Order from Noise: Toward a Social Theory of Geographic Information

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In the so-called Information Age, it is surprising that the concept of information is imprecisely defined and almost taken for granted. Historic and recent geographic information science (GIScience) literature relies on two conflicting metaphors, often espoused by the same author in adjacent paragraphs. The metaphor of invariance, derived from telecommunications engineering, defines information as a thing to be transported without loss through a conduit. Another metaphor, originating in the utopian movements of the 19th century, locates information within a hierarchy of refinement—a stopping place on the path to convert mere data into higher forms of knowledge and perhaps to wisdom. Both metaphors rely on long-forgotten debates outside geography and preclude us from seeing that there are important social and ethical concerns in the relationship between geographic information technologies and society. We examine the conflicts between competing metaphors and propose a social theory of geographic information. *Key Words: cybernetics, geographic information, GIScience, history of GIS.*

The global deployment of geographic information systems (GIS) over the past four decades has been facilitated by assertions that spatial information technologies are both revolutionary and universal (Dobson 1983, 1993; Openshaw 1991). For example, Openshaw (1991, 624) positioned GIS as a technology that can be applied to any purpose, in any place, at any time: "GIS can be used to analyze river networks on Mars on Monday, study cancer in Bristol on Tuesday, map the underclass of London on Wednesday, analyze groundwater flow in the Amazon basin on Thursday, and end the week by modeling retail shoppers in Los Angeles on Friday."

In this construction, GIS appears to be a universal toolkit (Wright, Goodchild, and Proctor 1997), and yet geographic information science (GIScience) has recognized critical integration and usage problems with these technologies. In the lively debate since the early 1990s on the limitations of GIS (Schuurman 2000), the terms of engagement have vacillated between the two endmembers of the GIS acronym—geographic and system. Is GIS the future of geography, or is it a power-laden technology that distorts the ethical and epistemological concerns of the discipline (Taylor 1990; Goodchild 1991; Openshaw 1991; Taylor and Overton 1991; Lake 1993; Pickles 1995)? Alternatively, is GIS a computer system, or a science (Pickles 1997; Wright, Goodchild, and Proctor 1997)? Most writings about geographic information (e.g., Sinton 1978; Chrisman 1984; Department of the Environment 1987; Goodchild 1992, 1997, 2000; Burrough and Frank 1995; Onsrud and Rushton 1995; Barr and Masser 1997; Couclelis 1997, 1998; Curry 1998) avoid definitions of information per se, focusing instead on what makes information geographic. This is understandable in a new field trying to establish itself. Thus, from the earliest days, the salient characteristic of geographic information has been its construction within the dimensions of space, theme, and time (Berry 1964; Sinton 1978). Ideas about information that are not part of the geographic matrix have seldom been dealt with in an extended manner by the GIScience community (but see Couclelis 1997).

The "I" in GIS

We draw on the literature of science and technology studies to examine the "I" in GIS critically, disinterring a deep history of metaphors about information that entered the nascent discipline from the cybernetics movement of the mid-twentieth century. These ideas about information were vital to the building and promotion of computer systems, but their persistence today may hamper the ability of GIS to respond to current needs. We suggest that GIScience, which has recently coalesced around the idea of GIS as a technology for communication (Goodchild 2000; Sui and Goodchild 2001), might address what computer scientist Joseph Goguen (2002, 5) calls the "scandal of information technology"; that is, the failure "to provide (or adopt) any notion of information that is sufficiently precise to serve as a basis for building technical systems, and at the same time can take sufficient account of the crucial

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social aspects which determine whether or not a system will be successful with its users."

Goguen does not provide an alternative definition of information; nor do we. A good deal more spadework needs to be done by GIScience on new ideas about information that might make GIS more responsive to the user before any alternative definitions can be advanced. In this article, we suggest new research directions that take account of the work people accomplish using information technologies. Our position is that GIS as a technology depends on the creativity of information users and simultaneously embraces both technical systems and situated communities of practice.

Information Paradoxes

The mid-twentieth century saw the emergence of mathematical definitions of information (Wiener 1948; Shannon and Weaver 1949; Brillouin 1962) that facilitated the development of digital computers and the subsequent rise of new sciences such as cybernetics, computer science, artificial intelligence, operations research, and cognitive science. These mathematical definitions were elaborated by several metaphors that envisioned how information operates in the world. Technologies such as GIS, which emerged at a somewhat later period, relied not just on the mathematical formulas with which these earlier sciences specified information, but also absorbed and made use of the same metaphors. Whereas the formulas have allowed scientists to write GIS software that works, the metaphors, perpetuated by popular culture and reinforced by the discourse surrounding the emerging geographic information technologies, are more problematic.

In popular constructions about the information society, information is seen as inherently paradoxical (Bowker 1994). On the one hand, in postindustrial society (Bell 1973) information has the power to transform our modes of production (D. Harvey 1989), our settled senses of space and time (Soja 1989), the societies we live in and through (Castells 1996), and indeed our very bodies (Martin 1994; Hayles 1999). On the other hand, information has no substance. It is not a thing, rather it is a relation (Poster 1990).

Two metaphors about information popularized by the mid-twentieth century cybernetics movement sustain these paradoxes. The first metaphor visualizes information as a substance or thing that passes between objects and/or actors in a communication process. This process is typically symbolized by a boxes-and-arrows diagram (Figure 1). In the idealized communications process represented by this diagram, information remains constant as it passes through various translations from sender to receiver. For the sake of brevity, we call this the *metaphor of invariance* since the message remains the same as it is moved from sender to receiver.

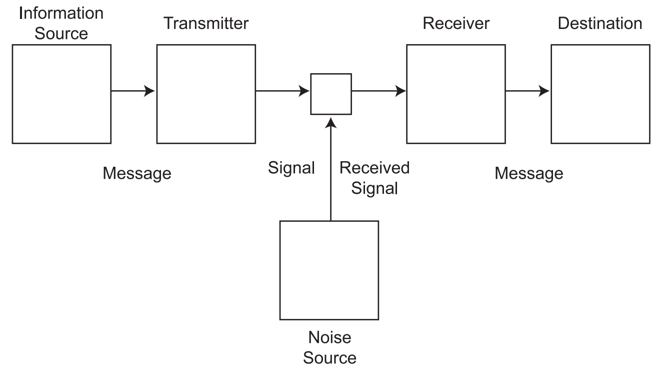

Figure 1. Metaphor of invariance. (After Claude Shannon and Warren Weaver. *The Mathematical Theory of Communication*. Copyright 1949, 1998 by the Board of Trustees of the University of Illinois Press, p. 34. Used with permission of the University of Illinois Press.)

The metaphor of invariance, which treats information as a thing and equates it with the exchange and transport of goods, has been embodied in such ideas as the information infrastructure (Kahin 1992) and the information superhighway (Sawhney 1996). In the GIS world, this metaphor has its most prominent application in the National Spatial Data Infrastructure of the Federal Geographic Data Committee (1993), which envisions a network for sharing geographic data modeled on the highway system, a necessary underpinning of good government and a healthy economy.

The second metaphor depicts information as one stage in a progression from raw data to wisdom, a process of successive refinement. We refer to this as the *metaphor of refinement*. Typically, this metaphor is visualized as a data or information pyramid (Figure 2). Information is

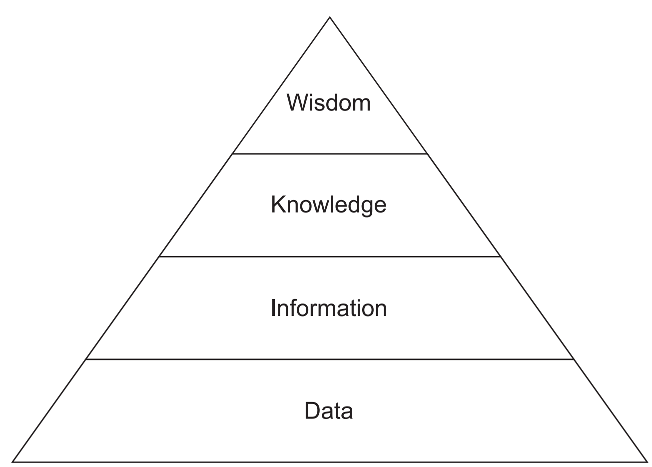

Figure 2. Metaphor of refinement.

treated as a boundless and renewable source of wealth to be exploited. The metaphor of refinement is a prerequisite to the frictionless functioning of the information society (Cleveland 1985; Beniger 1986). Conceptual documents proposing the creation of a digital library of geographic information depend on the idea of information as a source of wealth and explicitly reference the information pyramid (National Research Council 1999).

The remainder of this article discusses how these two metaphors stand behind present-day thinking about the role of information in GIS. A historical section situates the metaphors in the post–World War II culture of cybernetics, suggesting that these metaphors entered GIS through the rise of quantitative geography and the development of a theory of cartographic communication. We follow with a discussion of the role of metaphor in science, and we draw on the literature of science and technology studies to suggest alternative visions of information based on social and ethical concerns that can also be traced to now-forgotten developments in the cybernetic movement.

Information Metaphors and Cybernetics

Through wartime work on the regulation of servomechanisms for controlling antiaircraft guns (Heims 1991; Galison 1994) and solving problems of message transmission and cryptography (Mirowski 2002), Norbert Weiner and Claude Shannon published influential works defining the new science of cybernetics nearly simultaneously (Wiener 1948; Shannon and Weaver 1949). Fundamental to cybernetics was the activity of modeling. Cybernetic models permitted scientists to study the properties of systems independent of their physical realization. Very different systems—electronic circuits, brains, or organizations—were thought to be isomorphic when addressed using high-level concepts such as order, complexity, information, control, and difference (Heylighen and Joslyn 2002). Cybernetic ideas were introduced to wider scientific circles and to popular culture through a series of interdisciplinary conferences in the late 1940s and early 1950s, sponsored by the Josiah Macy Foundation (von Foerster 1949), that were widely reported in the popular press (*Time* 1950).

Shannon and Wiener are today regarded as the joint fathers of cybernetics, and they defined information in mathematically similar terms; however, they elaborated these mathematical formulas with different foundational metaphors, as described above. These differences may account, in part, for the paradoxical qualities that information assumes in the popular mind.

The Metaphor of Invariance: Claude Shannon

Shannon, a mathematician employed at Bell Labs, was concerned with the problem of transmitting messages over distance and through time. For Shannon, "the fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point" (Shannon and Weaver 1949, 31). His solution stressed efficient coding, using the binary logic of Boolean algebra.

In Shannon's model, information is transmitted from sender to receiver through a defined channel, visualized as a one-way series of arrows flowing between boxes (see Figure 1). Shannon's communication system is predicated on reducing uncertainty in the coding and decoding of messages sent and received by mechanical means. Information is defined mathematically as directly proportional to the logarithm of the probabilities of choosing one symbol over another from a finite repertoire of symbols, expressed in binary logic. Shannon's definition of information is counterintuitive to the popular understanding of information: that more information implies less uncertainty. For Shannon, a message with a high information content is one in which the set of possible messages displays a low degree of organization. For example, in decoding a message composed from a structured information source such as the English language, predicting the next letter in a sequence is much easier than predicting the next in a random sequence of letters. The link between probability and information is the key to efficient coding and decoding.

Shannon's communication theory implied nothing about the meaning of a message, and, indeed, in both *The Mathematical Theory of Communications* and the later Macy Conferences, Shannon asserted that his theory did not apply to semantics, the human aspects of communication (Shannon and Weaver 1949, 31; von Foerster 1950, 157). The communications process implied by Shannon's diagram has been characterized as a conduit (Reddy 1979) through which information is simply conveyed, much as water is delivered to customers thorough a system of pipes. On this view, language transmits ideas from speaker to listener through the reification of thoughts and feelings into an idea space. The receiver simply extracts a meaning that is already present within the idea space. This linear account of communication gives no credence to the active structuring and reinterpretation involved in the act of listening, nor to a communal or ritual view of communication that establishes shared meaning (Carey 1989, Schroeder 2003).

In Shannon's system, the encoding and decoding of messages are transformations that can be reversed so that the message extracted from the communication process is identical to the message encoded:

> The general idea is that we will have effectually defined information if we know when two information sources produce the same information . . . This is a common mathematical dodge and amounts to defining a concept by giving a group of operations which leave the concept to be defined invariantly. If we have a message, it is natural to say that any translation of the message, say into Morse code or into another language, contains the same information provided it is possible to translate uniquely each way.
>
> —(Shannon, quoted in von Foerster 1950, 157)

The invariance of information through transformations and the unidirectional flow of information have important consequences for the way information later became represented in quantitative geography, in the cartographic literature, in systems of map production, and ultimately in geographic information systems. For example, Waldo Tobler, an important figure in early GIS theory, designed his notion of geographical filters on the same framework of invariance under transformation (Tobler 1969; see Chrisman 1999). While Tobler drew on older formulas for transforming map projections in his work, he was also reading and referencing the cybernetic literature (Tobler 2000).

The Metaphor of Refinement: Norbert Wiener

Wiener, a professor of mathematics at the Massachusetts Institute of Technology, coined the word "cybernetics" from the Greek word for steersman. This navigational metaphor enlarges the scope of the new science of cybernetics beyond communication, emphasizing the interaction of organisms with their environment, a consideration excluded from Shannon's black-boxed communication system. For Wiener, information holds together a mixed human/machine hierarchy where feedback and notions of control and power are central (Hayles 1999). Wiener, developing his ideas from wartime work on the problem of aiming anti-aircraft guns (Galison 1994), posited a cybernetic machine that used information on the past behavior of constantly changing agents—the enemy pilot, the aircraft, the gunner, and the gun—to predict the future position of the aircraft. In this theory, information, or the messages that flowed among parts in this system, was a pattern of differences, a set of relations, not an object, as implied in the Shannon diagram (Hayles 1999).

In *Cybernetics,* Wiener (1948, 181, 187) includes a discussion of the implications of cybernetics for social systems that stresses binding power of information within a hierarchical social system: "The concept of an organization, the elements of which are themselves small organizations, is neither unfamiliar nor new . . . One of the lessons of the present book is that any organism is held together in this action by the possession of means for the acquisition, use, retention, and transmission of information."

The role of information as a mediator and the vision of a hierarchical superorganization composed of progressively smaller parts links Wiener's *Cybernetics* to the information pyramid (see Figure 2).

The information pyramid depicts successive upward stages of refinement or distillation, from the many and lowly positioned and valued to the few and highly placed and valued. This is also a metaphor of the mingling of the human and the nonhuman. Information mediates between objects in the natural world, as data, and the inner workings of the human mind, as knowledge and wisdom. The information pyramid parallels the organization of computer systems, with bits and machine language at the bottom and more abstract and humanly oriented structures such as application programs at the top (McCarthy 1966). The information pyramid is also a mirror of how the information-based sciences view their subjects—for instance how the early artificial intelligence community viewed the internal operations of the mind as hierarchy (Minsky 1986) or how operations research defined organizations (Simon 1960). Finally, the information pyramid embodies and normalizes theories of power, reflecting the hierarchical social structures of the old industrial economy, with manual workers on the bottom and knowledge workers and bosses on the top.

The information/knowledge/wisdom pyramid did not originate with Wiener but made its appearance in the late nineteenth-century utopian movement (Mattelart 1999) in such schemes as the World Corporation proposed by safety razor inventor King Camp Gillette (Gillette 1910) (Figure 3). In this utopian vision, the advancement of civilization is linked to progressive knowledge acquired by the individual worker.

The association of the information pyramid with information as a critical resource was cemented by the proclamation of an information society and an information economy in the 1980s (Drucker 1980; Cleveland 1985). Advocates of government information technology initiatives and electronic libraries also adopted the information pyramid as a central metaphor,

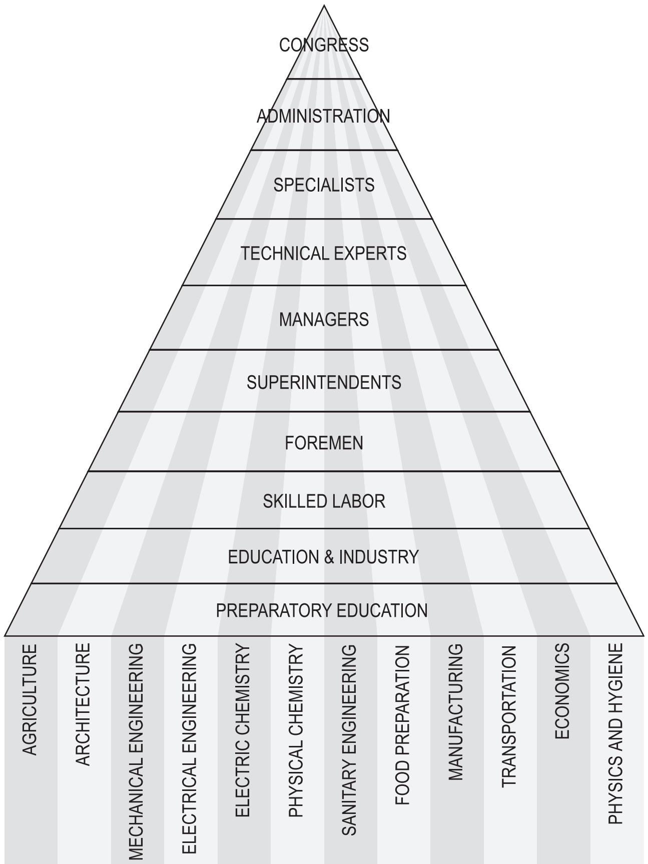

Figure 3. World Corporation. (After King Camp Gillette. 1910, *World Corporation*. Boston: New England News Corporation, p. 85.)

relying on its long associations with the advancement of civilization and the expansion of the economy (Vogt 1995; Larson 1998).

Expanding Shannon's Diagram: Warren Weaver

Shannon's emphasis on the faithful reproduction of the input at the receiving end of a message transmission derives directly from the circumstances of his wartime concerns with cryptography (Mirowski 2002). Cryptography is implicitly concerned with safely keeping messages secret—not with widely disseminating knowledge. It is a limited model for human communication because it intentionally omits any choice or purposive activity at the receiving end. Despite Shannon's attempts to confine the measurement and meaning of information to the solution of problems in communications engineering, mathematician Warren Weaver, an influential postwar science administrator who worked at both the Rockefeller and Sloan Foundations (Rees 1987), was determined to universalize Shannon's model by applying it to other all forms of communication (Mirowski 2002).

In the essay that served as the introduction to the hardcover version of Shannon's theory (previously published as Shannon 1948 without Weaver's essay), Weaver universalizes Shannon's information to a wide variety of applications, stating that communication was "all of the procedures by which one mind may affect another" (Shannon and Weaver 1949, 3), including speech, writing, music, and art.

For Weaver, Shannon's prescriptions against enlarging the scope of information to the semantic domain posed no significant problems. Weaver claimed that in the future the powerful body of theory concerning Markoff processes (Shannon and Weaver 1949, 28), on which Shannon based his conception of information, would unravel the problem of semantics. Imagining a future technology that will solve problems that current technologies create (Winner 1986) is consonant with Weaver's position as an architect of the postwar expansion of science and technology (see Edwards 1996).

Metaphors

Shannon and Weaver and Wiener are important to later developments in many fields, including geography, not just for the mathematical formulas with which they specified information, but for their metaphoric descriptions of information. Why are metaphors important? Our ordinary language is at base metaphorical (Lakoff and Johnson 1980), but metaphors also play a particularly important catalyzing role in the development of science. It has been said, "There's no avoiding metaphor in science" (Lakoff 1999, 2). Metaphor and simile have been understood as characteristic tropes of scientific thought (Harré 1986, 7; Sismondo 1996), associated with the formation of new paradigms (Kuhn 1962; Hess 1966; Haraway 1976; Fox-Keller 1995).

Metaphors in science function as agents of theory change because they combine objects in strange and unexpected ways (Barnes 1996; Latour 1996; Sismondo 1996). This formulation stresses the active function of a good metaphor, its experimental fertility (Haggett and Chorley 1967). An example of the close alignment of metaphors and theory can be found in Barnes's history of theory development in economic geography in which metaphors are seen as "acts of novel redescription" (Barnes 2001, 548); the sites for the crystallization of new theory.

Warren Weaver's essay (Shannon and Weaver 1949, 27) uses metaphor to emphasize the role of theory in science in a similar way: "An engineering communication theory is just like a very proper and discrete girl accepting your telegram. She pays no attention to the meaning, whether it be sad, or joyous or embarrassing. But she must be prepared to deal with all that comes to her desk."

The girl (presumably a secretary) who conveys the message is compared to a theory. Placing the emphasis on theory as a neutral conveyor of meaning is a move toward universalizing; it allows for the expansion of information theory into other domains beside communications engineering. Since it does not matter whether the secretary understands the message—in fact she does not care about the meaning—Shannon's information theory can be applied to any message. For enlarging the scope of the cybernetics movement, this was critical: "precisely the same arrangement of parts in the computer can represent the spread of an epidemic, the spread of rumors in a community, the development of rust on a piece of galvanized iron, and diffusion in a semi-conductor" (Pask 1961, 32, n. 10; quoted in Bowker 1993, 122).

This passage from British cybernetician Gordon Pask is very similar to the much later description of the universality of GIS by Openshaw (quoted earlier). Although it is not likely that Openshaw was quoting Pask directly, the metaphoric descriptions of how information technologies can function universally are very similar, attesting to the survival of cybernetic ideas about information in very different contexts.

Metaphors forge new realities through the juxtaposition of two seemingly disparate images. It is precisely because they do not directly map reality that successful metaphors can often have the effect of eventually structuring reality to fit (Black 1993; Sawhney 1996). For example, in GIS, the metaphor of the landscape as a set of layers evolved from the literal practice of landscape planners into a metaphor that early programmers used to guide the construction of GIS software (F. Harvey 1996). Later, the metaphoric became literal again as the use of these software packages encouraged organizations to collect data according to the layers. Although there have been recent developments in GIScience research that have reconceptualized the landscape in terms of object-oriented design (Worboys, Hearnshaw, and Maguire 1990) and agent-based modeling (O'Sullivan 2004), numerous practitioners continue to conceive of the landscape in terms of layers (Schuurman 1999). In a sense, they are locked into this way of thinking because it has been built into some of the most widespread software systems and textbooks (Tomlin 1990). The landscape-as-layers metaphor demonstrates how a discursive practice, which originated as a leap in scientific logic, can interact through time with the agencies of people, institutions, and technologies to enforce certain ways of seeing and talking about the landscape.

Cartographic Communications

The complex relation between cybernetics and geography must remain a site for further research and discussion. However, it is clear that many quantitative geographers put the mathematical practices of Shannon and Wiener to work while at the same time embracing the metaphors of invariance and refinement. The penetration of cybernetic formulas and metaphors in geography is amply demonstrated in what might be referred to as the essential treatise of quantitative geography, Chorley and Haggett's *Models in Geography* (1967). The essays in this volume are suffused with information theory (see, e.g., Haggett and Chorley 1967; Stoddart 1967). For the nascent science of GIS, or automated cartography, Board's (1967) article on the map as model is fundamental, since it is regarded as having kicked off a concern for cybernetics and information theory in cartography (Robinson and Petchenik 1975).

Board's essay and the somewhat later one by Kolácnỳ (1969) import the Shannon diagram and elaborate it with additional boxes and arrows to suit the cartographic model. In its most basic form, the Shannon diagram is discussed by Robinson and Petchenik (1976) in their treatment of cartographic communication (Figure 4). The real world becomes the source, the map becomes the signal, and the map users are the receivers of the message. The Shannon model was announced as a new paradigm that would provide a scientific basis for cartography (Morrison 1976). With the exception of a few instances in which attempts were made to analyze the information content of maps (see, e.g., Ratajski 1978), cartographers did not employ the underlying mathematics of cybernetics. Instead, the Shannon diagram functioned in the cartographic communications literature as a visual metaphor; a machine with which to think. The diagram allowed cartographers to envision their discipline as a rigorous qualitative science linking the real world, the cartographer, the map, and the map

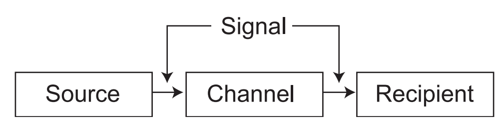

Figure 4. Cartographic communication. (After Arthur H. Robinson and Barbara B. Petchenik, 1976. *The Nature of Maps: Essays toward understanding maps and mapping.* Chicago: University of Chicago Press. Copyright 1976 by the University of Chicago Press. p. 7. Used with permission of the University of Chicago Press.)

user in one common system. This is the expansion of the Shannon diagram toward the information pyramid envisioned by Weaver and Wiener.

The relevance of the cartographic communications literature to current GIS practices was its inclusion of the user in the map-making system. For the Shannon model to apply to maps, it was necessary to see the Shannon diagram as pertaining to human communication, which would not have been consonant with Shannon's views, but which would have been supported by Weaver. In his classic paper on cartographic communications, Kolácnỳ (1969, 47) states: "It is the cartographic information that is a new concept connecting the creation and utilization of the map in one process." This implies that information is a substance that flows through the diagram, remaining invariant in the process. However, he also states: "Therefore cartographic information, which is never of a material nature, includes the meaning and sense of the representational map content" (49). So, information is at once both material, capable of doing work, and immaterial, a relation.

To accommodate semantics within the Shannon diagram by including both the thinking map maker and the thinking map user in one system necessarily involved cartographic communications in postulating what was happening inside the head of the user. Accounting for meaning required both information metaphors to be employed simultaneously, forging an undying link between map making and cognition that has been transferred to modern GIS research (Mark 1993).

Maps are inherently different from Shannon's model. The map is both a code and a message. The map encodes a particular spatial arrangement selected by the cartographer and expressed in cartographic code; however, the receiver does not have the same access to the code book as the map maker. In Shannon's model, the problem with transmission is noise in the channel; with maps, the message is not invariant, nor is meaning. The codes had to move inside the head, becoming representational mental schema (Morrison 1976). Thus, solutions to cartographic communications became closely linked with developments in psychology and cognitive science (Blades and Spencer 1986). The maps in the head were, in theory, aligned at both ends of the communication process by the map-maker's judicious selection from a repertoire of symbols. User testing for better symbol selection was recommended in the cartographic communications literature, but both map maker and map user were understood to have the same underlying mental structures (Nyerges 1991). Communication was not seen as a conversation between map maker and map user that involved mutual feedback but rather as a manifestation of the conduit metaphor where information was simply conveyed (Reddy 1979).

Further work is needed to explore the relation between cognitive science, which had a strongly cybernetic background, and the cartographic communications school. Morrison (1976) conceptualizes thinking as the manipulation of symbols functioning through the mechanism of search very much in the vein of cognitive science (Newell and Simon 1976), itself heavily influenced by cybernetics. Although the cartographic communications school was challenged from within cartography (Robinson and Petchenik 1975; Ratajski 1978; Harley 1989; Wood and Fels 1992; see review in Crampton 2001), cognitive mapping (Downs and Stea 1973) became very much a factor in how the relation between GIS and GIS users would be characterized (Mark 1988, 1989; Mark and Frank 1989; Mark and Egenhofer 1997; Mark et al. 2000).

Cybernetic Metaphors in Early GIS Theory

Like the cartographic communication literature, early GIS theory vacillates between the metaphor of invariance and the metaphor of refinement. As evidence, we offer Douglas and Peucker's (now Poiker) classic article, "Algorithm for the Reduction of the Number of Points Required to Represent a Digitized Line or its Caricature" (1973). In this article, Douglas and Peucker present an algorithm to resolve a critical problem in the transition between manual and digital cartography. Automatic digitizing of lines from maps resulted in more data than were needed to characterize lines in a database. In other words, Douglas and Peucker are interested in how to reduce noise in a communication channel.

Douglas and Peucker describe several digitizing arrangements that can be related both to Shannon's diagram and to the information pyramid. An automatic coordinate digitizer (the transmitter of Shannon's diagram) moves over the line on a map (the information source), encoding the line (the message) as a series of points, expressed as x,y coordinates transformed into electronic bits (the signal). The bits are output to magnetic tape (a channel). The computer reads the tape (computer as receiver) and in turn manipulates the signal and transforms it (computer as transmitter) so that the signal can be sent (over another channel) to a plotter (the receiver), which transforms the signal back into lines on a map (the message). This is a multistage realization of Shannon's diagram with the emphasis on information remaining invariant under several transformations. Douglas and Peucker's efforts were directed toward reducing the noise in the various channels so that the line drawn by the printer would duplicate as closely as possible, and with an economy of information, the original line on the map. These notions show the slipperiness of information as invariance-through-transformation slides into information as refinement.

The digitizing mechanisms described by Douglas and Peucker can also be viewed from the standpoint of Wiener's notions of information and the information pyramid. First, Douglas and Peucker (1973, 112) describe a human operator, linked to the digitizer and the computer, digitizing by the point method and generalizing as he goes along "subjectively select[ing] points which best approximate the line to the degree he desires." When run in the automatic mode, a computer can substitute for a digitizing person. The computer, "interfaced to the digitizing table oversees the whole operation, checks and double checks the data recorded, closes loops and signals when it senses a great many errors" (113). These two operations are mixed man/machine hierarchies, united by a flow of information, kept in check by feedback loops and directed toward a goal—the transformation of selected data points into a higher form of more universal knowledge, that is, knowledge that can be used for multiple functions such as map generalization, changes in projections, or compilation with other types of geographic data.

The algorithm itself can be seen as an instance of information theory. The algorithm is programmed to construct an imaginary line from an anchor point to a constantly floating end point. The perpendicular distances of vertices to that imaginary line are successively examined, and points within a certain threshold (or bandwidth) are eliminated, making the outliers into new anchor points, at which time the process is repeated in a recursive fashion. In accordance with information theory, this algorithm operates by patterns of difference from the expected, that is, the threshold values. By cybernetic definition, points lying outside this pattern of difference contain more information because they are unexpected. They are the differences that make a difference (Bateson 1972, 315). These outlying points become the turning points of the line, giving it order out of the noise of the cloud of points that are captured in the digitizing process.

So, by this early date in the evolution of GIS technology and theory, the impact of cybernetics and information theory had already been absorbed. Douglas and Peucker do not have to refer to the actual precedent literatures of information theory and cybernetics nor justify their use. These ideas have faded into the background because they are in the process of being incorporated into the very algorithms that will make up the next generation of GIS software.

Paradigm Shifts: The Tower of Babel and the Digital Geolibraries Movement

Paradigm shifts are very much on the agenda in GIScience research today. In a series of papers (Goodchild 1992, 2000; Wright, Goodchild, and Proctor 1997; Goodchild et al. 1999), Goodchild and his coauthors have called for the establishment of a science of geographic information, changing the meaning of the "S" in the acronym GIS from systems to science. An important motivation for the turn to GIScience is said to be the widespread use of geographic information in conjunction with new technologies for communication (Goodchild et al. 1999). On the one hand, the information science spawned by the Shannon model (which discards any notion of meaning) is held up as fundamental to progress today (Goodchild 2000). On the other hand, a retheorizing of GIS as communications (Sui 1999; Goodchild 2000; Sui and Goodchild 2001, 2002) and the closely associated digital geolibrary movement (National Research Council 1999), which builds off the information pyramid, attempt to recast GIS as a social movement embracing ordinary people—an audience for whom the meaning of geographic information must be paramount.

Most of the discussion about geographic information in the GIS-as-communications paradigm and in the digital geolibraries movement unconsciously perpetuates the hidden metaphors of information inherited from cybernetics and black-boxed into early GIS technologies. As we saw in the case of Douglas and Peucker (1973), both the myth of invariance and the myth of refinement are employed simultaneously.

Goodchild (2000, 345) asserts that geographic information is both a well-designed subset of information in general, and a commodity that is independent of the media on which it is stored, communicated, and used. "Well-designed" suggests obedient to known laws, and "commodity" implies information as thing. This formulation places geographic information back within Shannon's closed world of information measurement in which sender and receiver must agree on a code that is used first to express message content in a fixed alphabet and then to decode it.

The independence of information from its media also reflects the cybernetic dream of a universal modeling language. More directly, Goodchild appropriates the Shannon/Weaver information diagram to depict the process of information transfer in geological field knowledge (Figure 5). Goodchild's diagram envisions the current ability of the field geologist to convey information directly to the user through the advances of

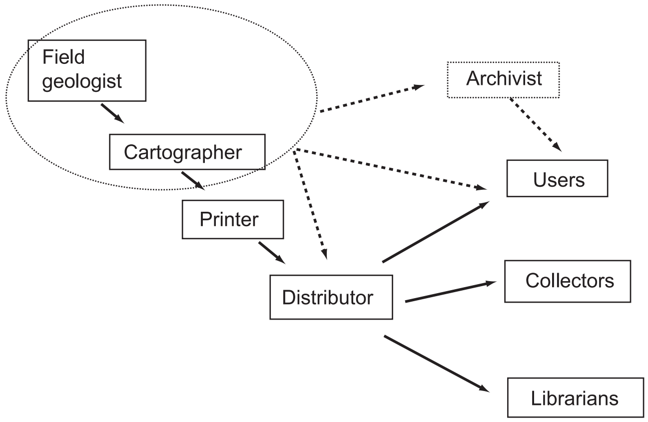

Figure 5. Communication of geological field knowledge. (After Michael F. Goodchild, 2000. Communicating geographic information in a digital age. *Annals of the Association of American Geographers* 90 (2): 348. Used with permission of Blackwell Publishing.)

information technology. However, it makes no provision either for user feedback or for the creative construction of information and knowledge by users.

Goodchild (2000, 347) argues that the scientific view of GIS might change under the new GIS-as-communication paradigm: "But in the world of computer as human communication medium, the question of whether information should be forced to adapt to the nature of the channel is much more debatable." Sender and receiver no longer share the same code. The Shannon paradigm cannot apply. And yet he sticks closely to the view of information as thing, and communication remains a boxes-and-arrows structure that transmits information invariably through a series of transformations.

This vacillation between information metaphors also characterizes the digital geolibrary movement. The digital geolibrary partakes of both the familiarity of the neighborhood library and the ability of the Internet to deliver information from anywhere to anywhere at any time (National Research Council 1999). The information pyramid is invoked to distinguish between raw data, the focus of early digital spatial data collections, and creative works of knowledge such as landscape descriptions, the stuff of traditional libraries (National Research Council 1999). The new distributed geolibrary can provide access to both types of information because both types of information look essentially the same to a computer—a collection of bits with footprints, retrievable using the same search mechanisms (National Research Council 1999, 44). This is information-as-thing.

Raw information, information-as-thing, is distinguished from knowledge. Scientists may simply need access to the raw data from which they will create new knowledge, however users without sophisticated tools may have to settle for the landscape descriptions (National Research Council 1999, 44).

Although recognizing that a digital geolibrary needs to accommodate the creation of new knowledge by individuals or groups (National Research Council 1999, 44), the authors of this report offer no consideration of possible mechanisms through which new knowledge or information created by end users could in turn be reincorporated into the digital geolibrary. Instead, the research needs discussed and the technical solutions proposed are envisioned in a top-down manner. Social concerns are bracketed off as concerns for privacy and copyright protection in a digital world.

This attitude is an expression of the information pyramid. The report calls for the accommodation of user's concerns in the design of systems, which is an advance on the Shannon model, but the ultimate structure is imagined as a hierarchy designed from the top down, valuing certain types of information and knowledge over others.

An additional danger of the hierarchical approach to information is that the progress up the pyramid from data to information to knowledge to wisdom is a process of refinement. Thus the digital geolibrary system is geared toward abstracting knowledge from raw data and information in order to help users find what they are looking for rather than beginning with the context of use. The digital geolibrary vision pushes GIS partially in the direction of the social, but is an incomplete paradigm shift because a definition of information that will support the social vision is lacking. Social concerns are not just icing on the cake, but require fundamental rethinking in the design of GISystems, placing emphasis on the crucial practices by which people interact.

The Search for Meaning: Toward a Social Theory of Geographic Information

In parallel with the criticism of GIS from within mainstream geography, cited above, problems of usage and meaning have concerned GIScience in the past decade. The reflective article by Burrough and Frank (1995) asked whether GISs are universal. They concluded that restrictive spatial paradigms on which current GISs are based limit their usefulness (see also Fisher 1998; Sheppard et al. 1999). However, although some have seen that outmoded definitions of information are also problematic, there has been no concerted effort to develop new approaches.

Recently, an edited volume on the foundations of GIScience addressed some of the inadequacies of the inherited cybernetic metaphors (Duckham, Goodchild, and Worboys 2003), but a close reading of these essays shows that the information metaphors are difficult to escape. In a chapter proposing scientific means to measure the value of geographic information, Goodchild (2003) sketches the beginning of a theory of context in which the value of information is based on the computer's ability to respond to queries. In this formulation, the implied user's relationship with the computer is through the activity of search, and his or her implied goal is the retrieval of a specific item of information previously defined by Goodchild et al. (1999) as a tuple. There is a strong tie to Shannon's notion of invariance: "A GIS is said to possess an item of geographic information (defined as one or more atoms) if *it is capable of responding to a query to which the item is the answer*" (Goodchild 2003, 27, emphasis in the original). That most users at some time or another turn to search engines to answer geographic questions is undeniable. But defining information so narrowly leaves out a whole range of activities for which people use geographic information.

In Goodchild's piece, GIS is portrayed as a thinking machine for the entire planet, thus invoking the image of the information pyramid. Goodchild (2003, 27) imagines Digital Earth as a kind of geographical Turing Test with the computer racing against a person to provide answers that are indistinguishable to an observer. Information is conceived scientifically. Outside science, there might be a reason to accept the legitimacy of "multiple, personal viewpoints" (27), such as those represented in the public participation GIS movement (Craig, Harris, and Weiner 2002) or in naive geography (Egenhofer and Mark 1995). According to Goodchild, building a GIS to support nonscientific information would be impossible because such a machine could not reason. The imagery thus is of the information pyramid encompassing the entire world, with scientific information as a force that equates human cognition with the computer.

In this same volume, Worboys (2003) advances a logical specification of information flow based on the utilitarian relevance theory of communication scholars Sperber and Wilson (1995). However, Worboys does not look at the problem of information from the standpoint of the receiver of a communication, rather his article perpetuates the conduit metaphor, as derived from Shannon. Information about a real-world object is simply conveyed through a channel. Worboys acknowledges that the conduit metaphor has its limitations in dealing with context.

Several other recent articles challenge the GIScience community to develop a theory of information that accommodates the social. Building on the notion of a semantic web for the World-Wide-Web consortium (Berners-Lee, Hendler, and Lassila 2001), the University Consortium for GIS has proposed a geospatial semantic web that would incorporate meaning into the search for geographic information (Fonseca and Sheth 2002). This would require building ontologies or "conceptual systems that people use in relation to given domains of objects" (Fonseca and Sheth 2002, 2). However, the authors state that the creation and management of ontologies is difficult because "ontology is based on agreements (and preferably consensus) among domain experts that can be geographically distributed. Ultimately their survival is based on user's acceptance. This to a good part involves a social and collaborative process" (Fonseca and Sheth 2002, 2).

Raper et al. (2002, 40) distinguish between representational and communicative components of geographic information (GI), insisting that these two components are reflexively connected: "Communication of GI is a coupled and reflexive process involving the creator and the user. At present creators of GI tend to assume that users have access to the methodological processes that gave rise to the geo-representation even though that it [sic] is usually not the case."

Raper et al. (2002, 49) conclude by stating: "in reality GI must be evaluated through holistic and reflexive cycles of making and remaking." Along with them, we assert that the key to a social theory of information must begin by examining the process of making and remaking. A social theory of information will account for how meaning is constructed as information technologies are used. This approach looks beyond the closed boxes and arrows of Shannon's diagram and at the same time upends the information pyramid to make the construction of local, situated knowledge and the activities of users important components of holistic GIS enterprises, rather than seeing users as the recipients of knowledge and wisdom descending from above. The notion of making and remaking is critical because it implies a reiterative cycle and a social learning process.

It is somewhat ironic that a pragmatic, contextual view of information to support this vision was developed in the second wave of the cybernetic movement in the 1970s and 1980s by such figures as Gregory Bateson (1972), Gordon Pask (1961), Heinz von Foerster (1980), Humberto Maturana (Maturana and Varela 1980); see also Pickering (2002). Unfortunately, the insights of the second-wave cyberneticists were not picked up by the disciplines that evolved from first-wave cybernetics such as computer science, artificial intelligence, or cognitive science. Consequently the founders of the GIS movement relied on earlier and less social views of information.

Anthropologist Bateson (1972, 315), who participated enthusiastically in the Macy Conferences, considered information meaningful only as "the difference which makes a difference" to someone. In other words, for Bateson, information was a process of mutual alignment and was not an object to be transmitted. To Bateson, it was a mistake for researchers concerned with communication to focus exclusively on the role of the computer and compare its operations with the human mind: "The computer is only an arc of a larger circuit which always includes a man and an environment from which information is received and upon which efferent messages from the computer have effect" (317).

Physicist Heinz von Foerster believed that the emphasis on information was misleading:

> since we think we know what information is, we believe we can compress it, process it, chop it up. We believe information can even be stored and then, later on, retrieved: witness the library, which is commonly regarded as an information storage and retrieval system. In this, however, we are mistaken. A library may store books, microfiches, documents, films, slides, and catalogues, but it cannot store information. One can turn a library upside down: no information will come out.
>
> —(von Foerster 1980, 19; quoted in Schroeder 2003)

Biologist Maturana took a constructivist posture. Knowing was as indistinguishable from being as the organism was inseparable from its environment: "The central feature of human existence is its occurrence in a linguistic cognitive domain. This domain is constitutively social" (Maturana and Varela 1980, 50). Note that the operational concept here is *knowing* (a process) rather than *knowledge* (a product).

Inspired by the predilections of second-order cybernetics to embrace the social, a body of work has grown up in such fields as science and technology studies (Haraway 1988; Star 1991; Bowker and Star 1999; Latour 1999; Star 1999), social informatics (Star and Ruhleder 1996), anthropology (Suchman 1987; Hutchins 1995), computer science (Winograd and Flores 1986; Goguen 1997; Brown and Duguid 2000), and artificial intelligence (Agre 1997) that employs qualitative approaches and ethnographic techniques to analyze the everyday activities of people who use information technologies. This work is centered on practice, highlighting the flexible and rhetorically contested nature of everyday life and the situated character of cognition. Ethnographic studies of "communities of practice" (Lave and Wenger 1991) have revealed the importance of apprenticeship (which they call legitimate peripheral participation) in acquiring the tacit knowledge needed for working life. These approaches have become highly visible in the corporate world (see, e.g., Suchman 1995). Insights from ethnographic studies on GIS practitioners and users could supplement GIScience research based on information processing views of cognition derived from the Shannon diagram to facilitate better collaboration (MacEachren 2000). Throughout this literature, the attention to the ethnography of actual practice often deflates the grandiose explanations of the refinement metaphor. The work done at the various levels of the pyramid do not conform to the utopian expectations of King Camp Gillette. Rote work occurs at the top of the pyramid as well as the bottom, and expertise of different kinds occurs at each level, though the value added at the bottom is usually undervalued (see, e.g., Suchman 1987).

We draw on this diverse extrageographic literature in what follows because these sources seem the most germane to our needs; however, we must point out that constructivist and science and technology studies approaches are not unknown within geography. For example, Curry (1994, 1998) has written extensively on geographic practices and their implications for GIS. Robbins and Maddock (2000) examined farmers as they interact with local landscapes to question the theory-laden metaphors behind scientific land cover classifications. Demeritt (2001) based his analysis of global meteorological models on a constructivist approach. This work in geography has taken place principally as a critique of epistemologies, and has not been directly related to information use. In the GIScience community there have been several empirical studies of users at the bottom of the informational pyramid that mobilized the theoretical constructs of science and technology studies (Harvey and Chrisman 1998; Martin 2000; F. Harvey 2003), but as yet there has been no shifting of the information metaphors in mainstream GIScience.

In calling for a social theory of information, we do not provide instructions on how to construct information systems differently. Rather, we ask what a social theory of information might contribute that current views of information within the discipline do not. How would the process of communication need to be reframed in order to escape the "procrustean" "imposition of a common methodology over context" (Burrough and Frank 1995, 111)? How could a social theory of information support "multiple, personal viewpoints" (Goodchild 2003, 27), "reflexivity between creator and user" (Raper et al. 2002, 49), and "relevance for the user" (Worboys 2003, 33)? These are two suggestions:

1. A social theory of information should account for resistance to technological change, beyond the limited

and overly linear model of early and late adopters (Rogers 1995). Creators of new technologies often try to remove what are perceived as constraints—people, older technologies, organizations, practices—without appreciating their "submerged resourcefulness" (Brown and Duguid 2000, 244). So, for instance, when a watershed worker makes a computerized map of the streams in a watershed based on data downloaded from the Internet and wants to check on the location and names of streams, she prints out a paper map and shows it to the hydrologists and biologists who work in the watershed. They scribble on the map, indicating problem areas (Poore 2003). Doubtless, some of this handwork could be done on a laptop with a drawing program linked to a GIS; however, the effort would be considerable compared to the ease of use and portability of a paper map, and many people would resist using computerized technology for such a purpose. This is not to recommend a return to the paper map, simply to point out that adopting the narrow channel of the Shannon diagram can squeeze out methods of working that are essential to collaboration.

Likewise in the case of the information pyramid, accomplishing a Digital Earth will require the support of a vast collaborating realm of web designers, computer programmers, researchers, catalogers, metadata preparers, and so forth, not to mention the organizations required to post the data and keep them current, the software routines and standards to coordinate the data, and the institutional frameworks to support an enterprise of that scale. However, accounts of the Digital Earth emphasize only the results—having information instantly available at your fingertips, a version of the Shannon myth of invariant communication—while downplaying the coordination work needed to accomplish the vision. The work that goes into the infrastructure is hidden (Star and Ruhleder 1996). "Infrastructure networks are, in short, precarious achievements. The links between nodes do not last by themselves; they need constant support and maintenance" (Graham and Marvin 2001, 184). By not focusing more attention on social and organizational issues, GIScience risks missing an opportunity to include the potentially excluded in the construction of Digital Earth (Star 1991, 1995).

2. A social theory of information should question the information-processing view of cognition derived from the Shannon model and expressed in the cartographic communications literature. Recent criticisms of both the computational and connectionist versions of artificial intelligence (Agre 1997) have challenged the notion that thinking occurs solely within the head. In this view, cognition is distributed, the activity of a community of people and objects, situated within a dynamic environment. Looking at how people work with such mundane objects as copying machines, Suchman (1987) has shown that problems of human-machine interaction lie in the imbalance between the situated organization of practical action and the regimented model embodied in systems. Latour (1999) has described how collaboration over scientific instruments and inscriptions constitutes thinking for a group of scientists from different disciplines doing fieldwork on the forest/savannah boundary. By observing navigators at work, Hutchins (1995, 8) demonstrates how any particular navigational task required many different kinds of thinking: "Some of them were happening in parallel, some in coordination with others, some inside the heads of individuals, and some quite clearly both inside and outside the heads of the participants." The navigators worked with pens on a chart, reasoning about the lines as evidence of their position. The representations were actual agents in the thinking, supported by the mathematics of the conformal projection (Sismondo and Chrisman 2001). Brodaric and Gahegan (2001, 134) describe how geoscientists bring their knowledge into the field where the environment's capacity for infinite permutation requires of them "constant adaptations of conceptual and pragmatic knowledge." People operate within ecologies of knowledge (Star and Ruhleder 1996). Meaning cannot be regarded as something fixed and transferable, rather, it is the ongoing achievement of some social group (Goguen 1997, 34) interacting in a specific place and over a specific period of time.

Reframing Communication

It is possible that the notion of communication should be reframed as conversation—a two-way process—and old ideas about information advanced within the paradigms inherited from cybernetics need to be modified (Schroeder 2003). Computer scientist Joseph Goguen (1997, 31) proposes that information is "an interpretation of a configuration of signs for which some social group is accountable." The central question for a social theory of information is how to express accountability flexibly without losing the social interactions in search of complete formalization. As long as research tries to focus solely on the bits transmitted through a conduit or succumbs to the mythology of refinement, it loses sight of the various ways in which meaning is established through the tenuous networks of trust, respect, and power through which people relate and organizations function.

Definitions do matter, since they often become dead metaphors when removed from the circumstances of their original creation. For this reason, metaphors must be continually reexamined. We must recognize that today it is counterproductive to employ the metaphor of information as passively flowing through a conduit. Information is actively transformed and reworked by its recipients. The originators of the information are no longer in control of meaning. Similarly, the hierarchy of information producer/consumer makes it all seem so effortless. Refinement does occur, but the work that goes into refinement is obscured. A better account of refinement would allow us to temper ideas about universality with more realistic goals.

By contrast, thinking of the social processes of the users and creators of information technologies places the emphasis on crucial work practices that go into creating meaning. Although abbreviated to the point of aphorism, Bateson's (1972, 315) phrasing is quite precise. Information is "a difference which makes a difference," that is, a measurement about which someone cares.

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