Interrogative Theory of Information and Knowledge

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ABSTRACT

This report offers an interrogative-based approach to differentiating and quantifying information and knowledge within text. We examine the work of Popper, Shannon, Weaver, Brookes, and Debons on information and knowledge. We offer a new synthesis of their perspectives, which provides the theoretical background for Interrogative Theory. Interrogative Theory suggests that text is a heterogeneous mixture of data, information, and knowledge, which can be separated and quantified through the interrogatives.

Several exploratory research efforts based on this interrogative paradigm have been undertaken, including a study of the effects of differentiated information and knowledge on problem solving. Data are presented from these studies. Applications of this approach are described including information system design, problem solving and decision making, text indexing, information overload, meta-data, and knowledge management.

Keywords

Interrogatives, Data, Information, Knowledge, Informs, Knowgs, Debons, Brookes, Shannon, Popper, Weaver

1. INTRODUCTION

Is there a difference between data, information, and knowledge, or do these terms mean the same thing? Are there implications derived from these differences which we should consider when designing computer systems, data marts, or libraries?

We have endured successive marketing campaigns touting databases, information systems, data warehouses, and knowledge management, but the vendors selling such systems are often stymied at describing the difference between data, information, and knowledge. If you can't tell what knowledge is, how can you manage it? How can you sell it?

We live in the "information economy", but what is the currency of that economy? How do we keep accounts in an information economy? What are the dollar bills, sawbucks, and C-notes of this system? We have more text stored than at any other time in history, but we cannot find the answers we need and complain about drowning in data and information overload.

Leading edge org-charts now include both a chief information officer (CIO) and a chief knowledge officer (CKO). But what's the difference between a CIO and a CKO? (Besides stock options, of course.)

We would like to offer a new approach to these questions. This approach provides a theory of information and knowledge which is sorely lacking. We submit that the text stored in hardware and retrieved through software is not a homogenous stream of "yada-yada-yada", but rather that text contains data, information, and knowledge, each with its own characteristics and value. This report offers an approach to differentiating data, information, and knowledge (D/I/K) within text, which we refer to as Interrogative Theory.

We will proceed in several steps. First, we set out some definitions, because words like information and knowledge have been used so interchangeably as to make them meaningless without clarification.

Second, this paper describes the work of early information theorists. Too often, we seize at techniques without appreciating the underlying theory. Third, this report offers a new synthesis, weaving the previous works into an integrated framework upon which to build. Next, the report describes Interrogative Theory as a method for differentiating data, information, and knowledge.

Then we will report the results of three initial experiments. These experiments demonstrate how the distinctions between D/I/K can be objectively tested. Finally, we will describe some real-world applications of Interrogative Theory in designing and improving information systems.

2. DEFINITIONS

The words data, information, and knowledge (D/I/K) have many meanings in many contexts. For instance, *data* is variously understood as symbols, numbers, or a Star Trek character. Some see *informing* as a process, while *informed* is a mental state, and *information* is a commodity, product, or thing. Philosophers see *knowledge* as justified true belief, while scientists see knowledge as documented empirical research.

Within this paper we discuss a cognitive spectrum of data, information, and knowledge. We focus on data-as-thing, information-as-thing, and knowledge-as-thing [9] located within text strings.

We structure D/I/K according to the questions that are answered. All of our questions are categorized by the **interrogatives**, sometimes expressed in the journalist's mnemonic NEOTWY: whe**n**, wher**e**, wh**o**, wha**t**, ho**w**, wh**y**. The interrogatives serve as a categorization of all human experience, describing time, place, identity of humans and non-humans, process, and cause.

The proposition that we will develop is that Information is text which answers the questions {when/ where/ who/ what}, and Knowledge is text which answers the questions {how/ why}. [14]

3. EARLY INFORMATION SCIENTISTS

This section covers the work of several scientists on the nature of data, information, and knowledge.

3.1 Karl Popper

Karl Popper is a philosopher of science, a student of the scientific process. He describes an ontology of three worlds as depicted in Figure 1. World-1 is the physical realm, World-2 is the realm of subjective reality, and World-3 is the realm of objective knowledge. World-3 contains our accumulated scientific knowledge, which is enshrined in (but does not consist of) the devices that store it. [20]

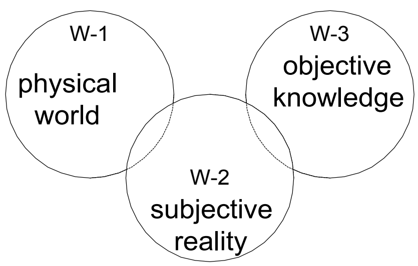

Figure 1: Popper's Three Worlds

For instance, a sensor system (a manufacturing process controller, or a temperature sensor) operates in World-1. A human system operator resides in World-2, and the human-computer interface (HCI) occurs in World-2. When the human consults with reference materials (an encyclopedia or technical reference), he interacts with World-3.

The worlds are positioned so that only the first two and the last two can interact; World-1 and World-3 cannot interface except through the intervention of World-2. Phenomena are observed by a World-2 observer, looking into World-1. Popper maintained that the activity of understanding consists of operating with World-3 objects, and described World-3 as an arena where linguistically formatted theories can be critically discussed.

Popper describes science as the evolutionary process of World 3, in which scientists offered bold conjectures to explain phenomena and the community refuted or accepted them. He defines knowledge through the interrogatives: "In seeking pure knowledge our aim is, quite simply, to understand, to answer *how*-questions and *why*-questions. These are questions which are answered by giving an explanation. Thus all problems of pure knowledge are problems of explanation."

Popper's description of knowledge as answers to {how/why} questions supports our position, but his ontology also makes a strong distinction: {when/where/who/what} are World-1 constructs, and {how/ why} are World-3 constructs.

3.2 Warren Weaver

Warren Weaver described communications as "all of the procedures by which one mind can affect another", and saw three different levels of communications problems: [22]

LEVEL A. The technical problem of communication.
LEVEL B. The semantic problem of meaning.
LEVEL C. The effectiveness problem of changing conduct.

We will return to Weaver's three levels later in this paper.

3.3 Claude Shannon

Claude Shannon's first historic contribution was his recognition that transistors could be combined to perform as logical gates, moving Boolean algebra from the theoretical into the physical and permitting construction of digital computers. He is a fascinating figure whose mentor was Vannevar Bush, President Roosevelt's WWII science czar.

Shannon's second historic publication, written with Weaver, was "A Mathematical Theory of Communication" in 1948 [21], following earlier papers by Nyquist (1924) and Hartley (1928). Shannon's communication model (involving an information source, transmitter, signal, noise, receiver, and destination) remains the accepted standard. His theory deals with transmission over a channel, minimizing noise, and effective coding. Although many have labeled it an information theory, it is more accurately a communication theory, focused on Weaver's Level A (the technical problem).

Shannon said that information is the reduction of uncertainty and that the significant aspect of a message is that it is the one message selected from a set of possible messages. He explained that the number of bits of information in a message could be calculated by $H = \log_2(x)$, where x equals the number of equi-probable messages that could be selected from.

Weaver explicitly limited Shannon's use of the word *informatio*n to a communications engineering perspective: "In particular, information must not be confused with meaning. In fact, two messages, one of which is heavily loaded with meaning and the other of which is pure nonsense, can be exactly equivalent, from the present viewpoint, as regards information."

3.4 Bertram C. Brookes

British information scientist Bertram Brookes argues that the practical work of Information Science (IS) should be organizing the contents of World-3, and that the theoretical task of IS should be the study of World-2 and World-3 interaction in order to organize *knowledge* rather than *documents*. [6]

Brookes described one of the first formulas involving information and knowledge: "Some years ago I expressed this relationship by what I called the 'fundamental equation': $K(S) + \triangle I = K(S+ \triangle s)$ which states in its very general way that the knowledge structure K(S) is changed to the new modified structure $K(S+\triangle s)$ by the information $\triangle I$, the $\triangle s$ indicating the effect of the modification."

Brookes called for tools to deal with Weaver's Level B: "We now have enormous files of unstructured data and a powerful technology for searching and transmission. What we have yet to do is to learn how to structure information into objective knowledge." [7]

Brookes also called for new IS measurements: "...all the sciences now recognized to be well-established began by describing the phenomena they were concerned with in purely verbal terms. They made rapid progress only when the basic entities of the phenomena were identified and found to offer measurable effects.... So we need a new calculus which measures information and knowledge in human terms." [8]

3.5 Anthony Debons

Debons is an experimental psychologist who helped develop the US Air Force's command and control systems during the 1950's and early 1960's. Debons' initial theoretical contribution is his EATPUT (Event, Acquisition, Transmission, Processing, Utilization, and Transfer) model of a reiterative information system. [12,13] A review of the EATPUT model would be worthwhile to anyone working in systems analysis or information systems.

In 1986 Debons proposed that {when/ where/ who/ what} serve as cognitive elements central to human awareness and are therefore information, measured in units he called *Informs*. He also proposed that {how/ why} serve as explanation and understanding and are therefore knowledge, in units he called *Knowgs*. [14] Information supports knowledge and makes it operational. It would be difficult to act on knowledge without having the supporting information.

Debons was asked to investigate the consistently high failure rate of students in a specific economics class. He parsed the course materials into Informs and Knowgs, discerning that the text and teaching focused on Informs, while the exams focused on Knowgs. Re-alignment of the course material and testing through the D/I/K concept resolved the problem.

Debons later established an information counseling service in which graduate students were trained to apply their research acumen to the real-world needs of walk-in clients. Client interaction revealed that most clients were in search of {how/ why} *knowledge* issues rather than {when/ where/ who/ what} *information* items. [15]

3.6 Other Writers

Other scholars have also used the Interrogatives to categorize the spectrum of data, information, and knowledge. Decision Support Systems expert Clyde Holsapple uses *how*-rules and *why*-rules to codify knowledge for inference engines. [16]

Swiss developmentalist Jean Piaget acknowledged a two-tier spectrum involving description (information) and explanation (knowledge), and described two results of knowledge: success (know-*how*) and understanding (know-*why*). [19]

Systems theorist Russell Ackoff uses {when/ where/ who/ what} to describe information, *how* to describe knowledge, and *why* to describe understanding, which he holds as a higher segment of the spectrum. [1,2]

4. A NEW SYNTHESIS

This section combines the works previously cited into a comprehensive perspective which forms the theoretical support for Interrogative Theory.

4.1 Popper and Debons

Figure 2 shows the interaction of Debons' EATPUT theory and Popper's three worlds. Debons' Event occurs in W-1, Acquisition occurs in World-1, and Transmission moves the process into World 2. Processing occurs in World-2 and defines the problem space. [18] Utilization begins in World-2, seeking information in World-1 and knowledge in World-3. Transfer moves the cognitive result of utilization back into World-1. Figure 2 demonstrates the synthesis of Popper's Worlds, Debons' EATPUT, and the problem space.

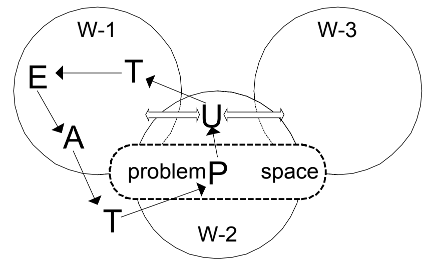

Figure 2: EATPUT and the Three Worlds

4.2 Brookes and Debons

Applying Debons' concept to Brookes' Fundamental Equation, substituting the Interrogative definitions of information and knowledge, we obtain:

$K(S)+ \triangle\{when, where, who, what\}= K(S+ \triangle\{how, why\})$

which is to say, a given knowledge structure K(S) plus additional information (in terms of observed phenomena) yields a new knowledge structure consisting of the previous structure with additional explanations of process and cause.

4.3 Popper, Brookes, and Debons

Brookes uses Popper's Three Worlds to partition human activity, and Debons uses the interrogatives as a distinction between information and knowledge. Figure 3 combines the three paradigms:

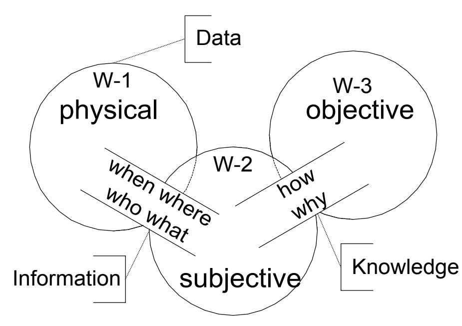

Figure 3: Interrogatives and the Three Worlds

As indicated in Figure 2, the problem space defined by the individual sits astride the three worlds. As shown in Figure 3, when the individual looks for answers to {when/ where/ who/ what} questions, information is sought and exchanged with World 1. When the individual looks for answers to {how/ why} questions, knowledge is exchanged with World 3. Until this point, we have not defined data, which is now represented in Figure 3 as symbols which do not answer any questions pertinent to the existing problem space.

5. INTERROGATIVE THEORY

Having reviewed the works of the giants whose shoulders we stand upon, and having synthesized their theories into a new structure, we can set out the terms of Interrogative Theory.

5.1 Description

Knowledge is text that answers {how/ why} in the problem space. **Information** is text that answers {when/where/who/what} in the problem space. **Data** is text that answers no questions within the problem space.

Separation of a text into data/ information/ knowledge (D/I/K) is accomplished *after* the problem space is defined. There is an epistemological relativity here: classification into the D/I/K schema is relative to the receiver's cognitive state. [3] This does not preclude a piece of data from simultaneously being information with respect to one application and knowledge with respect to another. [10]

Parenthetically, surfing the web is popular (and time-consuming) because individuals start out with a query from one problem space and encounter data which is not pertinent to the query. This serendipitous data sparks a latent interest for the surfer and becomes information in a newly defined problem space as the surfer starts along a new trail, reminiscent of Vannevar Bush's *memex*. [4]

5.2 The Interrogative Matrix

Armed with Figure 3, we can describe the cognitive chain reaction involved in problem solving. Events (often) cause *problems*. Problems can be defined as a discontinuity between expectations and events. Perception of a problem frames a unique *problem space*, a bounded rationality identified by making explicit any constraints and assumptions. [23] The problem space can be described by an Interrogative Matrix (see Table 1), listing the interrogatives in one dimension and the objects, constraints, assumptions, and alternative solutions in another. Gaps in the matrix pose needs, needs prompt questions, and questions initiate the communication of information/ knowledge. Communication offers an opportunity to examine information and knowledge as they pass.

Table 1 : the Interrogative Matrix

	When	Where	Who	What	How	Why
Object-1						
Object-2						
Constraint-1						
Assumption-1						
Solution-1						
Solution-2						

6. THREE EXPERIMENTS

In this section we report on three experiments that move Interrogative Theory into the laboratory.

6.1 Experiment One: Debons' Validation

Debons designed an initial experiment to evaluate his interrogative approach. Graduate students at Embry-Riddle, University of Pittsburgh, and Robert Morris College were asked to parse a given paragraph of text according to the interrogatives. Table 2 indicates the participant classification of text into interrogative categories.

Table 2: No. of Phrases placed into Interrogative Categories

	what	when	where	who	how	why
Test#1 (n=37)	13.92	3.55	1.92	1.84	2.45	2.11
Test#2 (n=48)	10.82	3.22	2.00	1.96	2.00	1.98
Test#3 (n=39)	10.43	2.7	1.85	2.03	1.85	2.00
Average	11.72	3.16	1.92	1.94	2.1	2.03

Among the 124 participants, there was a clear consistency in categorization of the text into information and knowledge as described by Debons. The average response revealed that the paragraph contained 19 Informs and 2 Knowgs, which has an intuitive validity: most public documents would contain more information than knowledge.

6.2 Experiment Two: A Shannon Test

This experiment was conducted to see if the implications of Interrogative Theory could be demonstrated through a Shannon analysis.

Shannon states that a message chosen from among a few equiprobable messages contains less information than one chosen from among many equiprobable messages. Given a fixed set of 27 characters (26 letters and a space) and a string length of 3 characters, there are 27^3 possible messages. With a string length of 6 characters there are 27^6 possible messages. This is a gross oversimplification, ignoring (for instance) the q-followed-by-u norm, but since these constraints hold true across both pools of possible messages, the demonstration is valid: longer messages are selected from a larger pool of possible messages.

Shannon says that in such a case, "H should be a monotonic increasing function of n. With equally likely events there is more choice, or more uncertainty, when there are more possible events". [21] Longer messages and greater uncertainty translates into more information.

Debons holds that descriptions of an event in terms of {when/where/who/what} communicate information, and that descriptions of an event in terms of {how/why} communicate knowledge, which is of a higher value than information.

Since Shannon's theory asserts that longer messages convey more information than shorter messages, and Interrogative Theory holds that {how/why} are on a higher plane than {when/ where/who/what}, it seems likely that {how/why} answers communicated in text should require longer strings than {when/where/who/what} answers:

H0: length {how/ why} > length {when/where/who/what}.

The experiment presented a taped vignette to a convenience sampling of 25 graduate students, who were then asked to write out their descriptions of the video in terms of the interrogatives.

The total number of characters (letters, spaces, punctuation) each participant used to communicate each interrogative response were tallied; average results are shown in Table 3.

Table 3: Lengths of Strings used to Communicate an Event through the Interrogatives

(n=25)	when	where	who	what	how	why
Avg. # of characters	7.3	21.0	35.0	51.5	114.2	99.1

Grouping the interrogatives according to Debons' paradigm, the average number of characters used to communicate {when/ where/ who/ what} answers is 28.7 characters, while the {how/ why} responses average 106.6 characters. The initial results from this experiment indicate that there is a difference between interrogative-differentiated information and knowledge, as suggested by Debons, which can be demonstrated through a Shannon analysis.

6.3 Experiment Three: Problem Solving

This experiment reflects our most significant investment in exploratory research, and focuses on measurement of the quality of problem solving as a function of available information and knowledge. .

6.3.1 Expectations

Figure 4 shows our expectations. The two independent variables are the quantities of information and knowledge, and the dependant variable is the quality of problem solving (Q-PS) in the vertical plane.

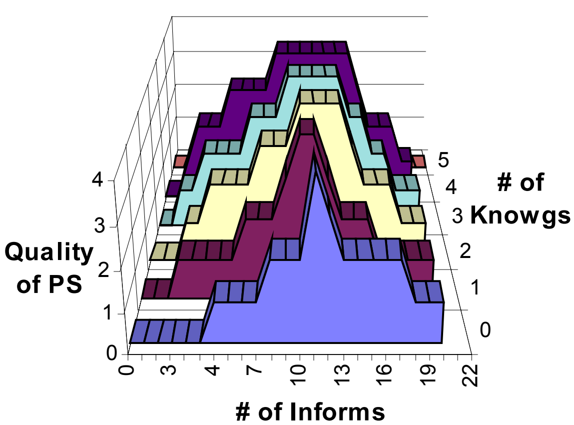

Figure 4 : Expectations of Quality of Problem Solving as a Function of Information and Knowledge

The front-most figure in the chart shows that as information increases with zero knowledge, the Q-PS is flat, increases slowly, peaks briefly, then decreases with the onset of information overload. As the level of knowledge increases in the receding planes, Q-PS increases faster, peaks longer, and diminishes to a lesser degree. The chart depicts that problem solving is impractical in high-knowledge, no-information states, since information supports knowledge.

6.3.2 Description

In this experiment, the independent variables are the number of Informs and Knowgs. The dependant variable is the quality of problem solving. Hypothesis H1 asserts that Q-PS is a function of the quantity of Informs and Knowgs available.

37 graduate students were faced with a logistical problem and asked to choose one of four solutions, or to indicate that they were unable to choose. The quality of problem solving was operationalized by the degree to which the solution chosen met primary and secondary constraints, as shown in Table 4:

Table 4 : Quantifying Quality of Problem Solving (Q-PS) via two Constraints

	Primary Constraint: Time	Secondary Constraint: Cost	Q-PS Value Assigned
Best Choice	met	met	4
Second Best	met	failed	3
Third Best	failed	met	2
Fourth Best	failed	failed	1
Unable to Choose	failed	failed	0

Participants were asked to choose a transportation mode to keep an appointment in an unfamiliar city, within time and cost constraints. The subject made an initial decision (d0) without any Informs/ Knowgs. In three iterations (d1, d2, d3), participants were given controlled dosages of Informs/ Knowgs and then asked for a decision. Visitors are welcome to experience the online instrument at http://members.tripod.com/~infosci (all lowercase, don't forget the tilde).

6.3.3 Results

The behaviors of 37 participants were split into two groups: one group (18) made an initial choice and never changed it, in spite of exposure to pertinent Informs/ Knowgs that would have improved their solution. This response was not unexpected; Jacob Jacoby has found that there is not always a direct relationship between information provided and information impact. [17] This "intractable" group reflects the (in-) effectiveness of information (Weaver's Level C).

The remaining 19 "adaptable" participants interacted with the text, changed decisions and improved their problem solving with increased Informs/ Knowgs as they progressed from the initial decision (d0) through subsequent decisions (d1, d2, d3). Table 5 shows the percentage of adaptable participants reaching the best decision (maximum quality of problem solving) at each of the four decision points, and gives the inform/ knowg levels for each decision point.

Table 5: Percentage of Adaptable Participants Reaching Max. Q-PS at four decision points, with Informs / Knowgs provided.

(n=19)	d0	d1	d2	d3
# Informs provided	0	2	3	5
# Knowgs provided	0	0	1	4
% reaching max. Quality of Problem Solving	11%	32%	68%	84%

6.3.4 Discussion

There are other variables that can substantially influence the problem solving response; a major concern is the ambient cognitive and affective contamination that the participant brings into the test situation. Half of the participants never wavered from their initial decision in spite of clues that they should change their position. However, this experiment does show a process in which controlled amounts of information and knowledge can be offered to a problem-solver, the results of which can be quantified and plotted. If we are able to continue this research, we hope to plot enough I/ K/ Q-PS data points to validate the three-scape suggested in Figure 4.

6.4 Experimental Summary

All of our research is exploratory. We have demonstrated initial empirical data supporting the use of the interrogatives to differentiate information and knowledge. Experiment One shows that participants consistently assign text to the same interrogative categories. Experiment Two shows that there is a quantum difference between interrogative-differentiated information and knowledge that can be demonstrated through a Shannon analysis. Experiment Three has produced a sensitive measure which tracks an intuitive validity-- namely, that Q-PS increases with incremental information and knowledge. A detailed statistical report of the experiments is available at http://members.tripod.com/~infosci/report.htm.

The preliminary work suggests that Interrogative Theory may have discriminating power. While these efforts cannot be considered conclusive, they do provide the basis for dialogue leading to refinement of the construct. These tests warrant further study under more rigorous, controlled approaches.

7. APPLICATIONS

The modern airline cockpit is a complex information system. Consider an airliner in trouble, with the cockpit system blinking, buzzing, and flashing with information, leaving it to the pilot to diagnose the underlying *why*'s of the problem and the *how*'s of the solution. A cockpit information system that conveys and prioritizes knowledge rather than information would be invaluable. Similar applications extend into medical diagnosis, military command and control, nuclear plant operations, and financial markets.

Just as our spell-checkers report reading levels, future word processors may report the amount of Information and Knowledge in a text, permitting the author to make sure that the document accomplishes the task and accommodates the audience. Beginner-level books contain information and very little knowledge (think about Biology 101, or the Windows-for-Dummies series). Advanced books contain knowledge and very little information; some advanced texts are unintelligible to the layman who lacks the supporting information. The use of Inform/ Knowg scales on dust jackets would help readers to choose a book wisely.

The interrogatives provide a new structure of indexing systems. Database builders could design their tables around a topical index cross-referenced by the interrogatives. Such indexes would permit people to search for information in the same way that language categorizes experience, making searches more effective and minimizing information overload. Interrogative indexes could lead to hyper-linking texts based on interrogative XML meta-data.

The Interrogative Matrix can assist and evaluate decision making. Persons making decisions could develop the matrix and identify missing cells. These matrices would be invaluable in post-hoc analysis, documenting what the decision maker knew and when she knew it.

Organizations invest large sums training and evaluating their people, which can be made more effective by considering the distributions of information and knowledge in content and evaluation for various groups. Most psychological tests are text-based; Interrogative Theory provides a new outlook for reviewing these tests to see if the mix of information and knowledge in the test instrument skews the results.

A picture is worth a thousand words because it communicates D/I/K into a World 1 re-presentation that makes sense to the viewer. Pictures take advantage of a very effective, low-bandwidth coding technique: the known sense world. (Abstract art is not worth too many words to people who lack the context.) Interrogative Theory offers an approach to measuring the informs and knowgs present in a picture and actually measuring the bits contained in images.

Finally, Interrogative Theory offers a legitimate approach to the nascent Knowledge Management field and to KM product development.

8. SUMMATION

Interrogative Theory answers Brookes' challenge to move past the technical issues of Weaver's Level A and Shannon's theory, and to move into the semantic challenges of Level B and Popper's World-3. To restate our thesis: information is an answer to {when/where/who/what} questions within the problem space; knowledge is an answer to {how/why} questions within the problem space.

The exploratory studies show that:

- Parsing of a paragraph into interrogative strings yields consistent results and a quantification of information and knowledge within the text.
- There is a difference between interrogative-differentiated information and knowledge that can be demonstrated through a Shannon analysis.
- The quality of problem solving can be tracked as a function of available information and knowledge.

The initial research conducted shows that more robust, rigorous study is necessary.

The ability to discern and exploit the distinction between information and knowledge has real-world implications, several of which we have suggested. There are applications in command-and-control, medical diagnosis, aviation, nuclear plant operations, and financial markets.

Karl Popper viewed science as a World-3 process of bold conjecture and refutation. In that spirit, we offer this paper on Interrogative Theory because we believe it offers explanation where we previously lacked explanation, and we solicit the comments of the Information Science community.

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