The Measurement of Social Change

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IS IT possible to build a synoptic instrument, similar to a telescope or a radar network, for viewing one's own society? How may we interpret the myriads of social activities that are presently undertaken? Preliminary explorations suggest that we need sensing techniques, or transducers, that pick up changes going on inside the society. External indicators, like air photos, are too superficial. We are faced with a problem of discovering what operating characteristics a deep-probing instrument should have so that it may be as practical and useful as possible.

Economists judge change in society by modifications in the makeup of the gross national product and the level of expenditures, political scientists can analyze elections and polls, but sociologists and anthropologists have no cumulative sets of accounts or aggregate indexes. They have had hopes, however, similar to those expressed by Lazarsfeld [3]:

> Our economic statistics are today quite well advanced. We know how much pig iron is produced and how much meat is exported every year. But we still have very little bookkeeping in cultural matters. The content of mass media of communication is an important and readily available source of social data, and it will not be surprising if this analysis becomes a regular part of our statistical services in the not too distant future.

These statistics have not yet come into being because the labor cost was high, the time lags were great, and the system description was incomplete, so it has been impossible to state how one set of measurements related to another.

Let us take a brief, searching look at the social system. Society is maintained and changed by the behavior of its members. Intuitively one feels that the basic unit of behavior is the *act*, but acts are not as easily counted and differentiated as particles, molecules, or organisms. Satisfactory data can only be obtained when *actors* are forced to confine their behavior within certain preset specifications or codes, which may be called languages, currencies, habits, or "standard operating procedures." This behavior must be observed in *public* spheres, since the objective, detached observer is missing in private affairs. The latter will require altogether different instruments and techniques for data accumulation, and will not be taken up here.

By far the most promising attack upon the problems of measurability is offered by lumping together small sets of acts into *transactions*. A *social transaction* involves, among other things, the emission of a *message* together with evidence of its receipt—apparent to an observer, but also, through one or another form of feedback, to the agency responsible for emission.

At any given moment, the population of the society can be divided into *senders*, *receivers*, and *nonparticipants*, much as the economist divides his population into producers and consumers, and each participant must play both roles. The *message* normally contains some information that is novel to the *receiver*, more that is redundant, and some symbols that are quite unintelligible. Some messages are not communicated directly to *receivers*, but are stored in libraries, files, and artifacts where they become a resource embedded in the social environment. Uncoded information may be gleaned from the environment through systematic observation. Scientists, weather observers, diagnosticians, and other professionals have been trained to reduce these phenomena to coded, communicable form (Fig. 1). The information flows should be sampled where the wavy lines occur.

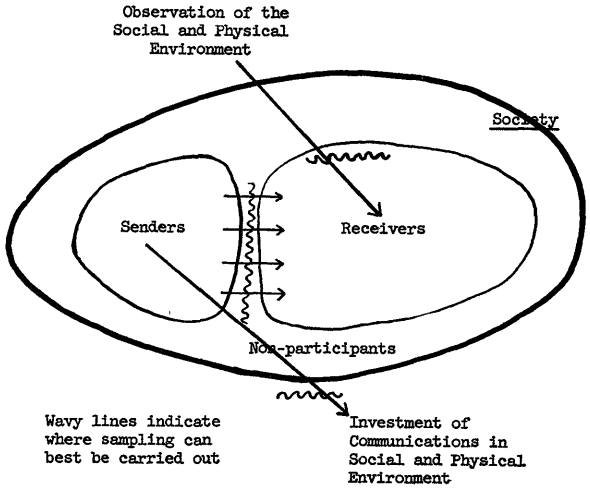

Fig. 1—Communications flows in society.

The term "information" at this point has been used in its intuitive sense. At a later stage, it will be shown that the demand for *information storage* (used now in its technical sense) in our instrument corresponds crudely with the volume of these flows in society—about as well as national income figures represent the combined satisfactions of consumers. The greatest difficulty in the design of our instrument is the conversion of all of the codes for human communication, oral, written, graphic, gestural, musical, etc., into a single code

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which is convenient for machine handling. We may have to incorporate human operators, whose skills resemble those of cataloguers in a library, for the more difficult features of translation. Fortunately, as we shall see later, the bulk of the information flow in modern society is in the form of printed language, which seems amenable to automatic sensing, coding, and abstracting (Luhn [4]).

Given the complexities in social communications, how would a representative and comprehensive overview of the social transactions be obtained for our instrument? The mass media—television, radio, magazines, newspapers, books, records, catalogues, direct mail advertising, etc.—could be recorded at the source. Schools, conferences, committee meetings, shop talk, live performances, etc., would have to be random-sampled. But on what basis?

Here we are forced to refer to a fundamental property of modern society. A *sender* can have many simultaneous *receivers*, but any given *receiver* usually accepts messages from but one *sender* at a given moment; on rare occasions he may pay attention to two or three, but no more. The decision as to the completion of a social transaction depends upon the *receiver*. He pays for the message by spending time taking it in. Human time is a moderately scarce commodity, and cannot be wasted indefinitely. People tend to switch dials and scan the newspapers and magazines until they find messages that are interesting to themselves. Message types that gain few receivers tend to be dropped by senders in favor of those which get more attention. Therefore, the social value of broadcast messages may be determined, as a first approximation, by the amount of *time* people devote to them.

Thus a comprehensive time budget of the members of the society—how they allocate time to receiving messages of various kinds, and time to other matters that do not involve social communications—provides a simple, additive criterion of value. We could attach the probable number of receivers, with some estimates of the time and place of reception, to the records of the messages themselves that are held in storage for our instrument.

The formulation of a society-wide time budget has already been explored by Meier [5]. A quantitative description of time-use has applications in public affairs independent of its employment in our system, and the techniques required for making economical measurements already exist.

Economists have found that macro-analysis is greatly assisted by subdividing the economy into such sectors as agriculture, manufacturing, households, etc. The rules for simplifying the accounting may be different in each sector. The choice of sectors in social analysis will depend upon the kinds of reinforcement provided by other approaches to social measurement, such as public opinion evaluation, the Census, and historical analysis. A first guess regarding sectors is provided in Table I.

TABLE I

COMMUNICATIONS-ORIENTED ALLOCATION OF TIME IN PUBLIC ACTIVITIES

Work	Travel	Play
School	Reading	Ritual
Radio and TV	Meetings and Parties	Personal Services
Shopping	Dining and Drinking	Miscellaneous

Possible Subcategories under Work

Factory	Housework
Office	Maintenance of Property
Construction and Mining	Services
Agriculture and Forestry	Miscellaneous

Another feature of our instrument must be introduced. If it is to be economically constructed, it should be decentralized. The headquarters would contain communications which are subject to national distribution, plus some measurements of exports and imports over continental boundaries, while branches would exist in every metropolitan area (Fig. 2).

In the course of proposing a design for this apparatus, we have piled feature upon feature so that it has by now become quite elaborate. It is expected to intercept and store a huge volume of messages, but this is made feasible by eliminating most of the redundancy in social communications, and reducing all the messages to a common code. The instrument attaches weights to these messages according to the number of persons and the amount of time spent receiving them; it indicates the times and places the message is received, and it must store all of this in a permanent record which can be scanned quickly and automatically. Fortunately it need not get every message that is received, but may start modestly by sampling at, say, a one per million rate. As the instrument is refined, and the representation of social change that is required must be finer-grained, the sampling rate may be advanced.

We are now ready to discuss who would use such an instrument and for what purposes. Planners and administrators who must make decisions for the public regarding parks, playgrounds, schools, traffic patterns, and various social services should be able to develop criteria for deciding from studies of trends in social communications and from comparisons with other sources of social data. Advertisers may be expected to develop their craft on the basis of the more detailed measurements of response they would be able to obtain. Politicians should be able to sense better the distribution of sentiment on various issues. Educators may assess the impact of special programs. Changing tastes, the appearance of new patterns of social interaction, and the passage of fads should all be registered as factual data—"how much," "where," and "when." The natural emphasis is upon local public affairs, mass entertainment, and the functioning of work, school, and commerce, because these matters make up the bulk of our communications activity.

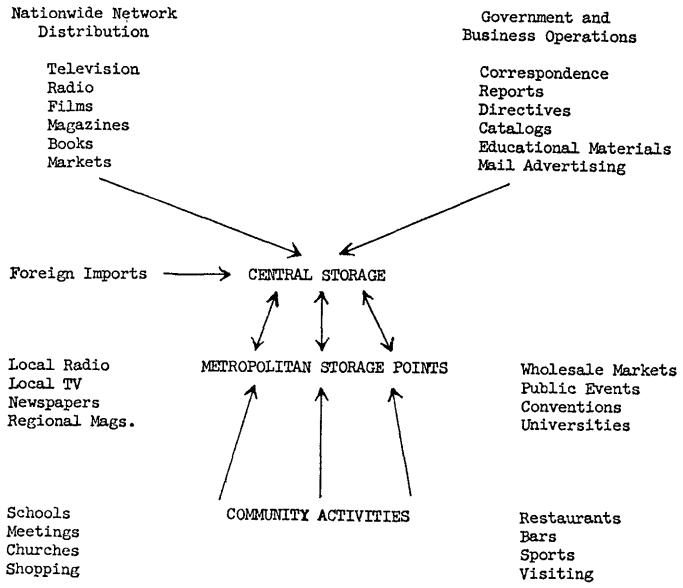


Fig. 2—Organization of social communications as imposed by the location of various activities.

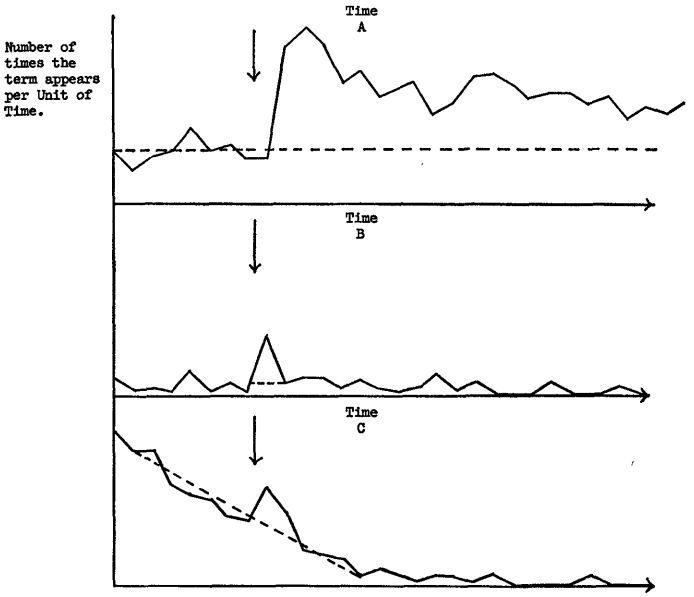


Fig. 3—The "trial balloon" stimulus as revealed by content analysis. Assume the stimulus contains concepts whose treatment in communications uses terms *A*, *B*, and *C* with high probability.

A skilled operator would ask his questions in terms of key words or phrases appearing in the content with a frequency of 10^{-6} to 10^{-8}. They serve as "tracers" of message content as it is spread through the population. Maps and time series can be prepared which show their buildup and decline. More detailed information about the changing attitudes of people may be obtained by reconstructing the contexts within which the key words appeared.

The severest criticism to be made of a representative record of social communications is that the content of the messages tends to be superficial. In many, if not most, social transactions people disguise their true feelings about a subject. An investigator may nevertheless make many nontrivial observations, and can probe more deeply, if he desires, by using the "trial balloon" technique (Fig. 3). An event, closely relevant to the subject of interest, is purposely created—it may be an announcement, an incident, or a rumor. The subsequent wave of "talk" that is stirred up may then be analyzed. The effect that is triggered off provides a good indication of the sensitivity of the public to that issue at that time.

These and other small-scale tactical uses in government and commerce should grow rapidly to the point where large installations may be justified which allow hundreds of simultaneous operators.

The strategic uses of an instrument of this sort are still more interesting. The accumulation of socio-cultural "wealth," for example, may be estimated in a manner analogous to that developed by economists, and the flows of information through society may also be estimated. A very brief outline of the steps involved, and the kinds of conclusions to be obtained, will be presented.

What is the total of all nonredundant information that is transmitted in society for a year? The limitation upon flow is the capacity of the *receiver* to understand the messages to which he exposed himself. A *receiver* has a limited repertory of terms. Reasonably good statistics exist only for English vocabulary.

The respective terms that are used in messages can be mapped according to their probability of occurrence in social communications, as in Fig. 4. The abscissa is some arbitrarily defined categorization of meanings, similar to the Dewey decimal system. When this same map is put onto polar coordinates, we can show stages in the development of a *receiver* as in Fig. 5. The protuberances on the periphery are associated with the specialties engaged in by the person. The map of transition probabilities between terms would have the same appearance.

There is a standing rule in society that a *sender* should have greater knowledge about the subject of the *message* than the *receiver*, if information is to be transmitted. Thus, on the average, the *senders* are more informed and more expert than the receiver, as shown in Fig. 6. Continued communication would cause the *receiver's* repertory of terms to grow in the direction of the *sender's*. He would learn something about the subject. *Senders* must choose their terms so that they lie on the periphery of the *receiver's* map, if they are to save time and maintain interest.

We are now in a position to estimate the amount of information flowing that is potentially useful to *receivers*. Let us define a restricted number of classes of receivers, say about a hundred, each representing a different segment of society, ranging from illiterates to various kinds of professionals, but exhaustive of the

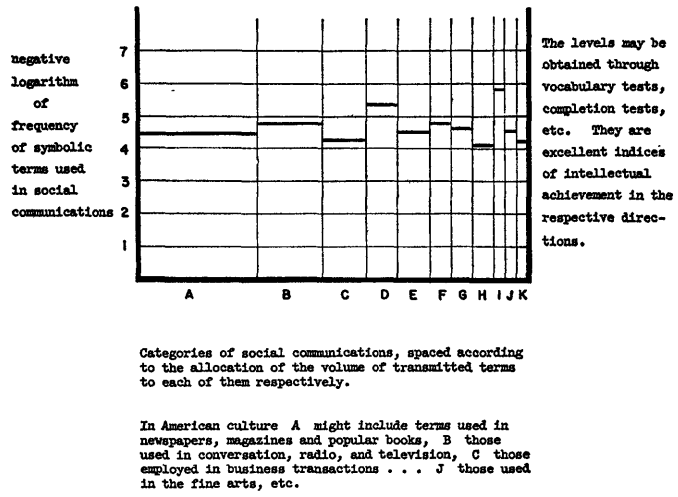


Fig. 4—Typical properties of a receiver of social communications.

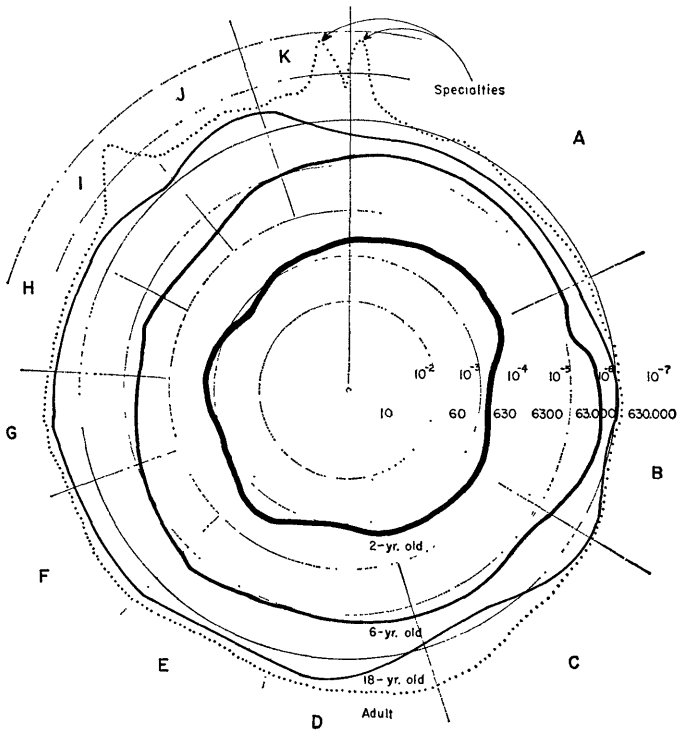
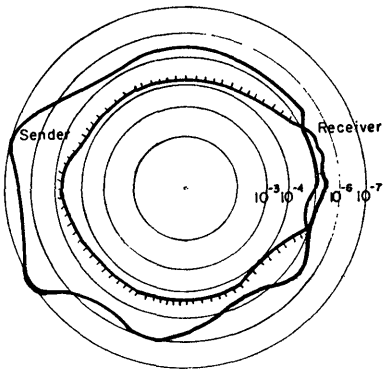


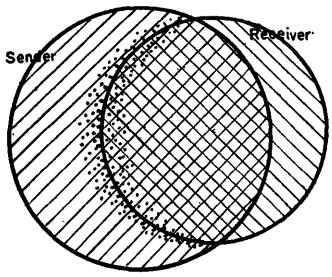
Fig. 5—Typical development of the vocabulary map in an individual. The powers of ten shown are levels for the frequencies with which terms appear. If the Zipf distribution (rank order times frequency is a constant) holds, each shell contains the indicated number of terms. Categories or contexts (A, B, C, $\cdots$ K) are assigned by convention as before.

population. Each would have a distinctive map. The messages transmitted in society and *stored* in our social record must have the *receivers* which choose to spend time on them classified according to category. Shannon [6] has described a method for using typical *receivers* for the measurement of redundancy.

Interestingly enough, the significant information flow *rate* tends to stabilize itself for a given context. Editing the rough spots out of manuscripts has this effect, and directing has this function for mass media. The pauses unconsciously inserted into human speech have recently been shown to work on the same principle [1]. This property, combined with miscellaneous other available information about mass public behavior in American metropolitan areas, enables us to arrive at the first approximation of information flow (Table II).



(a)



(b)

Fig. 6—Relationships between repertories in social communications. (a) The receiver expands his map in the indicated direction as a consequence of communication. (b) Simplified maps showing how the sender chooses terms which lie on the boundary of the vocabulary that is shared, if he wishes to optimize the transfer of information.

TABLE II

INFORMATION TRANSMISSION IN METROPOLITAN SOCIETY*
(POPULATION 5,000,000)

Mode of Reception	Time Allocated hours/year	Estimated Receiving Rate bits/minute	Estimated Flow bits/year
Reading	4×10^9	1500	36×10^{13}
Television	3×10^9	500	9×10^{13}
Lecture and Discussion	4×10^9	200	5×10^{13}
Observation of Environment	3×10^9	100	2×10^{13}
Radio	1.5×10^9	300	3×10^{13}
Films	1.6×10^8	800	8×10^{12}
Miscellaneous	5×10^9	100	3×10^{13}
			6×10^{14}

per capita average$\sim10^8$ bits/year

* Judged in terms of the probable repertories of *receivers*, not in the accepted sense used in information theory. Possibly a new term should be coined for information distributed over a population.

Comparisons between the poorest and richest metropolitan areas can also be exceedingly suggestive (Table III). Observers now agree that socio-cultural growth parallels economic growth but the introduction of measurements suggests that social communications must either precede economic growth or grow more rapidly than income. Apparently an expansion of socio-cultural activity is a necessary but not sufficient precursor of economic development.

TABLE III
INCOME AND INFORMATION FLOW EXTREMES IN URBAN SOCIETY

	San Francisco	Addis Ababa or Jakarta
Income	\$3000 capita/year	\$150 capita/year
Non-redundant* information receipt	$\sim 10^8$ bits/year	$\sim 10^6$ bits/year

* Again in terms of probable repertories of receivers. This assumes that 70–80 per cent of residents in the poorer cities are illiterate.

The heavy volume of information transmitted by reading is highly significant. A society like our own which is increasingly white collar reads more at work and at home. There are limits to human ability to receive information, however, which are believed to be in the neighborhood of 10^9 bits per capita per annum for a population with the present distribution of mental capacities. At the present estimated rate of gain, this theoretical saturation level is likely to be reached within two generations. The prospect is startling enough to cause us to investigate more closely the stresses associated with communication saturation in human organizations.

My feeling is that our instrument is already technically feasible. Simple calculations show that sampling social communications at a rate of ten parts per million presents storage requirements within range of existing equipment, but the desired degree of access remains unclear. Message collection in the field is not a problem, but the programming for storage and the cataloguing of nonverbal materials has been inadequately developed. Much experimental work and formal analysis will be required before a truly comprehensive cross section of social change can be achieved.

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Simulation of Sampled-Data Systems Using Analog-to-Digital Converters

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INTRODUCTION

UNTIL recently, systems simulation problems could generally be split into two classes: problems requiring only an analog computer for solution and problems requiring only a digital computer for solution. Any general problem has a number of characteristics which adapt it to either one or the other method of solution.

A systems problem is most readily adapted to analog computer simulation when it requires a relatively short solution time on the computer and a relatively inaccurate solution is acceptable; has relatively "high" frequencies; and has nonlinearities such as, for example, saturation, deadzone, or hysteresis. To be adapted to digital computer simulation, a systems problem usually possesses relatively low frequencies and requires a long solution time; can be adapted to an iterative form of simulation without introduction of an instability (this is usually implied by a lack of nonlinearities such as those mentioned above); and has a range of variable which exceeds that possessed by an analog computer solution.

Certain problems involving combinations of both groups of properties may often be split into two separate problems, one involving high-frequency nonlinear effects, and one involving low-frequency effects.

An example of such a problem is the simulation of the flight of a liquid-propelled ballistic missile. The missile's

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