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Information and Knowledge: Combining Justification, Truth, and Belief

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Abstract

Knowledge of a statement exists when the statement is true, it is believed, and it is justified. While there are somewhat unusual situations where the justified, true, belief model does not produce what some consider to be knowledge, this definition of knowledge serves as an adequate model for most purposes. Information being produced by processes is examined, and then expanded to show how different kinds of information combine to produce knowledge. Qualitative and quantitative definitions and variants of truth, justification, and belief are proposed, providing an informing based model of knowledge that can be applied to a range from individual statements to larger groups and societies. When justification and belief are diffused, such as through transmission, knowledge may be diffused or communicated. This paper presents a theoretical argument for treating knowledge as a combination of justification, truth, and believed statements, as well as a method for combining these statements. A discussion of empirical data that can be used to indicate belief, justification, truth, and knowledge in societies is provided and we show how the rise of Protestantism is associated with a rise in knowledge. We consider how Max Weber's hypothesis about the relationship between Protestantism and capitalism may be understood and historically and empirically supported in the context of the rise of knowledge as justified true belief.

Keywords: Informing science, information, diffusion, knowledge, justification, belief, Max Weber.

Introduction

One often hears phrases such as "knowledge industry," "knowledge age," and "knowledge is power," yet the term "knowledge" often remains poorly or completely undefined. How can knowledge be defined in a rigorous and discipline independent way, how can knowledge diffusion be modeled, and how can knowledge and its components be empirically studied? While there is seldom complete agreement on precisely what constitutes belief, truth, or justification, these concepts are important cornerstones to the development of a concept of knowledge and related ideas. In particular, many philosophers define having knowledge about a statement as occurring when the statement is justified, true, and believed, or a variant of this definition (Lycan, 2006). Empirical studies show that the folk notion of knowledge is largely consistent with the combina-

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tion of justification, truth, and belief (Starmans & Friedman, 2012). In this work, we move beyond laboratory studies in experimental philosophy to examine how information-based models of justification, truth, and belief might be applied to other kinds of models, testing our work by applying it to Max Weber's famous description of the relationship between Protestantism and Capitalism in societies (Weber, 2002). For Weber, Protestants felt that all occupations should be treated as worthy of hard work because they were blessed by God. Working hard and being successful was evidence that one was blessed by God, and this contributed to the rise of Capitalism. Other reasons for the relationships between Protestantism and Capitalism have been suggested (Young, 2009) and when we refer below to Weber's model, we refer to the existence of a (possibly non-causal) relationship between Protestantism and Capitalism.

Information may be defined as the characteristics or state of the output of any process (Losee, 2012). Given this general definition of information and the processes that produce the components of knowledge, the concept of knowledge may be precisely defined and measured in terms of information about several different phenomena. When beliefs and justification are communicated, this can result in the diffusion of knowledge. Conversely, the transmission of knowledge statements necessitates the transmission or diffusion of justification and belief. This model is applied to different domains, illustrating some of the potential contributions of this model, combining information-based models of justification, truth, and belief to produce an information-based model of knowledge.

We begin the presentation below by examining the nature of information in a precise and discipline-independent manner. We then consider how philosophers have described knowledge. Next, we consider the similarity between statements so that we will be able to consider a way of "combining" informative statements. Statements consistent with philosophical notions of justification, truth, and belief are considered. Combining these statements of justification, truth, and belief to produce statements of knowledge are next discussed. An empirical application of this approach is the diffusion of knowledge in society. Diffusion of statements of justification and belief are considered. Max Weber suggested the association between Protestantism and the rise of Capitalism: data that support the increase in knowledge with the introduction of Protestantism are given.

Information

While information may be defined or measured in a variety of ways, below we will treat all and only the characteristics of the output of any process as information about that process and the inputs to other processes (Losee, 2012). While one can measure the information present at these outputs, and thus the state of the process, using quantitative measures from information pioneers Nyquist, Hartley, and Shannon (Cover & Thomas, 2006; Gleick, 2011; Shannon, 1993), this general approach to information allows us to capture the interests of many different disciplines. Those believing that information belongs to just their own discipline or population may find the notion of discipline independence of information as undesirable or useless. Others prefer some element of the subjective in general models of information, while other information models exist in more deconstructionist or social realms (Bates, 2011), with similar spectrums occurring in the realm of knowledge (Boisot, 1998; Choo, 1998; Nonaka & Konno, 1998). Using a general model of information allows individuals to increase interdisciplinary communication, as well as to model a variety of information related phenomena across domains (Losee, 1997). However, using a common model of information may result in excluding certain aspects of the phenomena of interest to specific domains, or describing some phenomena in ways that are less useful to those in the domain. However, these discipline specific components that are not included as an integral part of discipline independent information may be included separately. Understanding information in a discipline independent manner provides a general approach to information and eventually to knowledge. The discipline independent approach is not meant to exclude narrower approaches to information that are not as general but might be simpler to apply in certain domains.

Defining information as all and only the characteristics in the output of a process, or the state of the output of a process, requires an understanding of a process (Losee, 2012). A process may be defined as any delimited area of the universe, with any forces impinging upon it and any matter entering it being referred to as input, and any other characteristics on the boundary of the delimited area that might be perceived from outside the delimited area as output. This is a much broader view of a process than one finds in the common input–process–output schema often found in various scientific disciplines. Using a broad model of information as the characteristics of a process's output allows one to view information in a general way, which is both rigorous and not human-centered, allowing us to address intelligence, and more specifically knowledge, in humans, animals, computers, and other domains in a scientific fashion.

The information in the output of a process is partially dependent upon the characteristics of the process and is also partially dependent upon the characteristics of the input. The output of a process has characteristics, and representations for all the characteristics together can be used to describe the output. Characteristics are the values that are possible for a particular variable: its state (Rosenberg, 2010). Characteristics may be referred to, so that a red fence at the boundary of a process may be referred to using the English language term "red," with the phrase "red fence" serving as a representation of an actual red fence. We assume that observing that a fence is red does not change the redness of the fence, although quantum theory suggests that on some levels, observation may change the state of what is being observed. If one is to describe or refer to the output or the information in the output of a process, it must be observed or sensed or measured. However, the information may exist in the output of the process without it being observed or sensed or measured. There is a desire in the work below to produce general models applicable anywhere rather than to make our discussion specific to a specific population (e.g., humans) or discipline (e.g., computer science or psychology). It is assumed here that outputs of processes are produced by virtually all processes, although black holes, for example, may not produce output and may not have output characteristics observable by those of us in this universe (Susskind, 2008).

The output of the process is in a state, which is totally dependent upon the combined characteristics of the process and the input. The general English language term for this form of dependence is "about," and this term is used here, although there are other forms of "aboutness" that do not address this kind of dependence. It should also be noted that the "output" of the process might be expressed as the "observable output" or the "measurable output," the characteristics of the output that are used by other processes.

The characteristics of a process's output may be arranged in a variety of ways. We refer to an arrangement of the output characteristics of an informative process as a statement, where a statement is an ordered list of output characteristics and representations of output states. A belief is a type of statement. The believed statement's characteristics are not inherently linguistic, but may also be visual images or some other form of mental representation (Cummins, 1991). This list of values can be compared to another list for their similarities or for the subject distance between them. One might, for example, consider the image of a tree that is visible through a window having characteristics that can be described by a botanist in a statement. The image on one's retina may have similar characteristics that may be describable in a statement that can be determined to be equivalent or similar to the statement by the botanist describing the tree outside the building. A statement might be non-equivalent to the botanist's statement if, for example, colored glass in the window changed the color of the image that appears on the information-accepting part of the retina, resulting in a different statement of what was seen through the colored glass.

Statistical relationships exist between characteristics and thus parts of statements. For example, the presence of leaves in one's observation increases the probability that one will observe other characteristics one finds on a tree, such as branches, a trunk, and ground in which the tree is rooted. A statement may be recoded to represent a tree with a set of statistically independent characteristics using dimensionality reduction techniques (Borko, 1985; Deerwester, Dumais, Furnas, Landauer, & Harshman, 1990; Hastie, Tibshirani, & Friedman, 2009). In some instances below it will be necessary to determine the amount of information in a statement, essentially with redundancy removed, but the features that will be used below often may be left as dependent with no loss of understanding.

Knowledge

When defining knowledge as a statement that is a justified statement, a true statement, and a believed statement, it is desirable to define each of these component concepts. A belief may be understood as a statement, or a set of informative characteristics that may be treated as a unit that is accepted as very likely true, or correct, by a human, with the human being viewed as a belief producing process. The strength of belief may be a discrete value, possibly a binary or nominal value, such as the statement is believed or not believed, or it may be a continuous value, with belief values above a certain cutoff being labeled as the statement is believed and those belief values at or below the cutoff being labeled as the statement is not believed. Believing or not believing a statement is different than believing that a statement is true or is false. Specifically, not believing means that the statement is not accepted, which is different than believing the negation of a statement, that is, accepting that the statement is false.

The truth of a statement may be understood as a relationship that exists between the statement in question and something else (Lynch, 2001). One might consider the truth of a statement to be a relationship with other statements, referred to as the coherence between the statement in question and the other statements. The truth of a statement may also be understood as a relationship between the statement and reality. Referred to as the correspondence theory of truth, an empirically true statement accurately reflects reality (Lynch, 2001). Something that is analytically true reflects processes or their outputs that are determined by factors other than the environment. For example, one might analytically argue that $0 + 1 = 1$ based solely upon mathematical methods (Whitehead & Russell, 1910), with no appeal to the world in which we live. The truth of empirical statements depends upon the characteristics and rules of this world and of the mathematical operators or other formal symbols representing processes.

A statement is justified when the holder of the statement has good reasons to accept the statement. A coherence form of justification of a statement suggests that the statement is consistent with the set of accepted statements to which it is being compared. Thus, coherent forms of justification address whether something is consistent with the statements representing a particular context. On the other hand, a foundationalist view of justification holds that some beliefs are basic beliefs, while other beliefs are justified because of consistency with other accepted beliefs. True and justified believed statements may serve as the basis for a known statement.

Knowledge may be defined in many different ways (Audi, 2011). Information may be defined as what provides the certainty needed to have knowledge (Dretske, 1981, 1983), and conversely, knowledge may have information as one of its components. Somewhat informally, knowledge may be treated as all learned material that makes sense, that is accepted, and that is stored in the human brain. More rigorously, a statement may be considered to be known when the statement is justified, true, and the statement is believed. The level of discussion of the relationship between knowledge and justification, truth, and belief exceeds that of all other discussions of definitions of knowledge in the epistemology literature. For example, one finds that in Plato's *Theaetetus*, the relationship is discussed between knowledge, in part or in whole, and justification, truth, and belief (Bostock, 1988, Sec. 202-210) .

For a statement to be known by an individual, the statement has often been treated as being believed by the knowing individual, the statement is true, and the statement is justified, suggesting that the statement is accepted by the individual for the "right" reasons and not for the "wrong" reasons (Audi, 2011; Lycan, 2006). While known statements have often been understood as a statement that is believed, justified, and is additionally true, Gettier (1963) provided specific examples of situations where these three parameters for known statements appear inadequate for accurately or fully defining knowledge. Gettier provided two specific examples, now referred to as "Gettier counter examples," where a person has a justified, true belief but it can be argued does not have knowledge.

Assume that Charlie has a justified belief that the person who will get the job is Alice, who has red hair. Perhaps the justification takes the form of Charlie being told by a trusted individual that Alice will get the job. Barbara, who also has red hair, will, in fact, get the job. Charlie has a justified, true belief that the person who will get the job has red hair, but is it fair to describe Charlie's justified, true belief that the person who will get the job has red hair as *knowledge*?

Alternatives to the justified, true belief (JTB) definition of knowledge have been proposed that specifically address the Gettier problem (Clark, 2002; Lehrer & Paxson, 2002; Lycan, 2006). Some scholars searched for an element that could be combined with JTB that would produce knowledge. We might consider this as an additional component, G (which represents a Gettier correcting factor), producing a JTBG model, or it might be seen as a negative component that takes away a certain amount of functionality from the JTB model. Some have suggested that justification was not needed at all in the definition of knowledge. Others have suggested that a true belief cannot produce fallible justification. Others have suggested that the arguments in justification need to rest on positive assumptions.

The JTB approach appears to be adequate in almost all situations, although there may be some situations where it is not a necessary and sufficient description of knowledge. The JTB approach may be seen as robust, in that it is usually effective except in what may be seen as unusual or contrived cases. Studies in empirical philosophy and, most recently, the study by Starmans and Friedman (2012), suggest that the examples that show justification, truth, and belief are held by the general public to be knowledge, even when philosophers do not consider the statement to be knowledge. The philosophical concepts of beliefs, justification, truth, and knowledge are basic concepts within philosophy that are useful in the philosophical description of the universe as well as for providing a standard by which one can communicate about the domain of epistemology. If these concepts are defined in a reasonably accurate and useful way by philosophers, the concept may serve as the basis for rigorous models that can be useful in the modeling of systems that use knowledge.

Relationships between Informative Statements: Information Similarity

Combining and comparing statements, such as believed, true, or justified statements, can be performed using an information similarity measure. The similarity between statements may be measured as information similarity, which may, in turn, be computed from the information distance. The *information distance* between two informative statements or process outputs x and y is denoted as $d(x, y)$ (Bennett, Gacs, Li, Vitanyi, & Zurek, 1998). How much information does one have about x, given knowledge of y, and how much does one have about y, given x? By taking the maximum of these two values, one can determine the maximum uncertainty that remains about one object when the value of the other is known, which serves as a measure of the information distance, the uncertainty between one statement and another statement. Sometimes one may choose to add a constant *c* to the amount of information to represent the size of the process that generates the information, in addition to the size of the information or uncertainty itself.

For example, assume that there are *4* bits of information in *x,* and *4* bits in *y*, *x* and *y* being either statements or processes that provide or contain information. Let us also assume that the *4* bits of information in *y* say nothing about the *4* bits of information in *x*, and *x* provides no information about *y*. The information distance here between *x* and *y* is thus *4* bits, the least information that one entity can have about the other entity. In the situation where one object provides full information about the other, there is no topical distance between the objects and the information distance is *0*.

The *normalized information distance* is a distance from *0* to *1*. Denoted as $d_N(x, y)$, the normalized information distance measures the number of bits by which the two objects *x* and *y* differ per bit in the more informative of the two informative objects. When $d_N(x, y)$ approaches *0*, then *x* and *y* are relatively similar, and when $d_N(x, y)$ approaches *1*, then *x* and *y* are relatively dissimilar.

Given two objects, the *information similarity*, $S_I()$, between outputs *x* and *y*, denoted as $S_I(x, y)$, is computed as *1* minus the normalized information distance $d_N(x, y)$, or $S_I(x, y) = 1 - d_N(x, y)$. The information similarity between *x* and *y* measures "the number of bits of information that is shared between the two strings [*x* and *y*] per bit of information of the string with the most information" (Li, Chen, Ma, & Vitanyi, 2004). We assume for our purposes that any two objects being compared have the same format for a feature vector or statement. The information similarity between two identically formatted binary vectors is the probability that a randomly selected bit is shared, or has the same value between the two statements. This is the percent of matching features, also referred to as the simple match measure (Gregson, 1975). The value of the information similarity metric is *0* when the normalized information distance is at its maximum and the similarity metric is *1* when the normalized information distance is at its minimum (Li et al., 2004). While computing the information similarity is dependent on which object is the most informative, if one assumes that most objects being compared are about the same size and have the same amount of information (although the actual information will differ), one can view information similarity as an estimate of the relative amount of information between the two informative objects.

When the two objects are not similarly sized, the information distance and information similarity may be computed using the Kolmogorov complexity measure; this can be approximated by compressing data and noting how much information is available or remaining (Quach, 2009). While compressing statements in natural language can lead one to an approximation of the entropy in natural language, the long term correlations that exist between terms in natural language makes precise estimates computationally difficult, although numerical methods have been developed (Montemurro & Zanette, 2011).

One can precisely describe the degree of similarity between one entity and another entity, or the amount or content of information in a statement about another, such as statements that produce belief, truth, justification, or knowledge representations. The content of a statement is sometimes the focus of interest, and sometimes the amount of information in a statement is the focus. We denote the statement content as A_s and the amount of information in an entity as A_m. The subscripts *s* and *m* might be understood as the qualitative statement content and the quantitative measure of the amount of information, respectively.

Notationally, we assume a general similarity function *S(x, y)* that may be computed as the information similarity function or as a probability that a feature has a matching value for a randomly selected element of both statements, the joint probability, which we denote here as $p_1 \odot p_2$ as well as using the normal comma notation. When these two probabilities are statistically independent, the joint probability is computed as the product of p_1 and p_2, so that $p_1 \odot p_2 = p1 \cdot p_2$. Combining multiple information similarity functions is denoted as $S(x, y) \approx S_I(x_1, y_1) \odot S_I(x_2, y_2) \odot \cdots \odot S_I(x_n, y_n)$, where x_i is one of the n components of x and y_i is one of the n components of y. When the information similarity $S_I(x, y)$ is a probability, one may combine the probabilities as a joint probability. The simple match $S_m(x, y)$ may be interpreted as the probability that a randomly selected characteristic in y is the same in x. If all feature probabilities are statistically independent, then $S(x, y) \approx S_I(x_1, y_1) \cdot S_I(x_2, y_2) \cdot \cdots \cdot S_I(x_n, y_n)$. When we need to compute the similarity between one object and a set of objects, this may be computed as the similarity between the single object and the most similar object within the set of objects.

We will see below that measuring the consistency between an object x and a second object y, denoted as $C(x, y)$, will be useful in modeling justification. Consistency may be computed as $C(x, y) = 1 - S(x, \neg y)$. The consistency between two objects is how much difference there is between one object and the inverse or opposite of a second object. Thus, if x and y are both the statement the sky is blue, the similarity between the sky is blue and the sky is not blue may be computed as $S(x, \neg y) = 0$, and $1 - 0$ produces a consistency of 1. Here $\neg y$ refers to the statement with the negation of the meaning of statement y, or, in the case that y is a set of statements, $\neg y$ is the set of statements with their meanings negated. Given an individual statement y that cannot be semantically inverted, the value of y is treated as null. The value of $S(x, \neg x)$ is treated as null or 0. The consistency between an object x and a set of objects $\{y_1, y_2, \cdots, y_n\}$ is the minimum of the consistencies between x and each of the objects in the set.

Statements of Belief, Justification, and Truth

Belief, justification, and truth provide models and factors that may serve as the basis for knowledge. The greatest similarity that exists between a statement and the set of existing statements within the self that represent one's beliefs is computed as the similarity between the statement and the statements that one accepts, S_b*(statement, believed statement)*. It considers how empirically similar information may be to existing ideas, with a high degree of similarity being indicative of a high degree of agreement between an existing idea and statements or perceptions.

The accuracy of a process's output is the degree of similarity between the output of the process and a normative statement or gold standard. This may be measured as the degree of agreement between an analytic or universally accepted statement and the statement being considered. Using the notion of similarity, one may compute the accuracy of a process's output as S_g*(statement, gold standard output)*, where the gold standard output is the ideal, an assumed correct statement produced by a process or a set of statements.

These two measures, $S_b()$ and $S_g()$, gauge the similarity between informative outputs from processes, one with the gold standard statement and the second one with the set of statements currently believed. The complement function may be used with the above similarity functions being written with the subscript c. For example, the consistency of a statement with believed statements may be denoted as $S_{c,b}$*(statement)*$= 1 - S_b$*(statement, ¬believed statements)*.

We may compute $S_{m,b}()$ as the quantitative degree of similarity between a statement and the set of believed statements, or we may compute the qualitative content $S_{s,b}()$, the statements that are similar between the statement in question and the set of believed statements.

Beliefs

Beliefs are statements, the outputs of processes that are accepted and thus incorporated by the mind. One can believe in an information object that represents a set of values or a statement. Beliefs may be produced based upon actions such as perception or analytic thinking. In the case of empirical observations, the self-similar accuracy of a statement is S_b*(statement, believed statements)*. The set of beliefs may be inferred from other statements, or perceived, or computed. The similarity $S_{m,b}()$ is high when there is a strong match between the output and the set of stored, believed statements and the similarity is low when there is little match.

The belief itself is the set of characteristics in the intersection of the statement in question and the believed or accepted statements, or $S_{s,b}(statement) = \cap(statement, believed\ statements)$. This represents those statements that are returned by the similarity function. For example, the statement the sky is blue is a held belief if it is also a member of the set of believed or accepted statements. If the set of believed statements contains the sky is gray and not the sky is blue, then the statement the sky is blue intersected with the set of beliefs will result in the empty set; there is no belief associated with the statement.

In some cases a statement might be analytic. For example, the statement $1 = 1$ might be seen as analytically true given many semantic definitions of the symbols in the statement. We assume here that analytic statements and processes can be believed in automatically, and once they are believed in or accepted, they become believed statements. Thus, we treat analytic statements and the output of analytic processes as something that may be automatically accepted.

The output of the believing process may be an informative, numeric probability, indicating the degree to which the input statement is believed, $S_{m,b}()$. The output may also be an informative statement of what is believed, $S_{s,b}()$.

True Statements

Truth exists when there is a correct or accurate perception, or a correct or accurate analysis is made from true facts. For empirical informative objects, the truth information may be construed as existing when there is a match between the informative object and objects that are considered to exist and be accurately observed. The similarity function $S_{m,g}(statement, gold\ standard\ statement)$ may be used to compare the objects being considered for a possible pairing. The truth of the statement in this situation may be determined by the value of the expression $S_{s,g}() = \cap(statement, gold\ standard\ statement)$. If the statement is the sky is blue, then this is a true statement if, and only if, it is a member of the set of gold standard statements.

Justified Statement

The information produced by a justification-like process may be understood as the consistency measured between a statement and some benchmark statements. In the case of an empirically-based justification, one might examine the consistency of statements and the set of beliefs held in the brain. More formulaically, justification for a statement exists when there is a high value for the consistency $S_{c,m,b}(statement) = C(statement, believed\ statements)$.

The qualitative justification for a statement, $S_{c,s,b}(statement, believed\ statements) = \neg \cap (statement, \neg believed\ statements)$, is the set of statements not in the intersection of the statement and the negation of the believed statements. These are the statements that are consistent with the original statement. When there is no intersection, the null set is produced, and then its negation is infinite in size, with all statements in the domain of possible statements being what is justified.

Consider the statement, the car is red. If the statement the car is not red is in the set of believed statements, the statement the car is red is in the complement of the believed statements. The complement of the intersection of the original statement that the car is red and the complement of the believed statements is the set excluding the statement that the car is red.

In another case, consider the original statement the car is red. If the believed statements contain the statement the car is red then the complement of the set of believed statements will not contain the statement the car is red and the intersection of the original statement and the complement of the believed statements contains the null set. The negation of this contains an infinite number of statements, including the statement that the car is red, thus the car is red is justified.

The justification for a statement may thus be a large number of statements. If one wishes the justification function to be either a single statement or a null statement, one merely computes the intersection of *C()* with the original statement: *C'(statement)=statement* ∩ $C_j()$. In this case, the justification for a statement is either that statement itself or nothing. When justifying statements, the analytic statements are considered only to the extent that they are accepted statements.

Combining Statements to Produce Knowledge Statements

A model of knowing a statement requires that the model be able to describe what occurs, partially or fully, that it be able to predict what will occur, and that it allows the user of the model to explain what occurs. The descriptions and explanations, based on the combination of justification, truth, and belief, are largely consistent with a popular philosophical explanation of knowledge discussed by philosophers during much of the past several millennia. This is not to argue that this is the only useful model of knowledge, but we suggest that it is useful for many domains and applications.

Knowledge may be defined for both empirical and analytic situations, combining the information values representing truth, justification, and belief. These statements are each the output of an informative process. If we approximate empirical similarity by the probability of similarity measures, one might combine the similarity values together to produce the following to represent the degree to which the statement is known:

$K_{m,b,g}$(statement, believed statements, gold standard statements) =$C_{m,b}$(statement, believed statements) $\odot S_{m,g}$ (statement, gold standard statements) $\odot S_{m,b}$(statement, believed statements).

The value $K_m()$ is the measure of the number of bits of knowledge. The known statement itself is the intersection of the three similarity values for justification, truth, and belief. The qualitative nature of knowledge may be determined as:

$K_{s,b,g}$(statement, believed statement, gold standard statement) = $C_{s,b}$(statement, believed statements) $\cap S_{s,g}$ (statement, gold standard statements) $\cap S_{s,b}$(statement, believed statements).

The statement of knowledge is $K_{s,b,g}()$, with the amount of knowledge in $K_{s,b,g}()$ being $K_{m,b,g}()$. Using these statements, one has a qualitative statement of knowledge and a quantitative measure of knowledge.

Given a statement, $K_{s,b,g}()$ returns the original statement when the statement is returned by the justification, belief, and truth functions, while if any of these three functions returns the null set, then the intersection of the three returned statements, $K_{s,b,g}()$, has a null value.

Diffusion of Informative Statements in Social Networks

Information moves through a society in a number of ways, from low-technology face-to-face conversations to using high-technology social networking software for managing one's social life. Diffusion moves primarily within groups (Gill, 2012), with the nature of the diffusion being dependent upon cultural norms and values (Gill, 2013). While the diffusion of information and technology through a population has been studied (Chatman, 1986; Rogers, 2003), the spread of combinations of beliefs, justifications, and knowledge have received far less attention.

One of the simplest models of transmission links connecting individual members of a group is the random graph model. A random graph is a set of nodes, which could represent people, with a link existing between each pair of nodes with a fixed probability *p*. In a system consistent with this model, one is as likely to communicate with someone at a great distance as one is to communicate with the person nearest you.

A small world network exists when there are links possible between any two neighboring nodes, and the probability of links existing between nearby nodes is greater than the probability of links between distant nodes. The implementation used here to represent a small world model is based on the model proposed by Watts and Strogatz (1998), who suggested that each node begins with *k* links to the nearest neighbors, with there initially being links to the *k/2* neighbors on each side of the node in question. Then, for each link from the node in question, the link is changed to connect with a randomly selected node anywhere in the set of nodes with probability *p*. Links are treated in this study as unidirectional links, representing the input to a process, and the output of a process at the ends of the links, and the directionality being provided by the nature of the process.

Knowledge may be diffused by slowly spreading informative statements through a network of nodes, which may serve as a surrogate for the transmission of ideas through a society. Combined with the diffusion of justification and belief, the diffusion of knowledge may be emulated. We assume that beliefs and the ability to justify something both diffuse, while truth is assumed not to diffuse but, instead, to be either present or not throughout the social network.

The number of nodes that have diffused information at a given point in time is often graphed with an “S” shaped curve. If one assumes that each statement contains one bit of information, then the *y* axis on the graph may be understood as representing the total number of bits of information about the indicated variable in the social network context, with the *x* axis representing time. The same shape is approximated by the diffusion of knowledge. The slope of the curve near the middle depends on how rapidly the information or knowledge is being diffused, with the middle being near vertical when the rate of diffusion is very high but is nearer horizontal when the rate of diffusion is very low.

Believed statements, true statements, justified statements, and known statements may be diffused through a population. For true statements, the curves representing the diffusion of justified and believed statements are above the curve representing knowledge, as the probability that a node in a network has both belief and justification, both necessary for knowledge to occur, is lower than the probability of either belief or justification taken alone. Knowledge is limited by the presence of justification, truth, and belief. The higher curves represent the fastest diffusion and are less constrained, and the highest curve, possibly representing just belief, also may be said to represent rumors or popular culture, the least constrained statements.

In circumstances where one raises the rate of diffusion of belief for true statements, and all other rates are held constant, the amount of knowledge either remains the same or increases. This may occur when there is a faster cycling, that is, the time required for a cycle to occur is shorter, or when either of the network parameters *k* or *p* is higher. The presence of believed statements may also rise when the statement in question is analytically true.

The improvement in knowledge can be implemented by increasing the diffusion of education. More general education on abstract reasoning principles may help one learn how to reason better. This might be accomplished, for example, by spreading information about probability or logic. When one raises the rate of diffusion of incorrect reasoning skills and all other rates are held constant, the presence of knowledge will drop. Similar decreases in knowledge may occur with the diffusion of mis-education, such as teaching that the world is flat or that $2 + 3 = 23$.

Statements of Belief Diffusing Through Society

Beliefs propagate through society as statements or propositions that are accepted by the recipients, often as the result of a communicative act. One may study single statements believed by individuals or degrees of presence of a belief in a society. Acceptance of a statement may be due to reasoning, which approximates justification, or because there is a power relationship that may suggest to the recipient of the statement that it should be believed. A statement uttered by a parent that is heard by a young child is likely to be believed by the child, unless the parent has shown through repeated actions that they are not to be believed. A believed statement may be developed as a consequence of perception, such as when an individual feels raindrops, resulting in a belief that it is raining, or hears a loud sound, resulting in a belief that something physical occurred that produced a sound. Intellectual skills, such as arithmetic knowledge, may result in one believing that buying two apples, when one already owns two apples, would result in one having four apples.

The presence of a belief held by a person may be inferred from several different indicators. The rate of growth of a variety of belief spreading mechanisms may provide indirect evidence of the diffusion of statements. A number of computer technologies move beliefs, such as earlier electronic bulletin boards, search engines, blogs, and social networking software such as Facebook and Twitter. Many continue to increase until replacement technologies arrive.

Individuals may perform actions that are indicative of the presence of a belief. Performing an action, such as carrying an umbrella when leaving one's house in the morning, may indicate a belief that there is a likelihood of rain sometime during the day. Joining an organization may also be a sign of the presence of a belief. For example, membership in a religious group may be indicative of beliefs supporting the basic tenets of the religion. Clearly, the absence of beliefs exists among some members of religious groups. One may belong to a group because one's parents belong to the group, or one may attend services because one is romantically interested in a member of the religious group.

Many beliefs are caused by the receipt of statements from any of a number of sources. Data about the quantity of mass communication, such as video and network ratings services used in the United States to measure the popularity of particular shows, represents how many people viewed each show. One may instantly believe a statement on a video feed, or it may take a number of viewings before one believes the statement. Assuming that a given statement is believed at a specific rate, the number of people believing the statement is proportional to the number who received the statement. Media produces beliefs in us all, and one may estimate the number of people with beliefs as proportional to the number of communication channels, the number of electronic media receiving devices, among other sources for estimates. Similarly, libraries often accumulate statistics about the use of their materials. These statistics can show the relative levels of interest in different types of materials, different subjects of materials, and different types of users who use certain types of materials. The spread of statements and then their acceptance as beliefs often follows a success breeds success phenomena, where statements that are believed by some tend to be more likely to be further diffused, being accepted by more, and so forth.

The spread of religions and their beliefs is a common example of the diffusion of beliefs, as well as through other means, such as political pressure and force. One classic example of the diffusion of religious beliefs is the spread of Christianity in ancient times, moving from Palestinian areas in several directions, eventually spreading into several current African countries, European countries, and many Slavic areas. Similarly, Judaism in earlier times spread throughout a smaller area, while Islam spread throughout much of the world at a later time. Most of these expansions and similar contractions show diffusion, where a religion would advance and then be repelled. Mormonism began in the United States in recent centuries and has spread throughout the world. Different religions have different numbers of members at different times. For example, at the present, there are more holders of Islamic beliefs in the world than there are holders of Mormon beliefs. Protestant grew from Roman Catholicism over the past half millennium.

Data illustrating the growth of religions may be most accurately collected with a more recently developed religious group. For example, the Church of Jesus Christ of Latter Day Saints keeps accurate records, back to early in the history of the church, showing that the number of believers continues to increase in this relatively young religious group. It may be approaching or past a point where the upper end of the S curve begins and the rate of growth begins to taper off.

While the Mormon church continues to expand rapidly, the number of believers in other groups may not increase as rapidly, or may level off, or may decrease. Examining data about the United Kingdom shows that the Pentecostals increased membership from 1989 to 2005 but the number of Methodist believers declined from 1989 to 2005 (Crabtree, 2012). Some religions in the United Kingdom have clearly peaked and are now in decline, while some continue to increase, reflecting differences in beliefs over time.

Diffusing the Abilities to Justify Through Society

Justification represents a form of reasoning, the ability to make rational decisions about beliefs and data. One may measure justifications for individual statements, as well as the degree of presence of justifying skills in a society. One may learn inferential skills or deductive abilities, through the learning of logical reasoning or probabilistic reasoning. Justification may also take place through direct or indirect perception, with a statement being compared to perceptions.

The presence of justification may be inferred a number of ways. Individuals may learn how to evaluate a statement and its context so as to be able to justify or not justify the statement. The learning of justification skills can be observed or measured, such as by noting a student's reasoning skills as evidenced by their grades in a particular course. A particular justification or reasoning skill can be tested. Most university level logic courses, for example, test the ability of people to reason logically and to recognize fallacies. Likewise, students in probability courses are often asked to reason about events using Bayes rule.

People can also self-report whether they have learned justification skills. There are often problems with trusting self-reported data, a potential weakness in using self-reporting as a measure of the presence of justification. Another problem with justification is that people often do not realize what they know how to do and what they do not know. Knowledge managers often try to find out what individuals in organizations know but do not know that they know.

Another important tool used to show the presence of justification is measuring the ability to communicate. An individual may explain why a process functions as it does, or why an entity became as it is. This information may also be given to another individual, providing them with justifying abilities. Teachers, for example, often have to analyze whether a student's answer to a question is right or wrong. This requires a general ability to analyze all the answers in a subject domain, showing a high level of ability in justifying in this particular domain.

There are a number of activities that are indicators of the ability of people to justify. The ability to reason logically is one of them, and one may test for the presence of logical reasoning. One can also monitor progress through learning logic in educational settings, noting performance on tests, exercises, and related work. Learning various mathematical skills may allow one to justify practical conclusions, such as to explain why a certain amount of tile would be needed to cover a floor in a room that had certain dimensions. Probabilistic reasoning similarly can be judged to be present or absent through performance indicators, although the presence of inferential justification skills may be somewhat more difficult to determine if the person being measured does not articulate the thoughts in the same manner as the observer, or they have different utility functions, or other variations exist between the observer and the person observed.

Aspects of intelligence tests measure how quickly one can perform certain tasks, which may indicate the presence and quality of skills, but a few tasks may ask for explanations which capture "why," and associated issues of justification (Benson, 2003). Some of this ability is present due to learning and some due to genetic abilities that develop as species evolve. The justification itself does not evolve, but the predisposition to develop the justification skills can evolve.

Similar to "intelligence" leading to justification, the ability to read also increases the probability that one can justify a statement. Reading leads to the incorporation of information in the form of both facts and methods, so that one who reads a mathematics text is more likely to be able to justify certain mathematical beliefs.

The diffusion of religious skills can be observed. In the area of religion, one can observe the spread of seminaries that teach religious skills, with the seminaries spreading in a way that often lags the spread of believers in the religion. Other religious schools may be designed to help develop beliefs and convert non-believers, and these schools may develop skills as a way of enhancing belief as well as developing skills. Such schools may precede believers to a limited extent.

As an example, the spread of reading skills has been shown to have occurred with the adoption of Lutheran beliefs in central Europe as Lutherans supported the reading of Bibles. People in this environment were usually labeled as either Roman Catholic or Protestant, or can be understood as Protestant or non-Protestant. Weber (2002) suggests that the rise of Protestants was associated with the rise of capitalism. For our purposes, we here have support for a weaker suggestion that the presence of Protestants resulted in a greater degree of justification by encouraging and thus increasing the ability to reason through enhancing believers' or potential believers' education, particularly reading abilities, so that religious texts can be read. "In the first year when women were admitted to university in Prussia in 1908, there were more than eight times as many female students of Protestant denomination than of Catholic denomination, 359 vs. 43, compared to a proportion of roughly two to one in the total female population" (Becker & Woessmann, 2008, p. 800). Similarly, "Protestant women stayed ahead of Catholic women in West Germany even after World War II In 1951/1952, 59 percent of female university students were Protestant, clearly exceeding their population share of 52 percent" (Becker & Woessmann, 2008, p. 800).

Justification and the ability to reason may be rewarded financially, and the rewarding may be taken as an indicator of the presence of justification skills. For example, it has been noted that the "average pay increased by $2000 for each single math classes taken after ninth grade" (Math Major Organization, n.d.). College math majors in 2005 were shown to have salaries that were 37.7% higher than that of college English majors (Duke University, n.d.). While English majors clearly have strong abilities in justification, being able to read and interpret text, math majors can clearly read, although probably not as well as English majors, but the mathematical and logical skills that are associated with math majors provide a different form of justification that are useful to employers. Rewarding for forms of justification shows that there are different levels of justification and possibly different kinds of justification that can be useful. The ability to perform math and the associated justificatory skills are rewarded by organizations hiring these employees. It is also the case that the higher salaries are likely correlated with a paucity of mathematicians, indicating that there is a scarcity of those who can justify mathematical beliefs.

Truth in Society

Truths can take several forms. Analytic truths are true because of theoretical reasons, such as when the semantics and syntax of a language support that $x = x$. Statements are empirically true when the statement is coherent with other statements or that the statement is consistent with aspects of reality (Lynch, 2001). Truth may most easily be determined by observing the match between a statement and a state in reality. The truth of processes may be determined by a matching of the processes in reality with the process mentioned in a statement. The statement "the house is yellow" matches with reality if the house in question has the state "yellow." The process statement "Caitlyn is walking her dog" similarly matches with reality if, in fact, Caitlyn is performing any of a number of activities that are consistent with "walking a dog."

For the determination of truth or falsehood, we must accept that there may be differences of opinion as to whether one religion is correct or another religion is correct, for example. Truth for our purposes represents a degree of matching with other statements (coherence) or similarity with the real world (correspondence truth). Statements may be true, false, or indeterminate. Statements may be observed and their truth evaluated by an observer, who labels a second statement within them as true or false based on the observer's judgment about the truth or falsehood of the statement. Truth about a statement may be identified by the person being observed stating that they believe a statement is true, or they may act consistent with something being true or false. In other cases, a statement with its falsehood may be given to a person, after which we know whether the statement they possess is true or false.

One example of the diffusion of true statements may be approximated by the spread of scientific laws, theories, and schemas through societies (Gill, 2011). Note that we are discussing the diffusion of true statements, not the diffusion of truth itself, since truth holds for all times and all locations. Science often produces statements that were previously not thought of, and thus the beliefs are not present. As science expands, it may be said to move closer to the truth, or to better capture the truth, while the actual distance between what is considered to be the truth and the actual truth must remain unknown. Galileo and Einstein both produced new models of aspects of the universe, both focusing science on new paradigms and reducing errors made due to earlier notions that were not complete in their explanations. On an average, the more individuals work on science, the more one expects the statements to approximate the truth. Similarly, the larger the expenditure on research, the more one expects the statements to approximate the truth. Note, however, that the statements may become close to true or far from true.

The truth of a belief may be treated as a societal value. Something is more likely to be judged as true if all members of a group accept the statement, as opposed to a statement accepted only by an individual. While diffusion of statements often exhibits an "S" shaped curve, something is either true or it is not. Truth might be best viewed as a horizontal line, where the statement either is or is not true for all situations. What is truly diffused with an "S" shaped curve may be the belief or the justification for the statement.

The spread of technology often serves to spread true statements; some statements are believed or justified, and some are not. Consider the distribution of polio vaccines, which work only if they are "effective," regardless of whether the recipient of a vaccination believes it will work or whether they can explain how the vaccination works. The percent of children at age 1 that have been immunized with a polio vaccine increased in Afghanistan from 24% in 2000 to 66% in 2010 and decreased slightly in Zimbabwe from 86% in 1997 to 79% in 2000 and to 84% in 2010 (World Health Organization, n.d.). In most countries, the percent of children with vaccinations increases over time, in part because of the efficacy of these vaccines in other parts of the world.

Diffusing Statements of Knowledge

Knowledge may be identified as either self-reported knowledge, such as when one asks an individual whether they "know that x," or knowledge may be identified by outside observation. Surrogates may be used as indicators of the likelihood of the presence of knowledge, such as someone being hired as an employee to conduct a certain job, possibly on the basis of a job interview.

Known statements may be studied separately within the individual, as a group of statements within the individual, or one may study knowledge about certain statements in a society. One might assume that a country has more knowledge than another otherwise comparable country if the first country produces more economic worth on a yearly basis, given similar geographies, economies, and politics.

The presence of knowledge may also be shown by the production of work showing this ability to reason about problems. Authorship may serve as an indicator of knowledge; if one writes about something one believes in, and one can explain the justification for the conclusions presented in the writings, and the conclusions are true, then justifying skills are present in the author. This could take the form of non-fiction or fiction, containing truths.

Brief social messages cannot usually be shown to be knowledge, as there is often not enough space in which to provide a justification. Material that is untrue cannot represent knowledge either. Astrologers' predictions, for example, cannot be said to be knowledge, because of the apparent falsehood of the statements.

Economic benefit may be taken as an indicator of knowledge. Knowledge (as evidenced by a higher economic status) exists when beliefs are spread through society, the ability to reason about the beliefs is enhanced, as is indicated by increased education, and the beliefs are considered to be true, as is indicated by their effectiveness. An individual might make a large quantity of money based only on their knowledge: their ability to reason about solving the problems for which they are being paid. Knowledge is shown by what an individual produces, but it can also be determined to exist when knowledge is consumed.

The presence of knowledge may be approximated by the increase in benefit that is felt to be due to the knowledge. While a belief, truth, and justification may individually also have an economic value, if one can argue that all three are present, and thus knowledge is present, the economic benefit may be due to the synthesis associated with statements being knowledge. The presence of knowledge also may be indicated by the presence of increases in income associated with the statements that go into making the knowledge. Knowledge within the sciences may be measured by the productivity of government Research and Development programs. Increases in knowledge about agriculture may be indicated by the increase in the income due to farming. National level economic numbers, such as the Gross Domestic Product in the United States, capture how much the society as a whole produces. This can capture the knowledge present in the society, taken as a whole.

One might argue that a belief has greater worth if it is trusted, because it can be justified, and others will find it more useful if it is true. Astrology is clearly of benefit to some but may not be as beneficial as a true science with knowledge.

Weber (2002) famously suggested a relationship between the rise of Protestantism and increases in capitalism. While there are disagreements as to what Weber meant or whether a given interpretation of his model is empirically correct, there is certainly some data suggesting that a correlation exists between certain types or levels of economic success and the presence of Protestantism. In earlier sections, the diffusion of beliefs and justification skills supporting Protestantism were considered. This can be combined with empirical data suggesting a link between knowledge and Protestantism.

Arguments have been made suggesting that, in parts of Europe, the predominately Lutheran areas are more productive than predominately Roman Catholic areas. We assume that this is because of the increased true statements and the ability to justify these statements that results in the increased economic benefit. It is not argued that the deity has produced these results directly, but that this economic benefit is due to attitudes or behaviors of the two largest religious groups in Europe: the Protestants and other Christians (largely Roman Catholics.)

Reading and education were generally more prevalent in Protestant areas of Europe than Catholic areas, suggesting the presence of belief and justification (Becker & Woessmann, 2008, 2009). In Protestant areas"... there were more people working in services and manufacturing, rather than agriculture" (Science Daily, 2011). The business successes that require greater learning suggest the presence of knowledge. The individual believes and can understand why they act as they do in business, and the business processes work (and can be thus treated as true.) "[B]y 1700…Protestant countries had overtaken the Catholic world in terms of income. A strong Protestant-Catholic income gap became well established over the next 250 years. There were no signs of convergence until the 1960s" (Young, 2009, p. 1). Protestants clearly had a greater degree of knowledge than Catholics.

Education clearly leads to more successful lives, although the exact amount and the nature of the relationship between education and income is somewhat controversial. IQ scores may also serve as an indicator of the presence of knowledge. IQ tests were developed and enhanced over the last century. An often used test in the U.S. was the Army Test of General Knowledge which was used in the twentieth century to help place potential military. On general IQ tests there are questions that ask for factual knowledge, such as "who is Julius Caesar," with questions addressing the types of knowledge held by people in different cultures. For example, justification of statements is often probed by asking for an explanation of proverbs. Justification and more general reasoning may ask for explicit explanations, such as "how are these two things alike?" or "what is missing from this drawing" or sequence of drawings. By capturing factual knowledge, one can capture believed statements, in addition to capturing the ability to justify, as is indicated by the ability to perform complex tasks.

People with higher IQ scores appear to experience better economic situations. They are admitted to better schools, which may in turn result in higher incomes. Education is often felt to correlate with potential earnings in a career. While this does not always hold, such as obtaining an advanced degree in religion, the more education an individual receives, the better will be the individual's economic situation. IQ scores test for the presence of knowledge in different areas, supporting the presence of a relationship between economic success and knowledge.

The diffusion of technologies through societies results in the increase in knowledge in the culture. Technology diffuses when people believe it (belief), they understand it (justification), and it works (truth). Does technology diffuse, that is, is knowledge generated in locations, because of the presence of belief, truth, and justification?

It has been statistically argued that "countries have adopted technologies 45 years after their invention" and that "newer technologies have been adopted faster than old ones" (Comin & Hobijn, 2010). Adoption of newer technologies and the diffusion of information and knowledge about them, appears to be much faster for medical magnetic resonance devices and Internet than for older technologies such as steam and motor ships and railways. "The cross-country variation in the adoption of technologies accounts for at least 25 percent of per capita income difference" (Comin & Hobijn, 2010). Adopting new technologies may lead to greater income, or those with greater income may adopt new technologies more quickly. The lag in the adoption of technologies is due to several reasons: partly due to a lack of belief that it works and an inability to manipulate the technology at first (lack of justification). Newer technologies may be adopted faster due to the economic value in rapid introduction, with economic benefits to those with rapid justification skills. These could also show the effectiveness of the technology, its truth.

Conclusions

We focus here on the diffusion of information and knowledge, often through human communication, and examine empirical data that may be described as representing beliefs, truths, and justifications, as well as knowledge. This data may be combined on the group or society level to provide support for Max Weber's hypothesis. Knowledge is increased as Protestantism rose, as the empirical data suggest, and this knowledge is associated with the rise of Capitalism. Defining knowledge and being able to measure the knowledge present in an informative statement allows one to analyze knowledge and to develop knowledge applications. Knowledge may be viewed as the combination of the output of three informative processes: belief, justification, and truth. There are several advantages to using this model of knowledge. A precise definition and measure for knowledge allows us to understand how knowledge is formed and how to increase the presence of knowledge. It allows for the rigorous description of knowledge in a given situation by suggesting what is necessary and sufficient for something to be knowledge. It also allows one to predict and explain the nature of knowledge, allowing one to construct knowledge from components and to explain why something is then knowledge. This prescriptive model of knowledge also provides a theoretical statement that can be compared to empirical results, allowing for the strengths and weaknesses of the model to be better understood and improved upon. Because it is based upon a general model of information and the output of informative processes, it can be applied to a wide range of problems, including those outside the human mind.

One conclusion that comes from this form of work is that the nature of justification and belief are personal characteristics, depending on what is accepted or held by an individual. Thus, one person's knowledge is not another person's knowledge because the abilities to justify beliefs differ from one person to another.

The arguments above assume that one can quantify the amount of justification, truth, or belief using the similarity-based models above. Methods are suggested that provide both qualitative definitions, or variants, for justification, truth, and belief, as well as quantitative measures. Using these quantitative techniques, one justifying statement, for example, might provide more justification than another statement, and thus have more utility in transforming a statement into a statement of knowledge. These quantitative measures are based on qualitative expressions that are developed here. Future work in this area might address how other models of truth, justification, and belief may be incorporated into rigorous models of knowledge.

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Biography

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