Galileo as a Cognitive System

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Cognitive Systems

During the recent past, research in many fields has focused on intelligent systems, both natural and artificial, under many new and old names. In general, an intelligent system, or a cognitive system, may be defined as any system which represents some aspect of its experience symbolically, and learns, reasons or otherwise manipulates those symbols in some way. In this paper one such system, the Galileo System, will be described.

Theory

Galileo theory assumes that cultures encounter their environment and represent their experiences internally. It further assumes that no particular system of representation is required by nature, but that any system of representations of experience is fundamentally arbitrary.

The Galileo system models cognitive experiences as a mathematical continuum, not unlike the "oneness" of ancient oriental thinkers. And, also like oriental theory, the Galileo system assumes that there are no natural divisions, categories or other cleavages inherent in this continuum.

Some portions of this continuum may, for arbitrary reasons, be set aside from the totality. Any portion of experience that members of a culture set apart from the background is called an "object". Objects are the most fundamental element of our representations of experience, and may consist of anything which can be designated or referred to.

The most salient and important of these objects are represented by the culture by means of relatively standardized symbols, such as words, pictures, sounds, numbers, and so forth.

Galileo theory assumes that cultural objects have no inherent definition, but rather derive their meaning by comparison with other objects designated by the culture. All meanings within the Galileo theory are therefore relative, with each object defined in terms of its pattern of similarities and differences with other objects.

While objects are the principle vehicle for understanding experience, Galileo theory assumes that the mathematical space which represents experience is continually meaningful, with points "between" objects having a meaning roughly the average of the meaning of the objects between which they lie. Thus a point in the Galileo space that lies midway between "red" and "white" would be the average of these two meanings, or "pink".

In English (and Westèrn languages in general), meanings of parts of the continuum not directly marked with symbols are usually indicated by combinations of words and adverbs, such as "somewhat friendly", or "tall, dark and handsome."

Type I and Type II Processes

Definitions of Cognitive Processes usually attend most to the term "Cognitive", leaving the meaning of "Process" to its ordinary language meaning. In English, however, the word "process" is itself ambiguous.

Any cognitive system, natural or artificial, may be thought of as a structure in communication with its environment. In general, this structure is a structure of information. Accessing this structure is of course a process. Thus, when a some system interprets a statement, for example, such as "Richard is friendly", it must break apart or parse the sentance and compare the elements with substructures within its own structure to determine whether it knows what each means, and what the combination might mean. This interpretation is, of course, a cognitive process.

When one analyses natural systems, perhaps most often the major goal is to determine what kind of structure "actually" exists in that natural system; whether it is a tree, for example, or a grid or script. In the development of artificial cognitive systems, major emphasis is probably more frequently laid on inventing a maximally efficiént system for accessing elements of the structure and making practical use of it in interpreting information from the environment.

The change of an existing knowledge structure, however, is also a process. This process by which a knowledge system changes, either in response to fresh inputs from the environment or due to internal forces, is usually referred to as "learning". If the process by which an information system accesses its own elements, that is, by which it compares information from its environment to information already in its own structure, might be called a "Type I Process", it might be well to call the process by which the system changes its structure a "Type II Process".

A successful analysis of natural cognitive system must entail a correct understanding of both Type I and Type II processes. Similarly, an efficient design for an artificial cognitive system must be efficient not only in the way it accesses information (Type I Processes), but also efficient in the way it changes in response to internal and external forces (Type II Processes).

In the Galileo model, the cognitive structure is represented as a mathematical continuum, some points in which are labelled. Extracting information from this system (Type I process) consists of finding the label or combination of labels which lie closest to the point in space we wish to identify. This process gives the "meaning" of that point in space, and is a Type I process.

In the Galileo model, a typical query would ask for the meaning of a word, phrase or combination of words, and a typical answer would consist of a set of words or phrases which lie in the neighborhood of the word or phrase to be defined, and whose geometric center lies "closest" to the word or phrase in question.

In practice, we do not expect that all possible distances between all possible labels are known by any subset of the members of the culture, but rather that the distances within "neighborhoods" are known to some approximation, and that the distances among neighborhoods in turn may be known. Any neighborhood can, of course, be taken as an object in its own right. This process can be indefinitely nested, such that neighborhoods may be objects nested within larger neighboroods, which are in turn objects lying within still larger neighborhoods, and so on.

The Galileo system models changes in the cognitive structure (Type II cognitive processes) as relative motions of the points in the space. One may think of these motions as actual movements of the labelled parts of the space relative to one another, but perhaps it is better to think of the space itself stretching and shrinking like a viscous fluid or gel. In general, we assume that assertions of the form "x is y" or "x is like y" result in "forces" which tend to pull x and y toward each other along the straightest line connecting them. We further assume that compound messages of the form "x is y and z" or "x is like y and z" generates "forces" which tend to move x, y and z toward their common center. (Alternative hypotheses exist which suggest elements will move toward a "weighted center", although no experiment has yet produced sufficient precision of measure to distinguish reliably among the competing hypotheses).

A significant advantage of the Galileo model over tree-like models of cognitive structures is the well-developed mathematics describing motions in space compared to the relative scarcity of mathematical models describing changes in tree structures.

Hybrid Cognitive Systems

The Galileo theory, like any theory, is simply a symbolic abstraction. The Galileo System, on the other hand, is an integrated set of theory and software derived from the theory, embedded in hardware and operated by and for the benefit of human beings.

While it is useful to distinguish "natural" from "artificial" cognitive systems for some purposes, it is important to recall that the boundaries of any system are always largely arbitrary. No system exists in isolation from its environment, and, under detailed analysis, the distinction between system and environment becomes increasingly "fuzzy" at the interface. Moreover, any two systems which may be considered distinct for some purposes might well be considered a single system for some other purposes. Thus a bicycle can certainly be considered as a system separate from its surround, and a human being may also be considered a separate system. Together, however, bicycle and rider may be considered a single system.

Compound systems might logically be composed of multiple natural systems combined into a larger system, or multiple artificial systems, like the chain and sprocket system, the braking system, etc., all of which combine into the bicycle system. Or, of course, systems might be compounded of both natural and artificial elements, as the bicycle-rider system. These systems compounded of natural and artifical systems might be called "Hybrid Systems".

The Galileo System

The Galileo System is a large-scale hybrid cognitive system which involves both human and computer systems. The computational component of the Galileo System revolves about a Sperry-UNIVAC 1100/83 mainframe computer, an IBM 3081 mainframe computer, four Digital PRO-350 microcomputers, a variable number of Lear-Siegler ADM31 and ADM3a and assorted other terminals, a set of telephone banks and associated hardware, and several hundred interrelated computer programs. (The actual physical configuration of the Galileo System varies constantly depending on equipment available, but the exact hardware configuration is not significant. Different versions of the Galileo System operate in other configurations, but this description will refer primarily to the Sperry-UNIVAC configuration.)

The human parts of the Galileo System consist of computer programmers, a staff of telephone interviewers , a professional supervisory staff, and cognitive scientists.

Also included within the human components of the system are the tens of thousands of human "informants" with whom the system interacts primarily through its telephone interviewers. A typical telephone conversation yields, in general, about 500 bytes of information that the system can "understand", and so òn a typical day the Galileo System may absorb somewhere between 25k and 50k bytes per port per day.

System Goals

As with any system, the structure and function of The Galileo System are best understood relative to the system goals. The Galileo System has two primary goals:

- o to develop an understanding of collective cognitive processes, and

- o to produce useful information about actual cognitive processes, leading to effective control of those processes.

Operation of the system

In practice, the usual use of the Galileo System is to discover the definition or meaning of a word or set of words, product, candidate, company or organization in some population. Thus a commercial client may wish to know how the general public defines its product, or a researcher may wish to know how the world's perception of Japan is changing over time.

The first step in this process is to identify the words or symbols which mark off the neighborhood where the object to be defined can be found. This is usually done by a series of in-depth telephone interviews (ranging from several dozen to hundreds in different cases). Respondents are asked only to discuss the object in as much detail as they wish.

Complete verbatim transcripts of these interviews are entered as they are conducted into the computer, where a series of programs (Galileo*CATPAC)(tm) parses the text, strips off articles, prepositions and other minor words, and counts the remaining words. The words are then searched for clusters by a diameter-method clustering algorithm, and dendograms describing the structure of the resulting clusters are produced.

The clusters resulting from the CATPAC analysis are thought to be the symbols or "markers" which define the neighborhood of the object we wish to define.

The next step in the Galileo process is to measure the relations of each of the marker concepts to the object in question and to each other. This is done in a standard way using ratio-scaled pair comparisons of each object with all others in a format produced by another sequence of programs, Galileo*AQM.

Telephone interviewers present these paired comparisons to a sample of respondents and enter their answers directly in to the system through another series of programs, Galileo*SPED. The system then produces spatial representations of the objects such that the distance between any pair of objects in the space is identical to its average measured dissimilarity. Simple tabular arrays of these distances are also produced, along with statistical information about the precision of the results.

Interaction with the mainframe components of the Galileo system is by means of a menu-driven interface (Galileo*TELEGAL)(tm):

The Galileo Company
MENU
(Type the number of the operation desired) 1 Instructions 2 Enter Interview Data 3 CATPAC(tm) 4 GALILEO(tm) Questionnaire 5 Enter GALILEO(tm) Data 6 Runstream for GALILEO(tm)v5.2 7 Run the Job 8 Develop Message Strategies 9 Plot ... 10 Display Concept Sizes 11 Display Standard Errors 12 Estimate Cost of Jobs 13 Leave a Message 14 Goodbye

Delivery

Results of these analyses are usually delivered to the end user or client via telephone to a microcomputer with local Galileo software onboard. A typical system is the CATS (Community Attitudes Toward SUNY) system, which was developed to monitor perceptions of the State University of New York.

In this system, the central Sperry/UNIVAC 1100/83 computer communicates with a set of four Digital PRO 350 microcomputers through a combination of Galileo software, Digital's PRO/Communication V2.0, and the Digital Telephone Management System (TMS).

Results of analyses are downloaded from the mainframe computer into the PRO 350 systems in the form of excerpts from the text of in depth interviews, frequency counts of words in interviews, lists of main clusters or concepts latent in the interviews, tables of distances among the objects in the space, statistical information, and coordinates of the objects in space.

These coordinates serve as input to Galileo*STRATEGY, a FORTRAN IV program resident on the PRO 350's. Galileo*STRATEGY can display a three dimensional subset of the Galileo space, while giving the user powerful interactive capacities. The end user can expand or shrink the space, move in or out from the picture, rotate any number of degrees in any direction, brighten and darken the objects, and interactively test potential strategies for modifying the structure of the space in desired ways.

Figure 1 shows a typical Galileo space produced by Galileo*STRATEGY. It represents the opinions a sample of the general population of New York State about the State University of New York. It shows that the distance between SUNY (The State University of New York) and "High Standards" is 45.43 units.

Figure 2 shows that the Private Colleges and Universities of New York are seen to be 48.7 units from "High Standards", or 107.1% of the distance SUNY is from "High Standards". This means that the general population of New York State believes SUNY excercises higher standards than do its private counterparts.

Type I Processes

In practice, the Galileo system user searches the system for the word or phrase of interest in a systematic way. First, Galileo*STRATEGY is run on the PRO 350 locally. Galileo*STRATEGY displays a list of every set of coordinates on the current directory. If the word appears on the directory, then it represents the name of a neighborhood. If it does not appear in the present directory, Galileo*STRATEGY will allow searches through all other directories.

If there are no matches in the PRO directories, the user can access the mainframe computer using PRO Communications V2.0 to search the main storage in the same way.

If the word or concept is still not found, the user may search all elements in all files ending in /LBLS to find out if the word lies in any neighborhood. If it does, then that neighborhood can be displayed by Galileo*STRATEGY. If it doesn't, no Galileo type information is available in the system, and the user can search very element which ends in /WORDS to determine whether that word has occurred in any in depth interview and how many times.

If Galileo coordinates are available for the word or phrase to be defined, then Galileo*STRATEGY can, by trial and error, determine how precisely any combination of words in the neighbohood can describe the meaning of the desired word or phrase. It does this by calculating the center of the geometric figure described by the words and calculating the distance from this point to the word to be defined. The smaller the resulting number, the more accurate the definition.

Alternatively, Galileo*AMG can automatically calculate the precise meaning of every possible combination of words in the neighborhood to determine which combination is closest in meaning to the target word. The best ten such combinations are typically made available in table form on the PRO 350 delivery system to the end user.

Type II processes

Since the Galileo system usually delivers its information to end users via telecommunication systems, it is easy to keep updated. The Galileo system is a continuous processing system, that is, it does not provide information in batches, but rather each day updates all tables, charts and sets of coordinates with information from the current day's input.

As the new information enters the system, the structure of the knowledge base in the Galileo changes to respond. In general, these changes are of two types

- o addition of new neighborhoods
- o change in the location of objects within neighborhoods

Addition of new neighborhoods to the Galileo database take place simply in response to the needs of the user community as a result of additional telephone inputs.

Change in the location of objects within existing neighborhoods takes place as a result of addition of new data to and the removal of old data from already existing datasets.

In the Galileo System, the locations of the objects in the space are given by the average of the coordinates of the individual persons polled. Changes, therefore, simply result from deleting old case and adding new cases to the data base and reaveraging. This results in a moving window of changing positions of the objects in the space.

Visually, changes in the beliefs and attitudes of the populations modelled in the Galileo system look like movements of the objects through the space. This provides a very convenient method of modelling changes which is at once simple to understand and mathematically efficient from a computational view.

Uses and advantages of the Galileo System

The Galileo system has found practical uses in those situations where individuals or organizations need to monitor and influence the attitudes and beliefs of large groups of people. Marketing and advertising research are common functions for the Galileo system, as are public service campaigns, experimental research, and other similar functions. Galileo has also been useful as a research tool for testing hypotheses and theories about cognitive processes in groups and populations.

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The Galileo[1] System: A Theory and Method for Analyzing Cognitive Processes

Galileo

Cognitive Processes -- 2

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I. Introduction and Background

Grid-theoretic approaches to the study of cognitive processes share in common the notion that cognitive structures may be represented by (generally) rectangular arrays of numbers, or grids. In general, these grids represent a set of constructs used by an individual or set of individuals in some situation, and the relation of the individual or group to those constructs.

Grid models differ primarily in the way data are collected (Bannister and Fransella, 1977) and in the way the data are analysed (Slater, 1972; Pope and Keen, 1981; Shaw, 1981). Regardless of the methods by which data are collected or analysed, however, most methods share the goal of determining some underlying structure from the data.

The Galileo Model (Woelfel & Fink, 1980), in contrast, has as its primary goal the analysis of cognitive processes. Process may be thought of as change of structure over time, and Galileo is specifically designed to measure changes in cognitive structure over time.

The analysis of change data inherently involves the measurement of differences and quotients. Any change, of course, represents a difference between a structure at one time and the same structure later. If we consider the rate at which a structure is changing, we must divide the amount of change by the elapsed time, and so, at the minimum, any analysis of rate of change involves examining ratios of differences. As we move to more sophisticated analyses of change, such as changes in the rate of change, or accelerations, we must consider even more complicated mathematical transformations of the raw data.

Since the (random) error component around a difference score is the sum of the individual errors, and since the error component around a quotient is the product of the errors of its components, the error around a rate of change (a "velocity") may be seen to be the product of the sums of the original error components. For this reason, the Galileo model places extraordinary emphasis on measurement precision. For the same reason, Galileo's mathematical model and computational software place a great premium on preservation of information present in the original data to an extent which is unusual in the analysis of cognitive data.

Finally, since large amounts of data are required to attain sufficient precision to perform meaningful analysis of time series, Galileo researchers have been intensive users of computer-based data collection and anaysis systems for two decades, and current versions of Galileo methods are heavily computerized.

Galileo differs from other grid models, then, because it has a different goal than most other methods, and this goal (the analysis of cognitive processes) imposes unique measurement and analysis requirements on the Galileo researcher.

II. Description of the Technique

The Galileo System is both a theory of cognitive processes and a set of computer software which implements the theory. The software is best understood in the light of its underlying theory.

Theory:

Galileo theory represent the domain of cognition as a multidimensional Riemann space. Every point in this space is considered to have a meaning. Points which are "close" to each other in the space have similar meanings, and points which are "far" from each other differ in meaning in proportion to their distance from each other. Since the space of cognition is assumed to be continuous everywhere, the Galileo model is non-categorical, and may be thought of as a "fuzzy-logic" model (Zadeh, 1977).

The Cultural Space:

Some of these points are sufficiently salient to a given culture to be given a name or label, which consists of a word or symbol or combination of words or symbols. These "labelled points" are called "landmarks" in Galileo theory, and serve as points of reference for measuring or "surveying" the space.

As already mentioned, every point in the space has meaning, not just the labelled points. Thus, in the neighborhood of the space which represents colors, we may find the label "red" and the label "white". A point midway between the two might be labelled "pink"; a point between the two but closer to red than white might be called "reddish pink", and so on. One may designate the meaning of any point in the space more or less accurately by a judicious combination of nouns, adjectives, adverbs ("slightly more red than pink") and other parts of speech.

In general, any n labels may be seen to form a geometric figure. The geometric center of that figure is the point whose meaning is given by that combination of labels. Thus, for example, if an object were competely defined as "large, heavy, and black", it would be located at the geometric center of the triangle which had large, heavy and black as its three vertices.

Entire regions of the space may themselves be labelled, so that one might identify the "neighborhood" in which one finds terms like "red", "green", "blue", and the like as "colors". These higher-level constructs may themselves be grouped and named, so that the (large) region including colors, sounds, tastes, etc., may be labelled as "attributes", and so on. Thus, while the Galileo model is infinitely "fuzzy", it is also capable of representing hierarchical structures as well.

Individual representations:

Clearly, the potential complexity of such a space is beyond that which could be held in attention at any moment by any individual, and, indeed, Galileo theory generally holds that the space is a property of the culture rather than the individual, with each individual holding a partial representation of the entire cultural space in his or her own cognition. These individual spaces may differ, perhaps even substantially, from the "average" or aggregate cognitive space. (Galileo software provides quantitative estimates of the degree to which any individual's space differs from the general cultural space, which may serve as measures of "cognitive deviance".)

Even the less complex representation of the cultural space resident in any individual is still far too complex to be held in attention at once, and so Galileo theory assumes individuals represent only selected "neighborhoods" in consciousssnes at a given moment.

The Self Concept:

Within each of these neighborhoods, each individual may label a point or subregion as "himself". Like any point in the space, the self has a meaning which is given entirely by its location in the space -- that is, by its distance relations with the other points or constructs. We expect that individuals will locate their self point close to those concepts which they believe describe them well, and far from those concepts which they believe describe them poorly or not at all.

Within the theory, an attitude is defined as the distance relation between the self-point and any other point; a belief is defined as the distance relation between any two points. Thus all attitudes are beliefs -- that is, beliefs about the self. The self concept may be defined as the set of all attitudes.

Since the entire space is never held in attention at once, it is assumed that the self may be defined differently in different neighborhoods. Thus, within the Galileo theory, the self is thought to have a relative and situational definition.

The location of the self point relative to other "objects" or constructs in the space is assumed to have behavioral significance. Any behavior, of course, may be represented as a point or region in the space, and behaviors are assumed to be performed with a frequency inversely proportional to their distance from the self point. Product market share is inversely proportional to distances of the products from the average self of a market, and so on.

Inconsistency:

Galileo theory does not assume that either individuals or whole cultures need to obey euclidean geometric rules in their definitions of the distance relations among the objects. Persons and cultures may, for example, define two points as "close" to a common third point, but not close to each other. For example, people may place "blue" close to themselves since it is a large part of their daily life, and also place "food" close to themselves for the same reasons. But they may place "blue" and "food' far apart, because foods are virtually never blue. Or, for example, people may place themselves close to "hot tea" and close to "iced tea", since they drink both, but relatively farther from "tepid tea", which, of course must lie "between" hot and iced tea, an impossibility on a flat, euclidean plane.

Triangles made of these distances will not in general satisfy the "triangle inequalities" constraints and hence do not lie in a euclidean space. They can, however, fit without distortion into a Riemann space. Galileo software is generally Riemannian, and will accommodate any pattern of distance relations. Should they prove empirically to be euclidean, Galileo software will automatically accomodate itself and produce a euclidean solution, but does not constrain the solution to be euclidean. (Woelfel & Barnett, 1982)

(It is important to note that the Galileo theory does not ascribe any special significance to the dimensions or axes of this space, since every point in the space is considered meaningful. The axes or dimensions are simply mathematical constructions which provide a convenient mathematical descripion of the locations of the points.)

Cognitive processes:

Once the notion of the cognitive space has been understood, it is simple to define cognitive processes as "changes" in the structure of this space over time. In general, any pattern of motions one can define for space in general can be applied to the Galileo model. We will discuss some of the main processes here: cognitive development, attitude and belief change, and planned intervention.

Cognitive Development:

The space of the newborn infant might be expected to be relatively empty and undifferentiated. Few points in the space are labelled, and few distinct neighborhoods could be distinguished. Galileo theory represents development as an expansion of the space, and an increase in the number of points which are labelled. Forgetting, similarly, is represented as a shrinking of the space.

Attitude and Belief Change:

Since beliefs are defined as the distance relations among points in the space, and attitudes are defined as distance relations between the self and other points, changes in beliefs and attitudes may be represented as motions of the points relative to one another. Rates of change may be described by the relative velocities of the points' motions, and changes in the rate of change as accelerations of the objects. These processes are well defined mathematically by straightforward generalizations of the equations of relativity physics, which also describes physical motion with equations defined on a multidimensional Riemann surface.

Inertial Mass:

The theory, following Woelfel and Haller (1970), assumes that any point in the space has coordinates which are the average of the coordinates of all those proposed to the individual by his or her experience. Put another way, different experiences, such as the information received from various other persons ("significant others"), or from direct observations, may suggest at one time or another that a given object is located in different places. The Galileo theory posits that the location actually established in an individual (or cultural) space will be the arithmetic mean (the geometric center) of those proposed locations.

If this is so, then it follows that objects whose location has been established on the basis of a great deal of information will be harder to "move" than will those whose locations was established on the basis of only a few inputs, just as a student's grade point average will be harder to change in senior year than in freshman year. This property of resistance to acceleration is defined in the Galileo theory as the "inertial mass" of a concept.

Planned Intervention:

Since the Galileo theory has a well defined mathematical model for predicting the meaning of any combination of words or phrases, it is possible to form hypotheses about the likely effects of any combination of such words and phrases on the cognitive structure of an individual or culture. Specifically, Galileo hypothesizes that any two concepts associated in some "message" (for example, "A is B"), will approach their common center in the space. Similarly, any n concepts associated in a message are expected to approach their common geometric center.

(Alternative hypotheses exist in the Galileo literature as to whether the concepts should approach the geometric center of the figure or some "weighted" center -- such as their center of mass -- but the practical differences among these versions of the theory are as yet usually too small to be measured precisely by data currently available.)

The Computer Model:

Since the process by which the Galileo theory is operationalized is so extensively computerized, it is useful to describe the measurement model in the context of the software by which measurement is implemented. The Galileo model is implemented in four phases, all computer assisted: identification of the landmarks (constructs) to be included in the neighborhood being surveyed; measurement of the distance relations among the landmarks; calculating the coordinates of the points for each of the time periods available and measuring their trajectories; and, finally, interactive display of the data.

Identifying the Landmarks (Constructs) in the Neighborhood:

The definition of any object of cognition whatever is given in the Galileo System by its location in space. One measures its location in space by measuring or "surveying" its distance relations among the set of other landmarks or constructs which lie in its neighborhood. The first step, therefore, in constructing a Galileo "map" of the neighborhood of an object or concept is to determine what other concepts lie in that neighborhood.

Although several methods are used by Galileo researchers, most commonly this is done by interviewing the subject or subjects in question. A computer program, Galileo*INTERVIEW, asks subjects to list the main attributes of the object to be defined. After several subjects have been interviewed, or after one subject has answered several questions, the data are passed to another set of programs, Galileo*CATPAC ("CATegory PACkage"). CATPAC is a linked set of programs which parses the text of the interviews, strips off punctuation, articles, prepositions and the like, counts the frequency of occurence of each word in response to each question, subject or "episode", and constructs a words by episodes occurrence matrix.

CATPAC then postmultiplies this matrix by its transpose to produce a words X words coocurrence matrix, which in turn provides the input to a diameter method cluster analysis program. The clustering program provides dendograms instantly on the computer screen. These clusters are then expected to form the list of underlying concepts which populate the neigborhood of the object to be defined.

CATPAC is very fast, accomplishing in a few minutes what ordinarily takes several weeks of effort by several people using conventional methods.

Measuring the Distances among the Clusters (Constructs):

The clusters output by CATPAC are then named (usually using one of the most frequently occurring words in each cluster as the name of that cluster), and entered into another interactive program, Galileo*AQM (Automated Questionnaire Maker). These questionnaires are then administered either in person, by telephone or by computer using another interactive program, Galileo*SPED (Simplified Process for Entering Data), which automatically inputs the data to an appropriate file.

The Galileo measurement model is particularly precise, asking respondents to estimate the differences in meaning between each of the $k(k-1)/2$ possible pairs of the k landmarks or constructs on a ratio level scale. Extensive research has shown this scaling procedure typically produces between one and two orders of magnitude more precision than do typical rating scales or categorical scales (Barnett, 1974; Gillham and Woelfel, 1975; Cary, 1985).

After these data have been gathered (or while they are being gathered, in many instances), they are passed through another series of Galileo programs which find the coordinates of the constructs or landmark objects in the Riemann space. Since precision is so important to a time-series modèl, all analysis conducted by these programs is distance-preserving. This means that the original raw distances can always be recovered from the Riemann coordinates without error.

Technically, the Galileo software calculates the centroid scalar products matrix B* following Torgerson (1958), then extracts all the eigenvectors, including the imaginary eigenvectors, from this B* matrix.

For time series data, this step is carried out for each time point in the series, then each set in the time series is rotated to a least-squares best fit to its immediate predecessor in time. These rotations can be constrained when additional data are available so that any subset of landmarks can be held stable and serve as a reference frame against which the relative motion of the remaining landmarks may be gauged.

Galileo provides too many options to describe in the remaining space, but the main hardcopy output for a typical anaysis might include

- A list of the job parameters
- A list of all errors identified in the raw data
- A list of all numbers higher than a given value
- A list of all values deleted from the raw data (if any)
- Statistics for each time period or dataset, including the mean distances for each pair, their standard deviation, standard error, variance, skewness, kurtosis, sample size, maximum value and percent relative error.
- Largest distance and smallest distance in each dataset
- Matrix of mean distances and sample sizes for each pair
- Principal Axes of the space for each dataset
- Eigenvalues for each dataset
- Warp Factor (degree of departure from euclidean space) for each set
- Rotated ("matched") coordinates in Riemann space
- Distance moved by each concept across each interval of time

- o Correlations among position vectors of the concepts across each time interval
- o Correlations among dimensions across each time interval

If the user wished to determine a strategy for changing any belief or attitude in any way and thus chose the Message Generator option, additional hard copy outputs would be available:

- o A list of every combination of concepts which could serve to produce the desired effect
- o Quantitative information about how effective each combination of concepts would be likely to be in producing the desired effect, including the distance to the goal before implementing the strategy, the distance remaining if the strategy had its theoretically maximum effect, and the ratio of these two values expressed as a percentage.

If the strategy had already been applied, say, in an experiment, message effectiveness outputs would be available:

- o For each interval in the time series, the correlation between the predicted trajectory and the observed trajectory
- o For each interval in the time series, the angle between the predicted trajectory and the observed trajectory
- o For each interval, the predicted distance moved and the distance actually observed.

Interactive Display:

In addition to this hard copy output, Galileo*STRATEGY provides a powerful interactive visual display (Figure 1). The first three dimensions of the Riemann space are presented on the screen with each object or construct represented as a sphere. The radius of each sphere represents the standard error around the location of the concept, so that there is a 68% likelihood that the concept's actual location is within the sphere.

In the initial display, the brightness of each sphere is inversely propoṙtional to the square of the distance between the sphere and the viewer's eyepoint, so that objects distant from the viewer glow more dimly than those closer.

The viewer can interact with the display in many ways. One can either zoom or dolly toward or away from the display, rotate the space in any direction by any amoung, brighten or darken the spheres, expand or shrink the spheres, or ask for numerical readouts of the distances between any two concepts or among any subset and any other subset of concepts. Similarly the user may inquire about the likely effects of any given strategy and receive an instant response which would include the current distance to the goal, the distance remaining after the hypothetical strategy were enacted, and the ratio of these numbers expressed as a percentage.

When a picture on the screen is particularly desireable, the user may dump it either to hard copy on a graphics printer, (Figure 2), or to black and white, (Figure 3), color print or color slide on a graphics imaging device (not illustrated).

III Applications:

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Galileo is a highly general model, both theoretically and computationally, and so has broad potential application across many fields. In fact, several hundred applications are already known, far too many to report in this space. Barnett (1985), however, has maintained a fairly complete bibliography of Galileo applications, which are available directly from him.

Although Galileo can be used quite generally wherever other grid-theoretic approaches are appropriate, Galileo may be particularly suitable:

o when high levels of precision are needed or desired,

o when deliberate intervention to change cognitive structure is planned,

o when multiple structures are to be compared, or

o when changes in cognitive structure are an object of study.

Furthermore, since CATPAC provides a fast and convenient way to identify underlying attributes or constructs, Galileo may be particularly useful when the investigator does not have a firm idea of what constructs are to be included in the grid.

Commercial applications usually require high levels of precision, since a single percentage of market share may often amount to several hundred million dollars. Commercial applications often involve deliberate manipulations of cognitive structures as well.

Figure 2 shows a very elementary commercial application in the alcoholic beverages market. Figure 3 shows a representation of the space of several of these beverages and the attributes by which they are defined as produced by Galileo*STRATEGY implemented on a Digital PRO/350 and imaged by a Polaroid Pallette. Figure 2 is produced by the Digital LA 100 printer from the Galileo*STRATEGY display.

Figure 2a shows the Strategy Selection Form superimposed over the display, and requests the user to specify a goal or "target." In this case (as is typical), the user has selected "YOURSELF" as goal, since research shows a very substantial negative correlation (usually about -.95+) of the distance between products and the self point with their market share. Next (not shown), the user is asked what concept(s) he/she wishes to move to that target, and also is asked to select a potential combination of constructs to test.

Figure 2b shows that Heublein (the product to be marketed with this campaign) is currently 96.25 units from the target, and that the strategy which uses the themes or attributes "SMOOTH", "DISTINCTIVE", AND "AUTHENTIC" can reduce this distance by over 82%, which makes it a very good strategy.

Figure 2c shows that a strategy which relied on the concepts "ELEGANT', "SUBTLE", AND "FLAVOR" would be much less effective, since it has the potential to reduce the distance by only slightly more than 26%.

This example is about as simple a commercial application as can be found, and most cases are much more complex, involving both multiple samples or market segments and multiple strategies.

Comparison of Spaces:

Since Galileo is specifically designed to model time-series, it has a powerful capacity to compare datasets. Figure 3a shows the beliefs and attitudes of a group of students of the State University of New York about SUNY. Figure 3b shows the beliefs and attitudes of a group of parents of SUNY students about SUNY.

Comparison of these two spaces is not as simple a matter as it may first appear, since the orientations of both spaces are essentially arbitrary; one may turn out to be "upside down" with regard to the other, for example, although, most likely, they will simply be rotated an arbitrary amount relative to each other.

In Figure 3, the space of the Students has been rotated as a rigid body to a least-squares best fit against the space of the parents. This rotation process does not affect the measured distances at all, but does remove artifactual differences due solely to arbitrary differences of orientation between the spaces.

Table 1 shows the distance between each concept in the space of the parents and the same concept in the space of the students. Since the Galileo program is designed to be a time-series program, the labelling of the output implies motion, but the comparison is appropriate in any case. Also, since the space is Riemannian, some of the distances are imaginary, which is represented in the table by minus signs. Only the magnitudes need be considered for the comparisons, however, with smaller numbers meaning greater agreement between the samples being compared. The overall difference between the two spaces taken as a whole is given at the bottom of Table 1, 12.689 units.

These numbers are all expressed on the original scale of measurement, and may be treated as ratios. Thus students and parents disagree about the location ("meaning") of GOOD STUDENTS by about 13 units, and disagree about the location of PUBLIC SERVICE by about 26 units, or about twice as much.

Table 2 shows the lengths ("magnitude") of the position vectors of each `construct for the parents (T1) and the students (T2), the scalar product of the two position vectors, the correlation between them, and the angle included between them. If the magnitudes are the same, the correlation 1.0 and the angle 0°, the position vectors are identical and the two constructs are in exactly the same place.

Once again, since the space is Riemannian, correlations can exceed one, and should be evaluated in terms of their distance from 1.0, thus the first correlation in Table Two, 1.008764, is nearly perfect, indicating that concept 1 (SUNY) lies at virtually the identical orientation in the space of both students and parents, but is nearly twice as far from the center of the space for the students (57.67 units) as it is for the parents (34.36).

Table 3 shows the relationships among the dimensions of the spaces of the parents and students. The first row, for example, shows that the first dimension of the parents' space is somewhat shorter (131.30 units) than the first dimension of the student's space (172.88 units), but that those dimensions are aligned fairly closely, lying at an angle of 17.2 degrees from parallel.

These outputs provide fairly complete information for comparison of the samples, both globally and with regard to particular elements, although, of course, the numbers become more meaningful as one gains experience with them in different contexts.

Time Series

Figure 4 represents the perceptions of 421 randomly selected telephone subscribers in the Capital District (Albany, Schenectady, Troy, NY) about the days of the week and common activities related to work and relaxation. Figure 4a represents all such calls that were conducted on Sunday; Figure 4b represents all those calls that were made on Monday, and so on. Thus, the seven pictures in Figure 4 represent seven frames of a "movie" about the way people's concepts about the week, work and relaxation change as the week progresses.

Within any frame of this movie, the days of the week form a distorted eliptical figure. Figure 5 represents the shape of this figure by its shadow on the floor of the space. This makes it somewhat easier to see that Monday is displaced to the right front of the elipse. As the shadow makes clear, this distorted elipse is in fact quite stable across the week.

While more is happening in this movie than can be described here, we will concentrate only on the motions of the concept "WORK". Notice that, on Sunday (Figure 4a), "WORK" is quite close to "MONDAY". On Monday, "WORK" is still close to "MONDAY". By Tuesday, "WORK" has moved to lie a bit closer to "TUESDAY" than to "MONDAY". On Wednesday, "WORK" has moved to be closest to "WEDNESDAY".

By Thursday, however, "WORK" begins to receed from the week (although it is relatively closer to "THURSDAY" than previously. By Friday, "WORK" has moved back to a position nearly between "MONDAY" and "TUESDAY", and, by Saturday, it is closest to "MONDAY" again.

This process should be expected to repeat itself week after week, and describe a periodic function in the cognitive structure which indeed coincides well with common understandings about the actual working behavior of individuals on a day to day basis.

Clinical Uses

As yet we are aware of no actual clinical uses of the Galileo procedures, although such applications are easy to visualize. Figure 6 shows the space of the emotions of several dozen undergraduate students at the State University of New York at Albany. Notice that the self point ("YOURSELF") lies quite close to "HAPPINESS" in this space. Motions of the self point in the emotions space could serve as a useful measure of emotional condition in the normal person, and, perhaps substantial deviations from the normal configurations of the emotions might indicate psychological or emotional abnormalities in an individual. In any event, Figure 6 shows that Galileo can be used to represent even fairly abstract emotional conditions with some precision.

The use of the strategic repositioning options of the Galileo program might prove particularly useful in therapeutic situations, especially if the therapist has a good idea as to what kind of cognitive structure is normal or healthy.

Extended Possibilties

A clear goal for Galileo analysis is the operation on a continuing basis of a system for real-time monitoring of cognitive processes. Although real time monitoring of the cognitive processes of an individual would require rather extraordinary efforts with current technologies, monitoring the cognitive processes of large populations in real time is not difficult for Galileo technology.

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Appendix

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