant.

3. The two sets of phenomena reveal similarities due to "convergence" as well as to genetic descent. The great linguist, Troubetskoy, contrasts language groups that are analogically similar *(Sprachbund)* with those that are homologous *(Sprachfamilie).* The existence of similar forces (internal and external), operative under similar conditions, is indicated by the existence of a limited number of types of changes which reoccur in historically unconnected languages and at different chronological periods.

4. In both phonology and genetics there are "accidental" (i.e., not predictable within the limits of the theory) abrupt changes. Geneticists cannot yet explain why "spontaneous" mutations occur, historical linguists cannot yet say why accent suddenly took the place of vowel quantity in a sound system.

5. In both realms one operates with a limited number of fixed loci. Just as every species is characterized by a definite number of chromosomes, so every phonological system at any given point in time is organized in terms of a specific number of phonemes. One can speak of loci in both instances. Some languages have more loci than others, but all languages have vowels, semi-vowels, consonants, at least one nasal and sibilant and at least two stops. There is a restricted number of articulatory positions (e.g. the tongue can be alveolar, dental, cacuminal, retroflex, kettle-shaped, etc.) and of sound types (stops, fricatives, affricates, clicks, and the like).

6. There appear to be linguistic analogues to the "position effects" on genes; most allophones are positional variants. Every language is made up of a combination of sounds, the vast majority of which have no meaning taken by themselves. The environment of the individual sound is determina-

[6] An island is, of course, not necessarily "isolated" in the sense meant here—e.g., England for many centuries.

tive. Similarly, no or few genes will produce identical effects regardless of the contribution of other genes which may or may not be present in particular positions. This shades over into linguistic analogues to modifier genes. Thus, in Navaho, only the presence of a long vowel or diphthong in a word makes possible rising or falling tone, as opposed to low and high tone. The high-low variation is possible alike with short vowels, long vowels, and diphthongs.

7. There are arresting, though perplexing, analogues between the fundamental entities themselves. In some ways the most satisfactory parallel is between chromosomes and phonemes, genes and distinctive features, and allelomorphs and allophones'; we have, however, not yet worked this out in an altogether acceptable way. At least, as chromosomes are made up of bundles of genes, so phonemes are resolvable into distinctive features. A listing of the relevant distinctive features constitutes, in fact, a definition of that phoneme. No distinctive features can be further decomposed by linguistic analysis.

We recognize fully that certain combinatorial principles in genetics do not apply in linguistics. This is most notable as regards the biparental source of genes in organisms reproducing sexually, with each parent contributing only the haploid number of chromosomes. It is also true, of course, that most of an individual's genes remain unaltered through life, whereas many of the phonemes of both individuals and groups can change within a generation. Nevertheless, let us boldly explore the analogies that appear in the four rubrics used in population genetics.

Mutation.' There are sudden sound changes, both regular and, sometimes, sporadic. An example of a sporadic change is the replacements of Latin "r" by "1" in the Spanish word for "tree" (arbol). Some examples of regular changes are: fricatives in proto-Indo-European became stops in Proto-Germanic; in early Aramaic a voiced labial spirant was replaced in all instances by a voiced labial stop; Vulgar Latin (and the Romance languages) replaced vowel quantity by stress accent. Most often, perhaps, mutations begin with allophones, leading later in some cases to new phonemes.[9]

Selection. It was a dictum of the older linguistics that "sound change is blind." In Old English, intervocalic "s" as in *ceosan* shifted to "z," whereas "s" remained in other positions. But Old Icelandic preserves a voiceless "s" in *kjosa,* and many other languages show no sign of voicing their intervocalic sibilants. Linguists were fond of examples of this kind to back up sweeping statements that the causes of sound change were unknown. Today linguists would modify this generalization to

[7] The first two of these analogies derive from viewing the phoneme as a set of distinctive features, each of which represents a selection from a binary juxtaposition. If one continues this analogy, however, one arrives at the juxtaposed pairs of the distinctive features, rather than the allophones as analogues to the allelomorphs. As indicated above, the allophones are more reminiscent of the position effect of genes. Still, in another way, the allelomorph-allophone anology is suggested in the process of phoneme modification in which one allophone changes into another until the phoneme is replaced altogether. One might also emphasize the highly functional significance of allelomorphs by comparing them to phoneme alternants. Thus, at one locus one may get a gene for antigens A or B or the gene for the absence of both (Blood Group 0). But one necessarily gets *one* of this series (including alternant forms for antigen A). Similarly, at the x "stop locus" in language one may get at bilabial positions one of the following voiceless forms: p, preaspirated p, postaspirated p, or voiceless lenis p.

[8] The documentation in this section of the paper is drawn mainly—though not exclusively—from the articles by Martinet (18) and Greenberg (8). Many of our statements are taken directly or in modified or paraphrased form from these publications. The original sources should, of course, be checked on any point deemed important. But, since we are not writing a contribution to technical linguistics, it would be pedantic to cite page numbers and modifications in detail. On the other hand, since more standard modes of biological analysis are here applied in a more novel manner to language, we have presented more sources and annotations in this section.

[9] Is there a parallel here to genetics? Bentley Glass (7) speaks of, "The origin of new genetic loci from old ones by the occurrence of small duplications or 'repeats', in the chromosomes, followed by a gradual differentiation of function and increasing independence of action, until the new loci have passed beyond the stage of pseudoalleles into that of clearly distinct genes."

the effect that some of the causes are either unknown or difficult to identify and verify. More important, much of what once appeared as "blind change" now submits to analysis in terms of phonemic theory. Some changes affect phones in all their contexts; others only phones in phonemically well-defined contexts.

Selection certainly operates in linguistic evolution in at least two respects: (a) in terms of sheer human. lazinesS—Zipf's (30) "principle of least effort"[10]; *(b)* in terms of communicative,- needs of speakers. Some single sounds are relatively rare in the languages of the world because they are intrinsically "difficult" to make, others not so much because they take more work or effort but because they have to be made just right. Unaspirated voiceless stops need critical timing; fronted palatal stops need critical pressure of air. Certain combinations of features and sequences of sounds present articulatory difficulties, and hence they tend to be smoothed out or eliminated. For example, a tendency toward palatization of front vowels has been observed in hundreds of languages. This simply makes these sequences easier to say. Such progressive changes as that of "Caesar" to "Cesar" are dependent on a shift from the slowly-moving rear tongue to the faster moving tongue tip, in articulating consonants. The liaison and the dropping of final consonants in French are due to the increase of rate with light stress, which forces the arresting consonant to shift to the next syllable in the syllable train or to disappear (22, p. 98).

No one would claim that changes in morphology, syntax, and lexicon are uninfluenced by communication problems; yet the significance of the sender-receiver relationship is equally clear for phonology.

Phonemic change involves, in decreasing order of frequency:

a. replacement of one phoneme by another (much the most common)
b. loss of a phoneme
c. transposition of phonemes
d. insertion of a phoneme

If the distinctive features, governing significant contrasts between two phonemes of a group of phonemes, alter, sounds that did not previously occur in the language may appear or a new patterning of existent sounds may result. In the latter case there often occurs the phenomenon of merger, involving a reduction in phonemic inventory, and the regularities on merging" illustrate both the principles of least effort and of communicative need:

1. The more uncommon a phoneme is in human speech in general, the more likely it is to be merged with another phoneme.

2. The lower the frequency of a phoneme in a given language, the more likely it is to merge with another phoneme, providing this second phoneme is not itself of excessively high frequency.

3. The closer the points of articulation shared by two phonemes, the more likely they are to merge.

4. The more distinctive features shared by two phonemes, the more likely they are to merge.

5. The fewer the pairs of different linguistic forms which are distinguished by two phonemes, the more likely they are to merge.[12]

The communication angle also comes out clearly in some recent collaborative work between linguists and communication engineers (8, pp. 156 ff.; 17). The number of distinctive features needed to describe the

10 However, Zipf 's thesis that "difficult" sounds are less frequent than "easy" sounds in the languages of the world needs further definition of conditions and in any case appears to he a great deal less than an exceptionless uniformity. It probably also needs to be supplemented by a principle of probability to the effect that "events corresponding to a greater range of combinations of factors are more likely to happen than those limited to a narrower combination of factors." See the review by Chao (4).

11 Mergings are often "avoided" by compensatory shifts throughout the system. See especially Martinet (18). This appears to be partly a matter of acoustic and articulatory economy, partly a matter of preserving the symmetry of the system (see below under "Drift.")

12 For example, in English the functional yield of the "p-b" opposition is very high. Hundreds of frequently used words are distinguished by this contrast. On the other hand, only a few pairs are contrasted by another voiceless-voiced opposition thigh-thy; mouth (noun)-mouth (verb).

number of phonemes would approach the minimum of $\log_2 n$,, where n is the number of phonemes in the system. But since the communication needs of both speakers and hearers must be taken into account, it was argued on theoretical grounds that factors of efficiency and redundancy should be equal." The actual number of distinctive features thus is predicted to be close to double the minimum number, permitting a redundancy of 50 %. In languages which have been analyzed this estimate has been borne out. In contemporary American the figure is 53 %; in contemporary Russian, 48.9 %; and in Spanish, where records at four time-points have been analyzed, the number oscillates over this mean-48.8, 57.3, 47.5, and, today, 50.0. In other words, the equilibrium between efficiency and redundancy" is maintained or, if the system gets out of line, rather quickly restored. Inasmuch as sounds are put together, among other things, to compromise between the needs of the speaker and the listener, it follows that the evolution of phonologies is subject to functional selection, and is not merely "accidental" and "spontaneous." Linguistic evolution in general can be conceived as regulated by the fluctuating balance between the expressive needs of man and his propensity to keep his physical and mental exertions at a minimum.

Migration. Just as genes "flow" from population to population, so do sounds—a subject of great interest to Franz Boas (1). Some Bantu-speaking groups borrowed clicks from Bushmen and Hottentots. Some Indo-European languages of India took over cacuminals from Dravidian or other pre-Indo-European tongues. Centuries after contact between peoples of different languages has ceased their languages may "perpetuate evidence" of the earlier contact (29). The problems of bilingualism (24), generational differences (21) and the like are excessively intricate. Casagrande (3) says:

> Linguistic change may occur in all the various aspects of language: phonology, grammar, vocabulary, and style. However, modifications in the highly systematic aspects, phonology and grammar, appear to progress at a slower rate, and while changes in these realms of language may be accelerated or even initiated by culture contact, they seem to result primarily from relatively autonomous linguistic drifts.

Bilinguals have, so to speak, two "phonological personalities." They speak language A with the "prejudices" of language B and vice versa. When bilinguals become imitated in respect of one or more features by the bulk of the speakers in a speech community, then a change becomes established." A kind

[13] This hypothesis receives some confirmation from the fact that the lowest frequencies of phoneme clustering are between phonemes maximally similar or maximally different. The results for 845 consonant clusters in a series of 20,000 phonemes tend to follow a normal curve. "It seems justified, then, to assume that at least in consonant clusters, maximum efforts for either encoder or decoder are avoided in favor of those situations where the effort is more or less equally divided" (8, p. 102).

[14] A somewhat forced analogue to "redundancy" in genetics: in *Drosophila* there are many different genes (far more than are "needed") which will produce eye color. Presumably this is "multiple security" for developmental processes.

[15] It may help to illustrate this very concretely from a known bit of linguistic history:

> In Old English there was a phoneme /f/ which had the allophone [f] initially, when doubled internally, and finally, and the allophone [v] when single internally (`five' had initial and final f, *seofen* 'seven' had internal [v]). This was part of the formal system of the old English language. After the Norman conquest . . . , words from French began to be used, informally by individuals who 'picked them up,'. . . . In Old French /f/ and /v/ were separate phonemes *(femme* but *vain, affaire* but *avoir*— and only /f/ in final position, *vif).* The English speaker who picked up such an old French word as *veal* 'veal, *calf*' (modern *veau)* could either pronounce it with initial [f] /f/, following his formal system, or could use initial [v] as an informal deviation from that system. When, however, French words became more widespread, the use of [v] in such instances became technically demanded and approved; we can imagine the kitchenhand from his lord's castle telling his friends back home about how calf meat is called *veal,* and when some one of them tried to say it and uttered an initial f, correcting him explicitly, `No, not [f . . .1, but [v . . .].' Finally, the technical knowledge of how to use [v] initially became widespread, the word *veal* (and others like it) became a part of English, and a new formal system was thus instituted, in which /f/ and /v/ became separate phonemes, as they continue to be. When the old formal system was replaced by the new one, the previous formal usage became an informal one—some speakers still said [f] in *veal,*

of contagion takes place. Swadesh (23) generalizes some of the processes as follows:

> The principle that seems to govern language replacement, both with respect to dominating and dominated groups may be stated thus: In an area and era of broadening economic and social intercourse, there tends to be more and more widespread use of fewer and fewer languages. Speakers of more restricted languages tend to become bilinguals and eventually, often after a number of centuries, the minor languages are eliminated. Factors in language rivalry include: population numbers, breadth of geographic spread, mobility of the population, economic and political dominance and activity. Numbers are a highly important factor but may to some extent be offset by other factors. In places and times (e.g. medieval Europe) of reduced intercommunication, linguistic communities suffer gradual fragmentation with local dialects of a single original language developing into separate and mutually unintelligible languages (23, p. 344).

Weinreich (24) finds four types of phonological interference: three phonemic (underdiff erentiation, overdifferentiation, and reinterpretation) and one phonetic (phone substitution). Even phonemes that already occur in a language become difficult when introduced in new sequences from a contact language.

Drift. There is little doubt that some features of phonological evolution are determined by tendencies immanent in the sound system at some earlier time-point—a type of systematic drift." This is shown by the fact that many changes in sundered speech communities follow remarkably parallel lines, even though the separate groups move into varied environments and are exposed to different historical and biological vicissitudes.

Trends more dependent on the internal dynamics of the system than on external selective factors (toward "function" as regards economy and communication) are also illustrated by the tendency to preserve symmetry in phonemic pattern. If, for instance, a language borrows through foreign contact ("migration") a voiceless velar spirant, it is probable that this will eventually be "paired" by the adoption of a voiced velar spirant, provided, the voiceless-voiced binary opposition is elsewhere prevalent in the system. There is no ninetional "need" for this. It is just a question of filling in what French and Spanish linguists call "the empty boxes"—i.e., maintaining neat symmetry. This is probably why such phonemes as and g do not approach each other (tending to merge) in English, in spite of the exceptionally low yield of this opposition. Though this specific form of the voiced-voiceless contrast is functionally insignificant, speakers (unconsciously) insist on maintaining it because it is an instance of a more generalized principle.

In other words, phonological evolution is seldom discrete. Because phonemics are involved, the evolution of sounds is always complicated by the pattern relations and hence cannot be explained altogether in functional ("selection") terms. If a "t" in the system "mutates" to aspirated "t" through unknown causes ("historical accident"), other voiceless stops in the series will sooner or later get aspirated. There appears to be no "functional" sense in this process; the "internal logic" of the system ("the theory of pattern attraction") just demands that all phonemes of a pattern_ become as fully symmetrical ("integrated") as conflicting factors make possible."

A firmer analogue to drift in the genetic sense is arguable. We recall that in the evolution of biological populations the random drift effect is strongest among small, highly inbred populations. Whether or not a similar effect in linguistic evolution is a consequence of small size and inbreeding requires more research than we have been able to accomplish; but there are fragments of evidence to support the hypothesis. Languages having numbers of phonemes

but this was no longer 'correct' or 'standard' or `proper' (9, p. 31).

[16] For a brief summary of "linguistic drift" see Harris (10).

[17] "Symmetry" or "internal logic", despite many violations, applies to grammar and other aspects of language as well as to phonemes; "mouses," and, "deers," are likely to be used by young children. Indeed, such expectation of regularity is built into all nervous systems; as shown by the conditioning and generalizing behaviors, which underlie induction, as well as by the splitting of experience into categories, which is basic to deduction.

within the known minimal range (Polynesians, Arunta, etc.) happen to be spoken by peoples who lived for many centuries in relative isolation from languages of markedly different sound types. Conversely, phonemic differentiation is most marked among small groups living where the communication networks were most complex (12).

The linguistic differentiation of the small groups along a relatively short but rugged coastline, as in Oregon, indicates the probable importance of the terrain. Here rugged mountains running to the coast separate the valleys of short rivers which flow from the Coast range; and linguistic (and probably population) differentiation is found between valleys. Moreover, the phonemic richness of speech is greatest at the valley heads, where cross valley traffic is greatest. The Caucasus, likewise an area where phonemic systems of strikingly different sorts were in sustained contact, is characterized by numbers of phonemes approaching the known maximum. The aboriginal New World was presumably populated by successive waves of migration from Asia, so the Americas had a plethora of families of unrelated (or possibly, in some cases, very dimly related) languages. American Indian tongues, in general, have a number of phonemes that is higher than that in many areas of the world. We hazard the speculation that a "function" of phonemic elaboration may be that of accentuating and preserving general cultural differentiation. Certainly the Caucasus and aboriginal America north of the Rio Grande represent locales where there is a high degree of "cellulation," the mixture of isolation and intercourse.

Here seems to be an analogue to the cellulation of partially isolated but interbreeding populations. It should be noted, however, that the principal evolutionary effect of cellulation in biological populations concerns their "evolutionary potential," i.e., the combination of variability and safety from extinction, and the analogue of this effect in the linguistic situation is not immediately clear. Partial isolation of small linguistic units and lively interchange with contact languages seem to be associated with phonemic richness, in contrast to the phonemic poverty of both the totally isolated units and (to a lesser extent) large thoroughly united ones; but it is not clear just how this phonemic richness affects either the viability or the rate of change of a language.

Although the complexity of the cultural-historical processes may preclude a simple formulation of equilibrium, such as the Hardy-Weinberg law of gene distribution, nevertheless effective equilibria are maintained—as evidenced by the findings on efficiency and redundancy. Perhaps, in principle, equilibrium is as important in the linguistic as in the genetic case but is not so finely demonstrable in detail, because historical accidents do not cancel each other out as completely in the cultural realm as in the biological. On the other hand, one must not demolish the various parallels too cavalierly, either. Thus, it is easy to say that, while alleles are interchangeable, phonemes are not; but the facts are (a), that some phonemes are interchangeable, and *(b),* if gene function is considered, alleles are *not* altogether interchangeable.

It is certain that the spoken language of the individual is culturally inherited—predominantly from parents, parent surrogates, and siblings. The "inheritance," however, is not a simple duplication but a learning process, involving trial and error, social reward and punishment, with a trend toward a pronunciation most closely resembling that of preferred elder people, including siblings. Moreover, this learning process need not be confined to the period of initial speech formation but may continue for years, so that a person's speech may change several times as his important daily contacts change. Thus, an individual's linguistic "phenotype" is not determined by factors inherited from two parents and combined by fertilization, but by a more complicated process, involving often a great many "parents" and a gradual stabilization of the phenotype in time. We might, to be sure, view the modification of the individual's speech as constituting a series of "somatic" mutations. In biological systems, however, somatic mutations do not significantly affect the fate of the germ plasm, which is the carrier of inheritance in organisms possessing sex; and there seems to be no equivalent of the "germ plasm" in language. The analogy may be closer, however, with parthenogenetic species in which biparental inheritance is absent and plasma genes are more important. Even in protozoa, with endomixis, plasma entities, as the killer factor of paramecium, do play an important role. The recently discovered ability of viruses to carry genie material from one type of microorganism to another—transduction—is also relevant. Evolution is thus possible by a series of small changes during the life span of individuals, not unlike learning. The best analogue of the genotype, however, is the inferred or constructed "ideal" structure of the total phonemic system.

Several possibilities present themselves as the analogues of the organism: the single instance of the spoken word, the word as it is ordinarily spoken by a particular speaker, or the total verbal output of a particular speaker. If the first is chosen, the "organism" is ephemeral, indeed; but it has a large succession of "descendants," the successive instances of the same word spoken by the same speaker. The progeny goes through an "adaptive process," as the pronunciation of the word becomes stabilized in the early years of the speaker; but it may also undergo more discrete "mutations," as the pronunciation is modified by other factors. If the word as most, frequently pronounced by a particular speaker is to be taken as the "organism," then we should consider the stabilization of phones as the ontogenetic development of the organism, while the modifications of speech in successive generations of speakers would be viewed as the phylogenetic development. If the organism is taken as the total verbal output of the individual, the considerations just above apply, except that the entire phonemic repertoire rather than the word is to be viewed as the "phenotype."

In any case, "somatic mutations" or "modifications" are transmitted in language, if by transmission we mean the modification of the speech of one individual by that of another. If the single instance of the spoken word is taken as the "organism," the above difficulties are eliminated—but others take their place. Shall we take the totality of spoken instances of the same word or the total phonology as the "species"? Presumably the latter. If the former, then the interaction of "species" becomes much more intimate than in biology, so that one cannot consider a species in relative isolation, as is done as a first approximation in genetic theory. The laws of "species" interaction probably acquire, under this assumption, a crucial importance that must somehow be discerned. If the total phonemic system is taken as the "species," then the "species" consists of thousands of grossly dissimilar phones ("individuals"). These are, however, strongly interdependent and a generalized. phone can, to a considerable degree, be identified by phonemic theory. As stated, the "ideal" structure of the phonology attributable to a linguistic community resembles a "genotype"; but if one looks primarily at the enormous concrete variability of phones, language appears less like a species and more like an organism, consisting of interrelated tissues and organs that vary through time and develop more by an embryological than a genetic process.

"Mutation pressure" in language, the tendency to develop "new" allophones or phonemes, instead of remaining relatively constant for particular units may well be dependent on a great variety of factors. (In genetic theory, mutation pressure is taken as relatively constant for each gene, but it does probably vary over a longer time scale; indeed, a number of the problems of analogizing here stem from the different times involved in biologic and social evolution.) "Mutation" would not include changes in phones brought about by bilingualism or sustained contacts with "foreign" speakers—these would be subsumed under the factors of selection and migration—but refers to spontaneous, nonimitative linguistic changes. Some of these are occasioned by influences other than the speech of other individuals, though the speech of others may often be a stimulus or "catalyst." Situational changes (climate, nutrition, flow of different biological genes into the population) can bring about alterations in modal "constitution" or "temperament" and these, in turn, are reflected in variations in standard respiratory patterns, speech tempo, stress, and the like. Other innovations in phonology may not indicate anything more than that propensity for variation which inheres in living matter and which becomes expressed in behavioral variation. But even in these "genuine" mutations (as distinguished from imitative-adaptive modifications), the direction of change may be influenced by environmental conditions—a circumstance certainly unproven in biology.

In considering "selection pressure," we must again discriminate between selection as it operates in bringing the speech of one individual nearer to that of another (by reinforcing certain responses and inhibiting others) from the selection pressure which is imposed by other, nonimitative factors. Under the latter type of selection pressure are those factors which favor certain sounds and sound combinations for anatomical and physiological reasons of "least effort." In general, innovations can be expected to be selected which interfere least with established motor habits of speaking.

At any rate, a definition of survival advantage of a speech unit analogous to the survival advantage of a gene could be constructed positively in terms of the potential spread of the unit through the population (its "fertility rate") and negatively in terms of its tendency to fail to establish itself or to be eliminated (its "mortality rate"). This definition is especially natural if the single instance of the spoken word is taken as the individual organism, and its repetitions (with or without modifications) as its progeny. It is perhaps noteworthy that the modification of the "progeny" may be of two kinds: (a) the repetitions of the same word by the same speaker in the absence of instances of pronunciation by others involve "internal" modification based, perhaps, on the needs of the speaker; (b) the repetitions following instances of pronunciation of others involve "external" modifications, which, if this particular model is pursued, seem analogous to an exchange of "genetic material."

One important question to be considered with reference to selection is on what units selection operates. It certainly operates on several. Under some circumstances (e.g., cliques, social classes, etc.) comparatively small phonological variations have "survival value." Selection also operates on sound clusters, words, intonation patterns for whole utterances; and in some cases selection may conceivably operate on the speakers. The difference between "s" and "sh" selected for slaughter, at the passages of the Jordan by the Gileadites, all who failed to say "shibboleth."

Finally, we explicitly note an additional complication: phonological change is sometimes initiated and influenced by alterations in the nonlinguistic aspects of the culture—and it is well known that a large number of variables enters into the processes of culture change in general. To be sure, genetic processes are not immune to culture change either—a radically different mating system in a small population will, over the generations, alter the genotype of the population—but some facts on phonetic and culture change, well summarized by Hoijer (11), are impressive.

Lexical borrowings, based on familiarity with new objects and ideas provide new phonetic contexts. For example, two phonemes that never earlier appeared in initial position in Chiricahua Apache began to do so as a result of lexical borrowing from Spanish. This altered, albeit in a minor way, the whole phonetic equilibrium of Chiricahua utterances. (Perhaps the analogue here is to modifier genes.) Or, newly formed compounds may produce sounds that have not previously existed in the language or may bring together phonemes or allophones that have not previously occurred in sequence. Such a disturbance of the phonetic equilibrium may bring in its train a whole series of compensatory shifts which eventually, like the first Germanic consonant shift, can lead to changes in almost every aspect of the phonetic system.

In spite of all the difficulties—and they are very real, possibly insoluble—we feel that the analogues between biological and linguistic evolution are also real and interesting. Without much straining, one can talk about all of the known major processes of phonological change under the same rubrics (mutation, selection, migration, and drift) that are necessary to the understanding of population genetics. While there are places where the similarities break down and while there are details of significance which do not bridge the two fields, it appears to us that the genetic categories cover all or almost all of the main phenomena of sound change. Moreover, it should never be forgotten that *genetic* categories are also, in some respects, still in flux. Bentley Glass (*7*, p. 233) has written as follows:

> As to the gene—clearly when we have before us a process of continuous differentiation in the genetic material by means of pseudo-allelism, the nature of the "gene" depends upon the stage in the process. A single biochemical unit, a segment, a repetitive sequence of identical units that can undergo recombination, or a sequence of functionally different pseudoalleles—the gene might be any one of these up to the time when it has become clearly a multiplicity of genes.

The over-all conclusions concerning the evolution and fate of languages should appear, then, as the consequences of the consideration of those aspects which turn out, on sufficient examination, to be analogous to the "genetic distribution." The task of a mathematical theory is to develop an axiomatization concerning the duplication of linguistic "organisms" and their modifications throughout their "lives" and to derive what are essentially equilibrium theorems (analogous to determining the equilibrium representation of a gene subject to mutation, selection, and migration pressures). A mathematical expression derived for the equilibrium genetic distribution of a linguistic population could then lead to predictions concerning the evolutionary fate of such populations.

CULTURAL EVOLUTION—A LABORATORY APPROACH

Although the success of the experimental method in the natural sciences has been so pronounced that its use there requires no further justification, how far this success can be extended to behavioral science is still an open question. Three conditions are crucial: (a) the possibility of imposing sufficient controls upon the situations examined so that one can truly talk about "an experiment"; *(b)* the generalization potential of the situations examined; and *(c)* the relevancy of the results to what is held of importance in behavioral science.

A great deal of methodological controversy revolves about the feeling of some social scientists that conditions a and *c* are somehow incompatible. With varying degrees of conviction it is asserted that what can be unambiguously (especially quantitatively) described in human behavior is not interesting or important, and that what is important cannot be subjected to rigorous experiment under controlled conditions. The behavioral scientist with an "exact science" orientation, whether he thinks in terms of a controlled experiment or the statistical evaluation of field data or a mathematical model of behavior, probably tends to be attracted toward situations which yield to his methods and tends to attribute importance to them. This frailty, however, has a counterpart the social scientist who depreciates the exact theoretical, experimental, and statistical approaches may do so because he is repelled by situations which do yield themselves to methods alien to those to which he has become accustomed.

In this section we describe an experimental program designed to simulate the evolution of cultures. Since, as will appear, the situations to be studied do lend themselves to experimentation, conditions a and *c* seem satisfied. What of condition b—to what extent can the findings in experimental situations legitimately be generalized to the evolution of real cultures in human societies?

The question must be answered by test and it is hoped that two things will be accomplished by pursuing our program. First, techniques will be developed, more appropriate than those available, for experimenting with human beings on levels characteristic of specifically human behavior; levels involving, beyond responses to stimuli, individual learning, and other traditional matters studied in experimental psychology, such behavior as the evolution of hypotheses and the internalization of unconscious assumptions, their transmission through "generations," the role of tradition, ritual, and communication patterns, the evolution of language itself, etc. Indeed, since the idea or insight is an element that helps generate culture, like a gene, by interacting with its fellows and the environment, and since a new idea is a discontinuous "mutation" of the generating unit, our experimental program, no less than the historical examination of language, is a direct study of analogies between biological and cultural evolution.*

Second, it is hoped that the experimental *in vitro* program will lead to formulation hypotheses concerning the evolution of cultures in *situ*. Not that there is a lack of hypotheses about human behavior, but that new experimental techniques may give rise to a new sort of hypotheses. Insights stemming from controlled experiment have often been more useful than those stemming from intuition or from uncontrolled observation.

Considering, then, the creation of a microculture, the evolution of which under experimentally manipulated conditions could be directly observed, we are faced more with a research program than with a particular set of experiments. The essential invention is to gather a small group of individuals, which is presented with some task to perform under specified conditions of operation, and then to rotate progressively the members of the group. The evolving group 'culture" will thus be transmitted to successive generations of individuals, as new members continuously replace old ones. By choice of the experimental conditions, particularly the task, it should be possible to follow the group generation of hypotheses; development of communication, both by spoken words and written symbols; crystallization of rules and customs, roles and statuses; creation of artifacts; or even, perhaps, selection of values. Such a microculture indeed appears in real life and is well exemplified in the individual "personalities" that develop in particular dwelling clusters in planned housing developments and that persist despite rotation of families. Some of the controlling factors, such as the position of the buildings, have been pointed out in the articles on "The Transients" by William Whyte in *Fortune* (25).

Of these possibilities, we have so far explored only the first two—hypothesis formation and communication development. We have considered technical devices which will presumably enable us to manipulate the selection pressures of the environment, the types of "mutation" and the receptivity of the group to them (a kind of internal psychological environment affecting unit flow), the explicit factors of flow and migration, and those of isolation and random drift. In more detail, the experimental technique is described in terms of the variables that can be manipulated and the probable consequences of such manipulation.

A single type of task is shown below in two different examples.

Given the patterns X and Y, construct a pattern in Z on the same principle:

Y Z

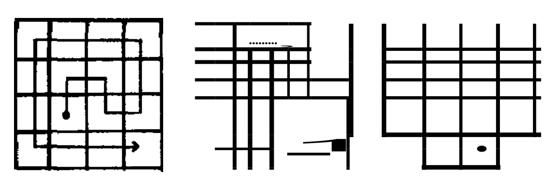


FIG. A

Similarly for X', **Y', and Z'**:

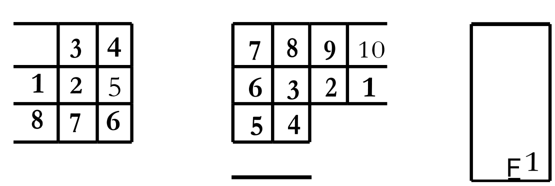


FIG. B

* Added in proof : Our attention has been called to related experiments of E. Rose and W. Felton, "Experimental Histories of Culture," Amer. Sociol. Rev., 1955, 20, 383-92.

The solution is contained in the following rules: The line proceeds to an adjacent square, or integers are placed in succession, in the following order of preference: (a) in the direction containing the largest number of empty squares; *(b)* up; *(c)* to the right; *(d)* to the left; *(e)* down. (The shape of the grid and the starting position can be changed arbitrarily.) The solution has not yet occurred to any subject. It is easy to construct tasks of lesser or greater difficulty;[18] indeed, drawing a path through a grid (or even an undivided area) may prove experimentally quite different from placing numbers.

Some basis of scoring the attempted solutions is required. To fix ideas, consider the second form of the task. A score can be devised by comparing the proposed pattern with the correct one (for the same grid and the same position of "1") by counting the mistakes in placing the next number, by counting the number of integers in the proper places, by assigning weights to mistakes (it is a bigger mistake to go down when up is correct than when to the left is correct, etc.), and in various other ways. Consideration of the total experimental situation will be relevant to the method of scoring, as will appear below.

Next, consider a single individual seeking correct patterns. He will learn something and thus improve his score if he gets information about his performance, even though the resulting learning curve will hardly be a consequence of inductive and dedtictive reasoning but more akin to the internalization of certain apperceptive habits, much as in the acquisition of a muscular skill.

The learning curve can be modified by introducing an additional factor in scoring, which will be of importance in the discussion to follow. A "tradition bias" can be introduced by allowing the "correct" response to move from that initially set by the experimenter in the direction of the actual past performances of the subject. Moreover, the relative weights of the objective score and the "tradition bias" can be varied at will, so that "experimentation" with patterns can be encouraged or discouraged in varying degrees. We note in passing that if the individual develops "theories" concerning the nature of the task, it is possible by means of the "tradition bias" to reinforce any theory he makes: his theories become self-fulfilling assumptions. Another way of discouraging too free "experimentation" is by introducing tolerance limits on the score, below which the subject "dies."

So far we have only a classical individual learning experiment. Our main interest, however, is not in the learning curve but in the psychological and possibly cultural by-products of the situation. The subject will make successive hypotheses about the solution to the problem, the nature of which permits a great number of more or less successful ones. Moreover, the exploration of the consequences of some hypotheses should be impeded by the subject's "commitment" to others. To some the numbered grid may appear as a modification of a magic square problem, so that they seek a rule governing the sums of the numbers in rows, columns, and diagonals. The idea that the rules apply to the ordered placing of numbers may or may not occur. If it does occur, again many hypotheses are possible about where the next number is to be placed—that its position depends on the position of the last, that it depends on the direction from which the last number was approached, etc.

Suppose now that our subject, having experimented up to a point or having "died," is replaced by another, to whom he leaves a "legacy" about "what life is like." This legacy may be transmitted in one or both of two different ways. First, the "tradition" accumulated in the scoring scheme modifies the situation itself. Grooves, so to speak, have been cut in behavior and these are "inherited" by the successor through the modified scoring scheme, even without any communication between individuals. Second, the "ancestor" may actually tell the

1b For example, this task is practically insoluble : given the series (a) 4, 5, 6, 5, 6, 1, 2, 11, 18. and (b) 3, 2, 1, 2, 3, 10, 15, 26, 35. . .; continue, by the same rule, series *(c)* 0, 3, 6. . . The formula is 12 $p - n^2$,—the absolute difference between doubles of successive primes and squares of successive integers—(a) starting with n = 0 (b) with n= 1, and (c) with n = 2.

"descendant" what he knows or thinks he knows about the situation. Either a modified environment or symbolic communication may thus serve to transmit acquired habits. In real life, members of one generation may tell those of another how they ought to live, transmitting information through symbolic channels; or they may leave a legacy of organization or technology which itself channelizes life into certain patterns, transmitting "grooves of behavior" without explicit communication. In principle it should be possible to compare quantitatively the relative effects of the two kinds of "time binding" in the experimental situation described.

Consider now a group of, say, three to six individuals engaged cooperatively in the task, but with individual members replaced from time to time by others, neophytes. Our "society" has a birth and a death process and, in due time, all the individuals are replaced. The foregoing considerations still apply, however, and the "culture"— the set of premises, categories, and ideas of how to deal with the environment (the task)—persists, being transmitted either through the internalized tradition bias of the scoring or through verbalized "education" of the newcomers or both. In a group new factors appear, of course, and these seem fundamental to the problem of simulating cultural evolution in a laboratory situation. To begin with, the "education" of the newcomers may be accomplished in at least two different ways, depending on how the task is to be performed by the group. If the efforts of the individuals are independently evaluated and if each works with his own patterns, then this "education" may be simply in the form of advice. If the group score is important, taken as the average of the individual scores, some pressure will be brought to bear to induce conformity to group norms. If, however, all the members of the group must work on the same grid, say, each contributing a number in a square, the pressures can be expected to be more severe on the neophyte, whose lack of experience or excessive enthusiasm for experimentation could lead to the group's extinction through a low score.

By far the most significant group factor expected to arise is intra-group communication. In contrast to intra-individual communication through unspoken thought, the verbal inter-individual communication in the group is amenable to considerable experimental control and also to complete observation, especially if only written communication is allowed. Let us consider this factor in some detail.

The language of group communication can enter as a variable in a variety of ways. In the simplest case, a limited vocabulary can be imposed on the group, from which all words used in communication must be chosen. The kinds of words permitted should influence the kinds of concepts that develop, and so guide the behavior of a given group in new test situations. Thus, certain lacks in the vocabulary, as of words designating direction or words designating position, might restrict the range of ideas explored in the learning process or lead to the invention of compensating idioms, while the presence of certain key words might predispose to certain hypotheses. If, for example, the word "sum" occurs in the vocabulary, there may be a strong tendency to see the grids as number puzzles, to which certain sums are the key. It so happens that five of the seven vertical sums in the examples given are multiples of three and the subject may well be led to use this sum in forming patterns, although no sum is a true key to the task. On the other hand, since certain sums might be statistically favored in the correct patterns, preoccupation with irrelevant criteria may nevertheless result in improved scores. Further, groups may be allowed to ask for additional words now and then, or even to "buy" them for score points, etc., to see whether ideational needs become acute. Or, groups might be permitted to develop their own vocabularies, subject only to size limitations. Again differential developments and their effects on the hypotheses formed, and thereby on the degrees and rates of adaptation achieved, would be at the center of interest. Finally, artificial languages only might be allowed.

There have been some preliminary explorations with the invention of artificial languages. A short passage (of some twenty words) is read to the subject, who is instructed to record the message, in any symbols he may choose to invent (any conventional or well-known code is disallowed), so that he can reproduce the message at will. Among several dozen subjects, all but one, who attempted a phonetic system, devised ideograms. Ideograms were often combined, as is done in Chinese, and conventional notations for successive abstractions or variations of an ideogram were invented. Thus, two ovals (the hemispheres) having been used for "brain" at one time, the word "idea" at once became an arrow into the ovals.°

If now the content of the messages is so biased as to favor certain classes of ideograms and their combinations, differential developments of "language" can be achieved through the subjects' own habits. These biases probably will be more stable than those imposed through a ready-made vocabulary. Thus equipped with a language, seemingly of his own making, the subject is instructed to teach this language to his group. It is expected that the internalization of the particular language will become more complete in the process of teaching it.

Suppose now, by doing all we can do to encourage "cultural differentiation" among several such groups, we "breed the cultures," i.e., establish fines of descent for the several groups through the process of replacing individuals. We may expect to see a process schematized as follows:

$F_0(L)$ $F_1(L)$ $F_2(L)$ •• or

$F_0(L_0)$ Ft(Li) F2(L2)

$F'_0(L')$ $F'_i(L')$ F'2(L') or

F'o(L'o) F'2(//2)

where the F's indicate the "generations" and the L's their associated languages. The total language resources could be kept fixed over the generations (L or *L'*) or be allowed to shift along with other elements. (L_0 to L_i, or L'o to L'_n).

Degrees of adaptation are indicated by the scores achieved. Adaptations may be to the "actual" environment (the task) or to the "secreted" cultural environment (sets of established habits). There may be cultures characterized by bold exploration (trying out new ideas), passing through troughs on the adaptation curves to reach higher peaks but sometimes becoming "extinct," and there may be others clinging to safe conservatism, unchanging and mediocre. There may be lines of descent characterized by easy adaptation to drastically changed situations (new shape or size of grid) and others quite rigid. We may observe the appearance of innovators, who may become "martyrs" or "leaders" toward success or failure. We may observe invention and possibly rationalizations against the acceptance of the invention, especially in the cases of strong traditional bias. We may observe role differentiation, (e.g., the assignment of the job of "educating the young"), and even the "education" process itself.

Finally, when several "strains" based on fundamentally different "philosophies" have been bred to some degree of constancy, they can be "crossed." An individual, for example, may be transferred from one group to another and either allowed to bring his language with him or not. If he does bring his language, he may teach it to the others or forget it and learn the new one. But, having learned the new language, he may still retain the orientation imposed by his old one. The variations one can introduce are legion; so at this stage we offer an experimental program, not a description of definite experi-

[19] Incidentally, certain ideograms are chosen so commonly for particular words—as a group of waving vertical lines for fire and a similar group of waving horizontal ones for water—that deep cultural or "racial" elements may well be involved. Experiments with different cultural or age groups will be especially interesting in this connection. At least, individual characteristics have been picked up in terms of ideograms chosen. Thus, the word "Greece", was represented by such symbols as: a short sword, a few columns supporting an architrave, a Grecian nose, and the like. Two individuals, who used an outline map of Greece, turned out to have very powerful, almost eidetic, visual memory. The technique of having subjects create drawings to fit concepts, rather than fit stories to presented figures, might be developed into an inverse type of projection test.

ments. The program can be carried out only stepwise, utilizing the successes, failures, insights, and disappointments inherent in any experimentation to guide subsequent steps. Nevertheless, the following considerations concerning possible ranges of these variables and their importance may be useful guides.

The *kinds* of subjects chosen for participation might be highly important. One could start with college students, as a reasonably characteristic sample of adults enculturated in our culture, but would hope eventually to include adults of a different culture, as the Navaho Indians; urban children, at different stages in the course of enculturation in our own culture; and schizophrenic patients, presumably with the standard enculturation but with abnormal individual reactivities to it.

The *number* constituting a given group must be large enough so that the rotating of individuals does not completely change the entity. This would demand certainly three, and probably four, participants. Conversely, since experiments indicate that group pressure toward conformity by an individual is already fairly maximum at a ratio of three to one, there would seem to be little point in increasing the numbers and complexity of the group much beyond six. Pending further empirical evidence, therefore, the groups will start with four or five individuals.

The *length of participation* of a given person and the rate at which individuals rotate in and out of the group are also important variables for experiment. An important factor to control is contamination of incoming individuals by premature exposure to gossip on the part of those who have been through the group. This could be completely eliminated if it were possible to run a continuous experiment within twelve, or even twenty-four, hours, insuring that those individuals rotating out of the group do not have access to the persons already selected to rotate into it. Other devices would be: to select subjects at a military staging area so that men rotate out of the group just as they are sent overseas; to use bedridden (orthopedic) patients in a large hospital, with communication entirely by messengers concerned with the experiment; even to use members of different branches of the same company located in different cities. Aside from contamination, considerations concerning rotation would involve: the degree of "learning" desired before transmission, the established conditions of transmission, the desired pressures toward conformity, and the like.

A related variable is the *conditions of interaction between two independently developed groups.* The groups might be mixed in *toto* or reshuffled into two new groups, a single representative of one might be introduced into the other, the ejects of both groups might become the entrants to a third mixed group, communication might be complete by personal interaction or limited to prescribed communication channels and terms, and so forth. Although here, also, some prior analysis is possible, probably much experimentation will be needed to determine the actual effects of these variables.

Along the same lines, the *patterns of interaction and action* within the group at any one time present several parameters for decision—and for empirical guidance. Should individuals be allowed to interact freely and, in effect, make a series of joint decisions, as for moves in a game; should each member of the group make a "move" simultaneously, or in a rotational order, or by self-selection (as raising a hand in a quiz performance to volunteer the answer) ; and, in each of these cases, should "moves" be at fixed identical time intervals, or with limits as to total time (as in a chess tournament), or with only successive temporal units noted. Moreover, aside from the actual making of "moves," similar questions arise as to permissible communication between members of the group. Should this be allowed after each move or only after each task has been completed and different ones are compared, freely within the group or along specified channels, etc. As an especially important subhead here, already considered sufficiently, is the question of the words or written symbols that should be permitted in *communication.*

Again related, is the problem of *trans-*

mission of the group culture to the new arrival. This might include material transmission, the group being allowed actually to produce or modify objects, or the scoring procedure, as indicated above; or semantic transmission, by verbal or written communication or by less explicit participation and observation. An especially important variable here would be the extent to which the ideas transmitted are explicitly formulated into words and rules, and whether or not the transmitting individual has been preinstructed as to the need of formal transmission of what he has learned.

The extent of the *pressure upon the newcomer* to conform to the group culture, as contrasted with his freedom to introduce innovations, can be influenced in several ways. If the "environment" is very severe—so that the group "dies" if its performance falls below a predetermined level—the premium will be on conservation rather than experimentation. If the group has been forced to create a rather extensive esoteric communication system, the newcomer can hardly exert an influence until he has become thoroughly acculturated, by which time he is less likely to introduce a completely fresh viewpoint. The rules chosen (by the experimenter) concerning interaction within the group could also favor freedom or conformity on the part of the newcomer. Finally, if the actual performance of the group has been allowed, by the scoring device chosen (see above and later), to influence the excellence of the performance, a deviation from the established ways of operation is much less likely to constitute an improvement than if such weighting has not been introduced.

As already indicated, the *scoring rules* can markedly influence the direction of change of the group. Two obvious factors are: whether individual performances are scored and totaled in some way, or whether a single group performance is scored; and whether both positive and negative factors are used—as introducing a penalty for sufficiently poor performance, or not. More subtle, and potentially highly important, is whether scoring is done on a fixed, continued, and uniform scheme—in which case the group must evolve towards a set goal; or whether the actual scoring principles are allowed to shift over the passage of time, by changing the weights given particular components in terms of what the group has actually done. If such a slanting of the score by group performance is introduced, the goal is not fixed but is to a desired degree generated by the group itself . As mentioned, such a situation would place greater restraints on an incoming member of the group. Such a procedure, moreover, would introduce complications when two groups were subsequently mixed, since each would be scored on a different basis. Possible difficulties here can be overcome in two ways. One is simply to grade each action taken by a given member of the mixed group in terms of the scoring level that pertains to the group from which he came. This would work quite smoothly if members of previously different groups were allowed to act alternately. The second method would be gradually to bring the scoring weight back to the initial conditions, so that both groups would end, as they started, with the same scoring rules. The initial period of group slanting would presumably be effective in fixing one or another tradition or hypothesis in the group during its cultural evolution.

Closely related to the scoring rules is the information given the group regarding its performance, the *scoring feedback.* This could range from essentially none, which would correspond to minimal selection pressures; through a statement merely of better or worse, perhaps most simply handled by allowing each run to consist of two performances and the superior one indicated; to the giving of a precise numerical score or even exhibiting the correct solution. A further variable would be the timing of the feedback, whether after each run, series, or entire experiment.

Another closely related variable is the *nature of the reward.* This might be in terms of individual performance and, indeed, could influence the continued participation of the individual in the group, if rotation out were in terms of performance rather than of time. Or, of course, partners or other subgroups could be rewarded, or the reward limited to the whole group on its total performance. Clearly, the degree of cooperation and cohesiveness would be strongly influenced by the reward pattern chosen. Moreover, this same factor can be extended, as between a given generation and following ones, by rewarding the individual or group in terms of immediate performance of the participants or in terms of subsequent performance of those taught.

Finally, but most important of all, is the *nature of the task* assigned to the group. The nature of the task will generally determine the *initial "set"* toward it—tasks resembling puzzles tend to act as invitations to match wits with the experimenter. But the same problem may be presented quite differently, as in terms of an esthetic evaluation of a design where the subject is not expected to reason out an answer, and his reactions might also be quite different.

In any event, it is possible to emphasize the generation of hypotheses or the generation of communication devices or both. The primary aim is to have a group generate a hypothesis or a group of related hypotheses concerning a task in such a way that it is possible experimentally to influence the direction in which these hypotheses will proceed. Perhaps the most restrictive kind of hypothesis, because the most logically determined, would be that presented by a number series, as discussed. Less restrictive, are such tasks as completing a picture or extending a two dimensional graph or selecting a set of cards. Still less related to a logical solution are tasks involving esthetic evaluation. Finally, at the other extreme, there may be no task as such; the group may be asked to do nothing but spend some time in a room talking. The "key" to the score would be an arbitrary list of actions, assigned positive or negative values, e.g., crossing the legs or other gestures, walking, standing, amount of talking, occurrence of certain words in the conversation. If the group is constantly informed of its current score, it will learn to improve it in the course of accidental variations of its behavior, without, however, being aware of just what is being learned. Here learning is devoid of all intellectual content. Yet if the group is required to pass on to successors what it has learned, it must rationalize, that is assign intellectual content to, its behavior. It would be interesting to see what course "cultural evolution" takes under these circumstances.

It would be surprising if the actual development of the program does not differ radically from that proposed at this preliminary stage; indeed, if the program is undertaken by more than one group of workers, they will almost certainly go in different directions. For a team of investigators also forms a "society" and develops a "culture," with its characteristic biases, adaptations, techniques, and "superstitions," and the business of breeding cultures and crossing them can be applied to the investigators as well as the subjects.

To sum up, the program offers methods of laboratory control of the following variables, thought to be important in the evolution of human cultures:

1. The world and its problems—the environment. By varying the scoring procedure the environment can be made mild or harsh, constant or erratic.
2. A society of individuals, self-sufficient with respect to the environment. The size of the society, its birth and death rates, and its composition with respect to the background of the members can be controlled.
3. The recording of experience in a language, subject to experimental control and observation.
4. The communication process within the society.
5. The transmission of knowledge and of environmental modifications to future members of the society.

Some questions which arise at this stage of conceptualization of the program are:

1. Can "strains" of these miniature cultures be "bred"; can a given "micro-culture" be kept stable in spite of the constant replacement of the members of the society? What are the factors making for stability or instability of the micro-culture? The question pertains not merely to the development of different habits in different

individuals under different conditions, but rather to the possibility of determining "cultures" which are a further abstraction removed from the "societies" in which they arise.

2. If different distinct strains are obtained, can their traditions be correlated with the languages in use, with the complexity and capriciousness of the environment, with other controlled variables?

3. Will rate and direction of development of the micro-cultures, as reflected in their performance of languages, show regularities depending on the experimental conditions? Is senescence possible?

4. Can one distinguish the "rational" and the nonrational factors in the repertoire of ideas which a group acquires about its task? Can the usual aberrations be observed ("cultural neurosis", xenophobia, what not)?

5. What happens when micro-cultures are crossed? Can resulting changes be correlated with the observed changes in the "technology"? Are changes occasioned by "immigrants" different from those arising within the "indigenous" groups?

6. Are there counterparts of the fate of biological species, such as fortuitous variations which under certain conditions lead to new and higher peaks of adaptation and under other conditions to extinction?

CONCLUSION

As stated at the beginning of this article, we are offering a plan for research more than any research results or even any particular experimental design. A bare minimum of actual testing has been carried out; but, although we plan to engage in an extended experimental program along the lines indicated, it seems wise to present this gleam in our experimental eyes without waiting until definitive results of the conception are available. The approach seems sufficiently novel so that major improvements could easily result from a wider consideration of the proposed experiments; and we warmly invite critical discussion and further positive suggestions, which may prevent unnecessary or useless experiments or suggest far better ones than have as yet occurred to us. Moreover, if the proposed techniques do prove feasible, the opportunities for fruitful research are almost unlimited. Similarly, the viewpoint here developed concerning the evolution of language might influence the observations and analyses of professional linguists. We would hope that many others would find investigations along one or another line indicated to be of sufficient promise and interest to pursue some ramification of them. Such fellow investigators we are eager to encourage to participate from the start.

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Samuel Rogers said:

Wordsworth and myself called on Coleridge when he was living at Gillman's. We sat with him two hours, he talking the whole time without intermission. When we left the house, we walked for some time without speaking.

"What a wonderful man he is!" exclaimed Wordsworth.

"Wonderful, indeed," said I.

"What depth of thought, what richness of expression !" continued Wordsworth.

"There's nothing like him that I ever heard," rejoined I.

Another pause.

"Pray," inquired Wordsworth, "did you precisely understand what he said about the Kantian philosophy?"

"Not precisely."

"Or about the plurality of worlds?"

"I can't say I did. In fact, if the truth must out, I did not understand a syllable from one end of his monologue to the other."

"No more," said Wordsworth, "did **I."**

From Irving J. Lee, **Customs and Crises in Communication,** Harper and Brothers.