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Galileo System: Current Method and Applications

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Abstract

The Galileo System is an approach to looking at social scientific phenomena using the methods of physical scientists. This article explains the Galileo System in detail and corrects inaccuracies made in previous explanations, specifically the use of the term Riemannian to describe the space created by the system. This article also looks into best practices for using the Galileo System and makes suggestions for future research.

Keywords: Galileo System, Galileo Method, Riemannian Space

Galileo System: Current Method and Applications

Theory

The Galileo System represents a novel way of thinking about social science measurement that is fundamentally different from traditional schools of thought. There is a standard belief in the social sciences that human phenomena are much more complex than physical phenomena and cannot be broken down into rule-based explanations (Woelfel & Fink, 1980). One does not try to uncover basic laws and principles for phenomena they believe too complex to be simplified in such a way. This belief is reflected in the traditional methods for studying social sciences, which make these phenomena seem chaotic and mostly undecipherable. For example, Pearson's correlation coefficient is derived by dividing the covariance of two variables by the sum of their standard deviation, and gives a value between 1 and -1. This coefficient has meaning to social scientists, but it is steps removed from the original measurement and the value the cosine of the angle between two variables really has in understanding the relationship between the variables is difficult to explain (Woelfel & Stoyanoff, 2007).

Woelfel & Stoyanoff (2007) sum up the problems with the current way of thinking and the philosophy behind an alternative method:

> The Galileo System…begins with the assumption that Norman Campbell was wrong, and that human attitudes and beliefs are no more nor less measurable than any other attribute. Secondly, it assumes S.S. Stevens was wrong, and that there is only one kind of measurement: comparison to some standard. Third, it believes that Karl Pearson was wrong, and that the root mean square deviation of a variable is not a universally useful standard for comparison. (p. 5)

The Galileo System views social phenomena and physical phenomena as fundamentally similar and does not view the given phenomenon being studied as something separate from the measurements being collected (Woelfel & Fink, 1980; Woelfel & Stoyanoff, 2007). The Galileo System does not use measurements specific to the social sciences, but is grounded in methods typically associated with the physical sciences (Cheong et al., 2009). It tries to create a unified system for looking at social phenomena, especially in the field of communication.

The Galileo Survey

The first step in using the Galileo System for research is to form a list of concepts related to the domain being studied (Woelfel & Fink, 1980). This is typically accomplished by interviewing members of the population under investigation and surveying past research. Once these concepts are generated a Galileo Survey can be developed.

Each survey begins with a criterion pair, and consists of pair comparisons of all of the concepts so that for n concepts there are $n\ (n\text{-}1)/2$ pair comparisons (Woelfel & Fink, 1980). The participants are asked to give a number for how far apart they think these concepts are from each other. If they believe the concepts are similar, they will use a small number; if they are different, they will use a large number.

The criterion pair creates a standard by which all other concepts can be measured (Woelfel & Stoyanoff, 2007). It gives participants a scale, but the size of the scale does not affect the arrangement of the concepts in the space developed by these measurements (Evans, 2010; Gordon 1988). Criterion pairs should be neither the most similar nor dissimilar of the chosen concepts and should be considered a reasonably stable relationship by the population being studied (Evans, 2010; Woelfel & Fink, 1980). For example, using “chocolate and good are 500 units apart” may seem sensible to some members of the sample, but chocolate lovers would see this as a poor pairing, thinking chocolate and good should be much closer together. Using “chocolate and vanilla are 500 units apart” would be considered a much better criterion pair because all members would generally agree about how different the two concepts are. Choosing a good criterion pair is important and should be considered carefully.

Although the criterion pair is considered an important part of the Galileo Method, participants may not be using it the way researchers think they should. A recent study (Lovejoy, 2013) tested how accurately the data collected adhered to the given criterion pair. The criterion pair stated that two terms were 500 units apart, in the two groups tested the average for this pair of terms was 337.35 and 330.46. This indicates that the criterion pair was not closely adhered to. This may indicate that the criterion pair is not needed and that participants may have some collective idea of what numbers they consider to be large and small distances. However, even if the criterion pair is ignored its inclusion might help participants who may be confused as to how the survey works. Future research should look into how the criterion pair affects participant responses and whether it is necessary.

The Galileo System follows the principles put forth by Woelfel and Fink (1980). They propose that in order to create a communication theory similar to those in the physical sciences the three principles put forth by Born (1965) must first be applied. First is a standard of comparison needs to be created, second how to use this standard to observe this phenomena must be agreed upon so any observer will make the same measurement, and third if any phenomena cannot be measured using this agreed upon standard and method, it should not be included in the theory. They add to these two original principles that the theory should aim to minimize the information needed as input for the system and maximize the amount of information given as output by the system (Woelfel & Fink, 1980). That is the theory should find a balance between the cost and benefit of information needed from the participants to information gained by researchers.

The Galileo System follows these principles. It creates a standard of comparison, the criterion pair, uses a standard way of collecting and analyzing the information, the Galileo Survey and Program, and only includes concepts that can be measured using pair comparisons. The survey given to participants is very simple, and the amount of precise and reliable information gained from these pair comparisons is very large; ratio-level data that can take on any value for all word pairs (Woelfel & Fink, 1980). The Galileo System creates a unified theory in line with physical scientific theories.

The system is more useful than other communication models because it measures all the concepts the same way, making it easy to make direct comparisons (Fink, Monahan, & Kaplowitz, 1989; Kincaid, Yum, & Woelfel, 1983; Woelfel & Barnett, 1982). Other social scientific methods use different scales to measure each construct and researchers must use their own discretion to decide how best to combine different scales to test their specific hypotheses.

The Galileo System has been shown to have high reliability and validity and to be more precise than typical social science measurements because it uses a continuous ratio-level scale (Gillham & Woelfel, 1977). Using the Galileo System, precision can be increased by adding more respondents (Woelfel & Stoyanoff, 2007), which cannot be said for other social scientific methods. Once the Galileo Survey is administered, it is analyzed using the Galileo Program (Woelfel, 1993).

The Galileo Program

The calculations made by the Galileo Program (Woelfel, 1993) are relatively simple. Each pair comparison is averaged over all of the participants, creating a group level measure.

These become cells in the dissimilarity matrix D (Woelfel & Fink, 1980). The program then creates a coordinate system (matrix C) from the dissimilarity matrix using a method based on Young and Householder (1938) and Torgerson (1952). The elements of matrix C are given by $c_{ij} = \frac{1}{2}(\frac{1}{n}\sum_{i=1}^{n} d_{ij}^{2} + \frac{1}{n}\sum_{j=1}^{n} d_{ij}^{2} - \frac{1}{n^2}\sum_{i=1}^{n}\ \sum_{j=1}^{n} d_{ij}^{2} - d_{ij}^{2})$ (Woelfel & Fink, 1980, p. 61, slightly modified for consistency).

This gives the “double-centered” inner product matrix of D, given as the “Normal Solution” in the Galileo Program (Woelfel, 1993). After the matrix C is created, the next step is to find the diagonal matrix (matrix E) of C using the following formula $\mathrm{C} * \mathrm{E} * \mathrm{C}^{-1} = \mathrm{D}$. The columns of C are the eigenvectors of D and the elements of matrix E are the eigenvalues. Galileo lists the eigenvectors from largest to smallest in the output. The first eigenvector corresponds to the largest eigenvalue and is the principle direction of the configuration created by the data, the second eigenvector will be perpendicular to this one, and the third will be perpendicular to these first two planes (Woelfel & Fink, 1980). These first three eigenvectors are represented in the graphical output of Galileo, the Galileo cognitive map. This map should not be used as the basis for any analysis, since it is only a three dimensional representation of a higher dimensional space, but it does give a visual representation of the data, which may help researchers understand their data.

Torgerson referred to the procedure that creates the “double-centered” inner product matrix as Multidimensional Scaling (MDS). However, Torgerson believed that the space created should be Euclidean and any deviation from this Euclidean space is seen as error (Woelfel & Evans, 2009). Non-metric MDS was created to "correct" for the non-Euclidean nature of data when necessary. Those working on what would become the Galileo System did not believe the “triangle inequality” rule of a standard Euclidean space makes sense within a cognitive space and the data should not be forced into a Euclidean space using non-metric MDS. For example, an individual might consider "vodka" as close to "beer" and "beer" as close to "wings," but not view "wings" and "vodka" as close together in their cognitive space. In order to differentiate themselves from the non-metric MDS researchers, Galileo scholars began to refer to what they did as metric MDS, however “metric” was a misnomer since in mathematics a metric space must satisfy the triangle inequality (Cheong et al., 2009; Woelfel & Evans, 2009). In order to avoid any confusion, current Galileo researchers simple call what the Galileo Program does the Galileo Method, dropping the term MDS entirely despite both methods being rooted in the same original equations.

When violations of the triangle equality occur the eigenvalues, matrix E, will include both positive and negative numbers, creating a space with an indefinite inner product (Woelfel & Barnett, 1982). The Galileo literature often refers to this space as Riemannian, however a true Riemann space is positive definite, meaning it does not allow for negative eigenvalues. A Euclidean space is a special case of a Riemannian space, and has special properties, which make it the simplest type of Riemannian space; however by definition both types of spaces have positive definite metrics. The space created by the Galileo data can be considered pseudo-Riemannian, which would allow for negative eigenvalues (Lee, 1997) but it is more precise to call it an indefinite inner product space or more simply as a high-dimensional non-Euclidean space.

The warp factor, which is reported by the Galileo Program (Woelfel, 1993), is supposed to measure the degree to which a space is non-Euclidean. Since the roots of negative eigenvalues will be negative the sum of the roots associated with real dimensions will be greater than the sum of all roots; the ratio of the sum of the positive roots to the sum of all roots is the warp factor. A value of 1 would indicate no warp and that the space is Euclidean. Although this number has not been specifically researched, it is suspected that it will be higher when there is higher confusion or disagreement about where a concept should fall in the space or when participants are not very knowledgeable about how the concepts being studied are related to each other (Woelfel & Fink, 1980).

A recent study (Lovejoy, 2013) looked into how much variance could be explained by negative eigenvalues, another indication that the space is non-Euclidean, compared to how high the warp factor for the space was. The variance that is given by the Galileo output is derived from the diagonal elements trace of the C matrix (Woelfel & Fink, 1980). Each eigenvalue is expressed as a percentage of the trace, so that each axis can be described "in terms of the amount of variance or squared distance in the map it accounts for" (Woelfel & Fink, 1980, p. 63).

In the first space looked at three of the twenty eigenvalues were negative. Two of the negative eigenvalues account for 9.24 and 4.11 percentage of the variance respectively. This space is very clearly non-Euclidean in nature. The warp factor for this space was 1.14, which is not substantially higher than 1 which indicates the space is Euclidean. In the second space two of the twenty eigenvalues were negative, however the largest variances were explained by positive eigenvalues. In fact, over 50% of the variance could be explained by the first two dimensions (33.12 and 20.70) and 97.82% of the variance could be explained by the first five dimensions, all of which are positive. The warp factor for this space was slightly higher at 1.27, though still close to 1. How much of the variance can be explained by negative eigenvalues and how high the warp factor is do not seem to be related. Future research should look into what exactly is measured by the warp factor and if there is a better way to indicate the complexity of the space.

Applications

The information gathered by the Galileo Survey can be used to gain information about the group's attitudes and beliefs. In accordance with Symbolic Interaction Theory, the Galileo System holds that individuals perform behaviors that are consistent with their self-concept and that the self-concept can be measured using the term *Self* in the Galileo measurement (Cheong et al., 2009; Woelfel & Stoyanoff, 2007). When *Self* is included as a concept in the Galileo space, the self-concept of the group can be defined by the measurements of the relationship between *Self* and all other concepts (e.g. Woelfel & Stoyanoff, 2007). In this system, beliefs can be defined as the relationship among concepts in the space and attitudes as the relationship between *Self* and the other concepts in the space (e.g. Cheong et al., 2009). Understanding the attitudes of a group towards concepts and how these concepts interact with their self-concept is the main purpose of the Galileo System.

The Galileo System can also analyze the differences in these attitudes for two different groups (e.g. Kincaid, Yum, & Woelfel, 1983). Since all the measurements are made in the same way each space can be rotated to create a common origin for comparison. In order to compare two spaces the Galileo Program rotates each space 1 degree iteratively until the sum of the squared distances among each concept across datasets is minimized. When negative eigenvalues are present, the eigenvectors can be imaginary numbers, when this occurs these imaginary eigenvectors are split from the other eigenvectors and these two pieces are rotated separately treating the eigenvectors corresponding to negative eigenvalues as though they were positive in their own space. These two parts are then reassembled into one space (Woelfel & Fink, 1980). This same method can be used to analyze a group over time, where each time period is added as a new space to the Galileo Program.

The Galileo System can also analyze all of the possible messages that could be created using the concepts in a space and decipher the most effective way to move any two concepts closer together using the Automatic Message Generator or AMG (Woelfel & Stoyanoff, 2007). A task that would be impossible for a human looking at two-dimensional depictions of the data is easy for the computer using the high dimensional information gathered by the Galileo Survey. For example, in Taylor, Barnett, and Serota (1975), the researchers were able to generate a message intended to move the Democratic candidate closer to the self-concept of votes, in hopes of getting him elected. The message was successful in making this movement in the Galileo space and in the election.

For several decades the use of physical science standards and formulas to approach social science research by using the Galileo method has resulted in precise, reliable, and useful results (Woelfel, 2010). Some recent examples include Marshall (2006) who found the method a better tool for organ donation research than the usual Likert-type scales and Vishwanath and Chen (2006) who found Galileo more useful than the typical list based methods to view differences between adopters and nonadopters in the diffusion of innovations. Cheong et al. (2009) found the Galileo System to be much more useful than either the Uses and Gratification or Diffusion of Innovations approaches to investigate self-concept and media choice. The method has been used in almost every type of marketing and advertising research from new product development to customer satisfaction (Woelfel & Stoyanoff, 2007). Larson et al. (2009) in a RAND study prepared for the US Army advocated the use of Galileo to find ways to use soft power to improve US relations in the Middle East and other parts of the world. The authors note, "Woelfel’s theory was the closest that any social science approach came to providing the basis for an end-to-end engineering solution for planning, conducting, and assessing the impact of communications on attitudes and behaviors." (Larson et al., 2009, p. 19). The Galileo System has been shown to be a sound framework for looking at social scientific phenomena and has been successfully and usefully applied in several different fields.

Conclusion

The Galileo System is an improvement over other methods, however, it is not a perfect system. It needs to be continuously revised and enhanced as researchers find better ways to use and explain it. Researchers should be cautioned to avoid misleading language used in the past to explain the system, including the use of the terms metric multi-dimensional scaling and Riemannian. Future research should further investigate the use of the criterion pair and the meaning of the warp factor. By using precise scientific language to explain the system and fully understanding all of the parts of the survey and output, researchers will be better able to spread information about this efficient and effective system for researching social scientific phenomena.

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