Materials of the Data Map

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ABSTRACT

Data mapping is the essence of being human. This report follows the process of data mapping; the transmission of a structured utterance from one domain to another. It starts with signals in the world and moves through experience and engagement with the world through those signals. The paper develops descriptions of the materials and mechanisms of data mapping. The descriptions are aids and conveniences in the effort to understand the systemic workings of the process of communication. From a systems perspective one might find points of leverage in their own involvement with the processes of communication and data mapping. Recognizing these leverage points can help in activities of art making, information design and in simply living.

Keywords: *Art, Communication, Data Mapping, Information Design, Perception*

INTRODUCTION

This paper is an artist statement of sorts, an informal excursion exploring the process of communication—tracing the passage of a message or signal from transmission to reception. Receiving messages is one half of living. Responding to messages is the other half. This paper concerns itself with the materials and mechanisms of the former. It offers and advances simple and useable definitions to help artists and designers as they develop and create their own messages. From an analytical perspective these ideas can become quite difficult to understand, but I believe that there is perhaps a less rigorous yet practical way to think about how we engage the world. The hope is to provide a "clear portrayal of the complexity" that is the process of data mapping, from our visualizations and sonifications of information to the more fundamental ways that we experience life (Tufte, 1983).

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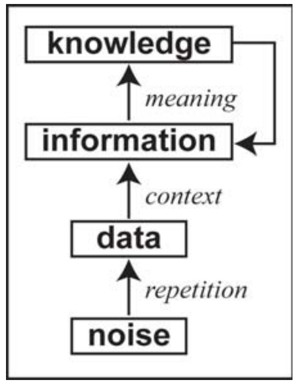
DATA MAPPING

Being human is data mapping and information processing—processes both basic and complex. Data mapping does two things to a signal.

1. A data map *abstracts* the signal. This abstraction accommodates mediation, fitting the format of the medium that will carry the signal.
2. Abstraction *reduces* the content of the signal and reduces the amount of data carried in the signal, facilitating its transference and possibly its eventual comprehension when received further along the signal path.

Each medium is itself mediated, again abstracting and reducing a signal. Sound for example starts as a vibrating object. Vibrations

Figure 1. The information food chain. New knowledge can change the context for data, thus changing the information, thus creating new knowledge (an ongoing feedback loop)



are transduced into changing pressure moving through the medium of air. That energy is transduced again into the tension of the eardrum, carried as mechanical energy by the ossicles of the inner ear, which is mediated through the cochlear fluid into the complexities of the auditory nerve and the brain. Often signals are abstracted into many maps in parallel, which we then receive synchronously—hearing and seeing for example. A signal that is simultaneously seen and heard (perhaps also felt and smelt) is a common example and a daily experience for all of us. By the time we receive signals from the world we are far removed from the source of the transmissions. All we receive are shadows, abstractions, maps of data being sent across the distances between us and the real we are immersed in. The signal loss over these distances is immense, yet miraculously communication still occurs.

To begin this excursion some informal definitions will help. What follows are some lists, some charts, some conveniences that are themselves maps of how we wade in the ebb and flow of the ocean of information surrounding us. Processing this information is the essence of being alive.

THE INFORMATION FOOD CHAIN

The terms data, information and knowledge are often used erroneously as synonyms. Their use in this paper has them situated in a dependent relationship similar to organisms on a food chain (Figure 1). The discussion begins at the base of the chain where no signal exists. Here there is unfocused energy and the promise of a signal—noise.

Noise

Noise is the primitive, the base upon which everything depends. Without noise there is nothing. Noise is the fundamental utterance of difference. *It manifests as randomness.* For example, in audio synthesis noise is simply created by mapping a sequence of random numbers into amplitude, as seen in Figure 2 (Dodge & Jerse, 1985). We essentially hear all frequencies at once. If this sequence changes at rates within the audio spectrum the sound is a rumble or hiss, perhaps the "shhh" of the ocean or the rustling of leaves. Some believe this will be the sound of the universe at the end, at maximum entropy. The visual equivalent is usually described as white light, the seeing of all frequencies of the visible spectrum at once. Perhaps a more accurate equivalent might be the snow we see on a TV screen that has no signal, which would average out to gray light (Figure 3).

Noise is essentially a non-signal (but not nothing) that is always different so paradoxically always the same. The most important thing to understand about noise is that, if measured, at any given moment its value is random. Dif-

Figure 2. A graph of a white noise audio signal in the time domain—amplitude on the y-axis (randomly changing) and time on the x-axis

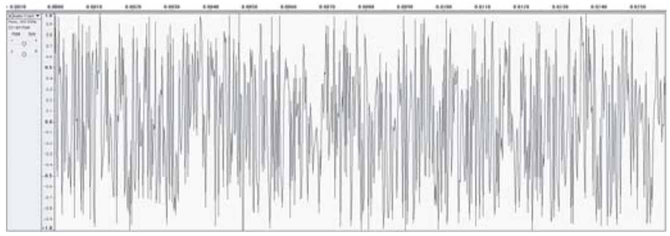
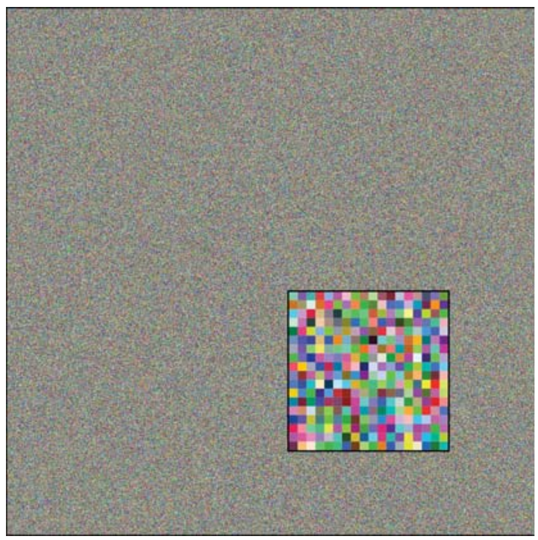


Figure 3. White noise from randomly colored pixels that will visually average to gray. The insert shows a magnification of a small square of pixels from the image



ference is constant. There is no relationship between any two values from one instant to the next. From the ground of noise as defined here we move up the chain to data.

Data

Data then is what noise is not. Data is the opposite of constant difference. It brings in sameness or *repetition*. Data is a signal with structure. Without repetition there is no structure. There are an infinite number of ways that aspects of a signal can repeat. Many are subtle. But if there is no repetition then each instant of an utterance is random and thus noise.

In a binary world we see the difference between tossing a true coin (heads or tails, zero or one) or tossing a weighted coin. With the true coin each toss is random and there is no structure. If one side is weighted or favored then we will have some repetition and a pattern will emerge—noise has becomes data. Another paradox here is that repetition establishes a difference that stands out from the noise (the random ground of constant difference). Consider the SETI project listening to the vast universe of difference that is cosmic noise, searching for a signal, a structured utterance—seeking to "find constant or slowly pulsed [repeating] carrier signals, something like a flute tone against the noise of a waterfall" (http://www.seti.org).

Usually it is data that is mediated along a signal path. Data manifests in various ways. In a digital space it is simply on and off coded as the binary 0 and 1 (Petzold, 2000). Action potentials in the neuronal networks of our brain are data too, manifested as the electro-chemical spikes that move through those networks. It is data, abstracted (and encoded) the moves most efficiently along a signal path.

Information

Information is where a signal becomes useful for us. Data, a structured utterance, becomes information when it situates within a *context*. Consider for example the binary information stored on the hard drive of a computer. If we have a tool that will allow us to look at the data we can see the structure there. We will see a pattern in the zeros and ones. While we may see structure in the data there is no useful content until we put the data into a context. Before a context is established, data from a digital audio file or an image will look pretty much the same. If we open the data in iTunes it becomes audio information and we can hear it. If we open the data in Photoshop it becomes a visual image.

It is here at the stage of information, when we process data within a context that we begin to understand something such that we might choose to respond. Data must sit within a context and become information before we can do anything useful with it. Abstract data can be mapped into many contexts. This is a point of leverage and the basis of visualization and sonification in information design and in digital art.

"In a digital space we have data abstracted to number. Number can then map into a variety of outputs. The number 255 can represent a saturated red, heard as middle C, or both simultaneously! Thus any image can be heard, any sound can be seen. Here we find the true power of mathematical abstraction, and a way to integrate the visual arts and music. Using digital technology to map (or re-map) mathematical descriptions or numerical models, we can bridge music and visual art. We can see Beethoven's Ode to Joy. We can hear Monet's Water Lilies. Once visual art and music are reduced to number they are the same. A digital synaesthesia occurs. With our ability to map numbers as we please mathematics becomes a metaphoric language from which we can create poetry" (Evans, 2005).

Knowledge

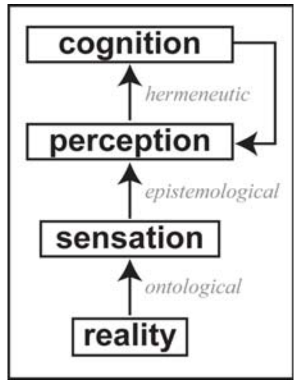
Knowledge results from learning, when information is stored in our brain and made available for use in either short or long term memory. *We metabolize information into knowledge from the catalyst of meaning.* When information has value for us we store it. We remember it. There are evolutionary mechanisms at the base of this process, unfolding from instincts for survival and the genetic mechanisms of fear and pleasure (Zull, 2002). During our development as individuals, and as a species, the processes of valuation and meaning have become quite complex. These processes are the core of much of what we call culture.

A key thing here is the difference between teaching and learning. Teachers pass on information while trying to make it meaningful for the student. It is the student that learns—the student alone converts information into knowledge. Knowledge is personal. It cannot be shared. That new knowledge can now be used in the construction of future knowledge. This is an important thing to consider as *all knowledge is built on prior knowledge*.

HOW WE READ THE WORLD (THE EXPERIENTIAL CHAIN)

Again there are some terms here that are frequently used erroneously as synonyms—sensation, perception and cognition. These processes are different, individual links along the experiential chain (Figure 4). They engage data, information and knowledge at different stages of a signal transmission. Here too are some conveniences for thinking about the mechanisms of information processing in life and specifically the process of data mapping.

Figure 4. The experiential chain. Note the similarity to the structure of the information food chain. Our concepts can change our perceptions, which can change our concepts (another on-going feedback loop). The distances cover what 'is' (the ontological), to what we believe is (the epistemological, the foundation of knowledge building), to the connections (interpretations, the hermeneutic) that are the materials of knowledge and the basis of our actions



Reality: What is There

First and foremost is reality—what is really out there. It is crucial to understand that we cannot wholly know what is out there. (This is not just a philosophical stance it is a fact.) Energy from our world enters our bodies through our senses. We are removed from that energy in both space and time. We are always and forever experiencing the past not the present, and the 'there' not the 'here'. We experience signals once removed from the source, abstracted and mediated through the physical soup in which we exist. These mediated signals are further abstracted and reduced by the mechanisms of our bodies. (Here we see again the idea that a medium is itself mediated.)

Sensation: What We See

Our senses are our first stage of data mapping. Reality transmits signals via various substances or media. These transmissions are abstractions of the source. (Just as *any* signal we transmit is an abstraction/reduction of who we are.) Information from a reality source is reduced/abstracted to data that accommodates the medium of transmission. If that mediated data falls within the limits of our senses then we can receive the data and map it into a form that we can use. For example, when objects move in our atmosphere the pressure of air molecules around those objects changes in response to that movement. The changing air pressure is *not* the motion of the object. The changing air pressure is an analog, a model, a mapping of the motion of the object. The object and its motion are already displaced in space and time from the map of changing air pressure. All we have is the trace, the index of the motion moving through the air.

If that motion is close to us, is of sufficient amplitude, and occurs at a rate of vibration between 20 and 20,000 cycles per second our eardrums will respond to the vibration manifested as the acoustic energy of changing air pressure. From the eardrum the energy is converted into electro-chemical energy through various mechanisms and is eventually transmitted over the auditory nerve to the brain. The thalamus in the brain is a key step on the signal path, functioning as a relay from the senses to the cerebral cortex (Carter, 2009). In the cortex the data is contextualized.

Perception: What We Think We See

From the thalamus sensory signals are distributed throughout the brain (primarily the cortex) for further processing. Visual sensory information, for example, is divided across many layers of the cortical brain for processing. Our older brain (on the evolutionary scale) processes "where" information such as motion, depth and position, while our higher, newer brain processes "what" information such as object recognition, color and faces (Livingstone, 2002). At the perceptual level information is processed unconsciously and automatically. We also create schema or preconceptions (perceptions) about the world. These schema filter our responses to the signals coming in. Sometimes these schema are not accurate, but they still impact how we perceive the world.

Consider that perspective drawing was developed in the 15th century. How was it that it took so long for Western civilization to realize that visual distance does not equal actual distance? (Kemp, 1990). What we actually see is a wall getting shorter from base to roof as it gets further away, but we know (or assume) it is the same height in physical space so we think we see them as parallel Based on that perception we draw the walls as parallel lines. The essence of learning to draw is "learning to see"—understanding and traversing the divide between sensation and perception. "This tendency to form schematic representations [what we think we see] appears to interfere with our ability to draw, and by inference, to see what in fact may be there to be seen. Only when one takes deliberate steps to bypass or otherwise disconnect this tendency…does the true nature of the subject emerge" (Hoffman, 1989).

Cognition—What We Think About What We Think We See

Cognitive science and neuroscience are developing a growing understanding of how we think.

"The mind is inherently embodied.

Thought is mostly unconscious.

Abstract concepts are largely metaphorical.

These are the three major findings of cognitive science. More than two millennia of a priori philosophical speculation about these aspects are over. Because of these discoveries, philosophy can never be the same again" (Lakoff & Johnson, 1999).

We construct our cognitive reality out of the sensations we record, matched against the networks of connections (knowledge) we have stored in our memories. Our knowledge impacts how the new sensory information is perceived, and as the pattern matching continues, abstraction of patterns continues and the mapping goes deeper into our neuronal networks. We can begin to reason based on these metaphoric matches—we conceptualize.

We desire, fueled by the instinct to survive, and so we make predictions and we act based on those predictions. "Pain and pleasure are the levers the organism requires for instinctual and acquired strategies to operate efficiently. In all probability they were also the levers that controlled the development of social decision-making strategies" (Domasio, 1994). Pattern matching, reasoning and predicting define our interpretations of the present in relation to the past (what we know) and the future (what we predict). Those conceptual metaphors, those pattern matches are data maps. They are the devices of our desire and the drivers of our actions.

BRIDGING THE DISTANCES (NAVIGATING INTENTION)

Now we are at the core of the data map, as we move from one process to another the signal must be reduced, abstracted and mapped. For example electro-magnetic energy in the real world hits the retina of our eye where a small subset of the spectrum is sensed, transduced (mapped from one form of energy into another) and sent over the optic nerve to the brain (again mostly to the thalamus where signals are divided and dispatched for further processing). The familiar signal path starts in reality, is mediated into energy mapped into sensation, which is mediated into energy mapped into perception. Human experience is a constant navigation across these mediations—distances traversed on the vehicle of the data map. Also along the entire signal path there is noise in each stage of the transmission—noise from the physical imperfections of our senses and from the chemical, biological and psychological imperfections of our bodies and our brains. Curiously, in many ways, it is this noise that defines us as individuals and makes life interesting.

The Ontological Distance (Reality→Sensation)

This is the divide between what is and what we can actually experience—from reality to sensation. We are at the mercies of our bodies (of which the brain is a part). We are not able to receive reality complete and in toto. We can only receive the abstracted subset of signals to which our senses respond. The reduction of data here is dramatic—from the infinite information around us to the small finite subset that is processed by our limited, highly restricted senses! And, constrained by the laws of physics, we can only experience our embodied responses to what exists outside our bodies and across the nerve pathways within our bodies. Those signals take time to travel to us and through us; hence we can only receive what occurred in the past.

The Epistemological Distance (Sensation→Perception)

This is the divide between what we sense and what we will eventually process as information and metabolize as knowledge—from sensation to perception. The gap between what we see and what we think we see is large. This distance involves genetic and cultural factors. Habituation for example is hardwired, allowing us to dismiss signals that are constant and understood to not be a threat to our survival. Imagine a mechanical clock in your living room. In a matter of minutes you no longer hear the tick-tock of its gears and pendulum. You eardrum is still responding, still sensing the signal, but your perceptions have filtered it out such that you no longer hear it.

The Hermeneutic Distance (Perception→Cognition)

Here is where we bridge perception and cognition. We begin in earnest to connect the new information to what we already know. We *interpret* our new perceptions within the network of neural connections and the glial landscape of cells that comprise the material basis of who we are (Edelman, 2007; Fields, 2009). We make connections, matching the patterns in a perceived signal to patterns stored as synaptic connections in our short and long-term memories (Kandel, 2006).

The conceptual domain (the firing neuronal connections in our brain) is a substrate of meaning allowing the new signal ("the strange") to be understood in the context of the known ("the familiar"). New synapses form in the brain connecting the new to the old. Knowledge is constructed. The steps of data mapping from sensation to the new cognitive connections formed in our neural networks are the means of that construction. Each step is a metaphor—an analogy accomplished with an abstraction that allows an association, a pattern match from one conceptual domain to another.

THE METAPHORIC LOOP

Maps are metaphors and metaphors are the basis of the construction of knowledge (Lakoff & Johnson, 1980). As all knowledge builds on prior knowledge, metaphor is the glue that connects and binds the known to the new. The mechanism of the metaphor is a process of association, a constant loop of compare and contrast of the old and the new, the familiar and the strange. When metaphor is a mapping across conceptual domains it is possible to reason about one domain from knowledge of the other.

For example I can reason about an emotional space based on my embodied understanding of physical space. I understand 'in' as the experience of being physically contained, such as 'in' a room. I have physically, with my body, experienced 'in'. I also physically experienced and know that I can exit and get outside the room that I am 'in'. My friend says he is "in a bad mood." This is a metaphor that maps an emotional space into a known experience of physical space. I can reason from the mapping of emotional space to physical space that he might be able to exit the emotional space he is 'in', and so hopefully the bad mood is temporary. The map provides a mechanism for reasoning from my embodied knowledge to an understanding my friends current emotional state, to predicting his future state (Johnson, 2007).

The Loop

A Metaphor is a pattern match found between conceptually unlike things. It manifests as a loop of desire that is the essence of being cognitively alive. It parallels our more basic desires for food, and sleep (Evans, 2009). Our survival instincts have us scanning our environment in search of difference. If something changes it might be a threat to survival (fear) or enhance survival (pleasure). We compare and contrast signals coming in to signals stored, looking for a pattern match. If there is no match then the incoming signal is new and strange. We need to know and so search more deeply for a match. Some dimension of the new must match something in memory or we cannot know the new. The search for knowledge is ongoing—a constant process of neural computation—a continual search for "*a best match* between the [sensory] inputs and current brain state" (Feldman, 2006). Desire to know the new is strong. Our survival might depend on it. Life is the constant processing of our surroundings in support of this desire.

"The relation between what we see and what we know is never settled" (Berger 1972). This is a relation of the strange and the familiar—the loop of creativity (manifested as innovation) and learning (Figure 5).

Learning

The tension inherent in desire is a motivation for learning. A fundamental mechanism for learning is analogic thinking through metaphor. "In regards to cognition analogy is everything" (Hofstadter, 2001). All knowledge builds on prior knowledge though the pattern match of conceptual metaphor. New information enters the system and is understood in relation to the already known. The strange is connected, compared and contrasted with the familiar (Gordon, 1961).

Creativity

Creativity is also a process in the metaphoric loop, but here new connections are found within the already known. What is required is seeing the known in new ways—making the strange familiar. In developing "the creative habit… Metaphor is the lifeblood of all art, if it is not art itself" (Tharp, 2003).

THE STRUCTURES OF CONNECTION

Recent research in network structure provides insights into the mechanisms of connection and communication, and also can help us to understand them as a system. Recognizing points of leverage in the system brings an ability to enhance and foster the key components of the system—learning and creativity. Of specific interest are the traces of signals through our neuronal networks that are the materials of cognition. Conceptual metaphors are the key connectors at the cognitive level. How is it that metaphor is such a powerful tool in our engagement with the world? An understanding of network structures can help answer the question. The following network structures provide simple models that can serve as maps of information flows (Newman, Barabási, & Watts, 2006).

Figure 5. The metaphoric loop of learning (new knowledge from new information) and creating (new knowledge from known information)(Gordon, 1961)

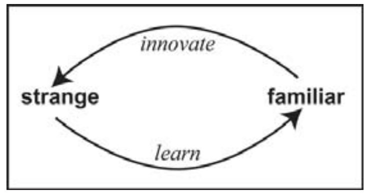
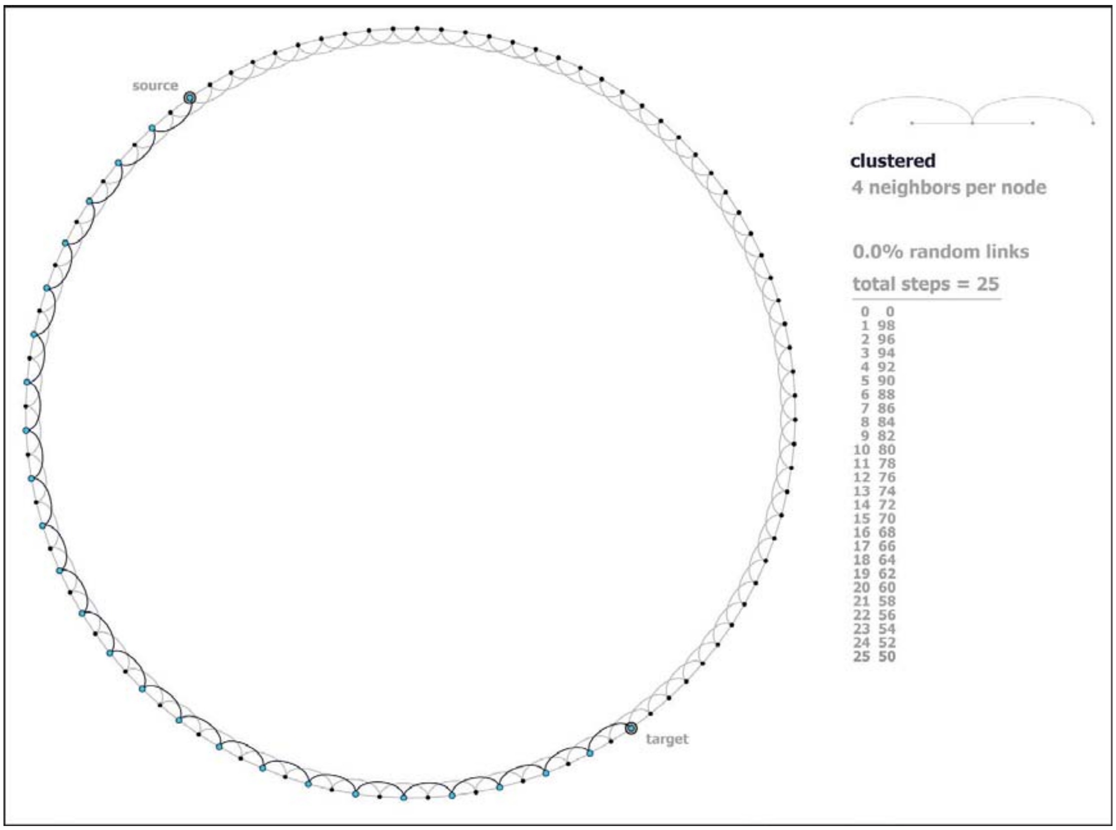


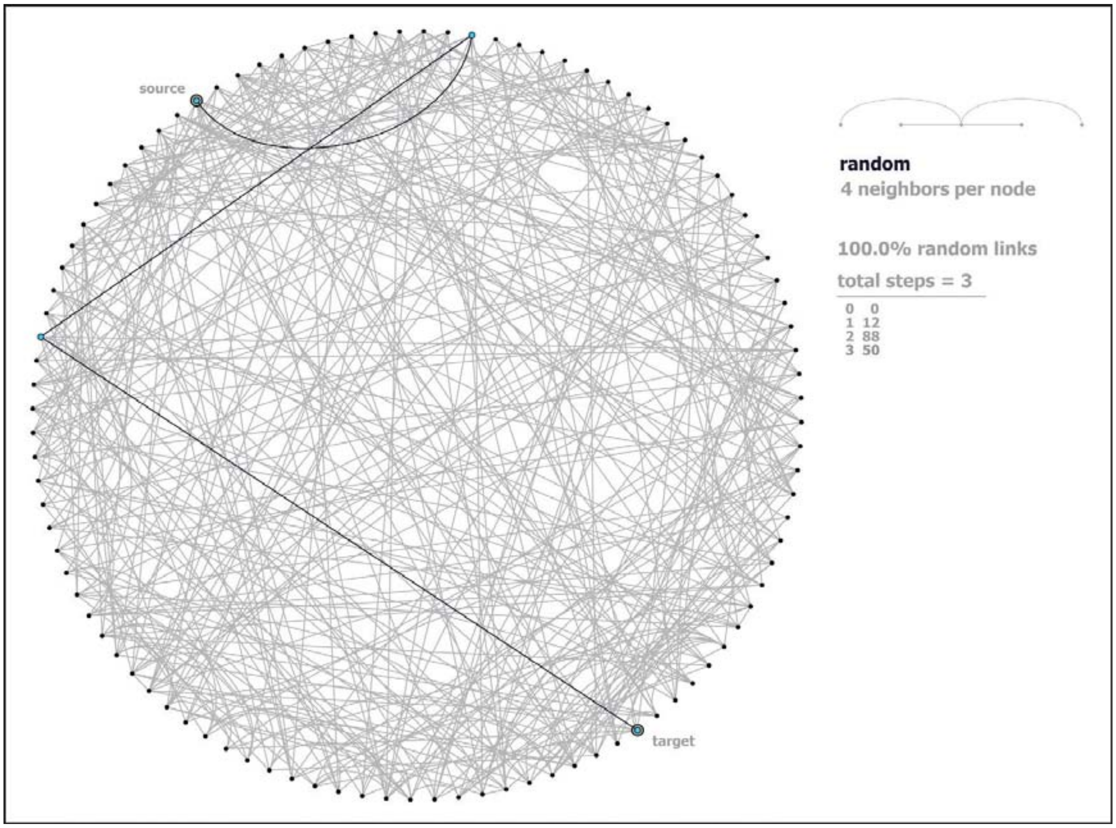
Figure 6. Graph of a100 node clustered network, showing the 25 steps needed to traverse the network from the source to the target. Clustered networks are highly structured but poorly connected



Clustered Networks (High Structure / Low Communication)

Figure 6 is an illustration of a clustered graph or network. The figure shows a network of one hundred agents or nodes, with each node connected to its four closest neighbors. A cluster shows a high structure of repetition as each node has many nodes in common with each linked neighbor. The clustered nodes could represent a close circle of friends or perhaps a group of wired neurons. What the graph shows is that while clusters are tightly structured, information does not flow through the network very effectively. To move a signal from the source node (#0) to the target node farthest away from the source (#50), will take at minimum twenty-five steps.

Figure 7. Graph of a 100 node random network, showing the 3 steps needed to traverse the network from the source to the target. Random networks are not very structured but highly connected



Random Networks (Low Structure / High Communication)

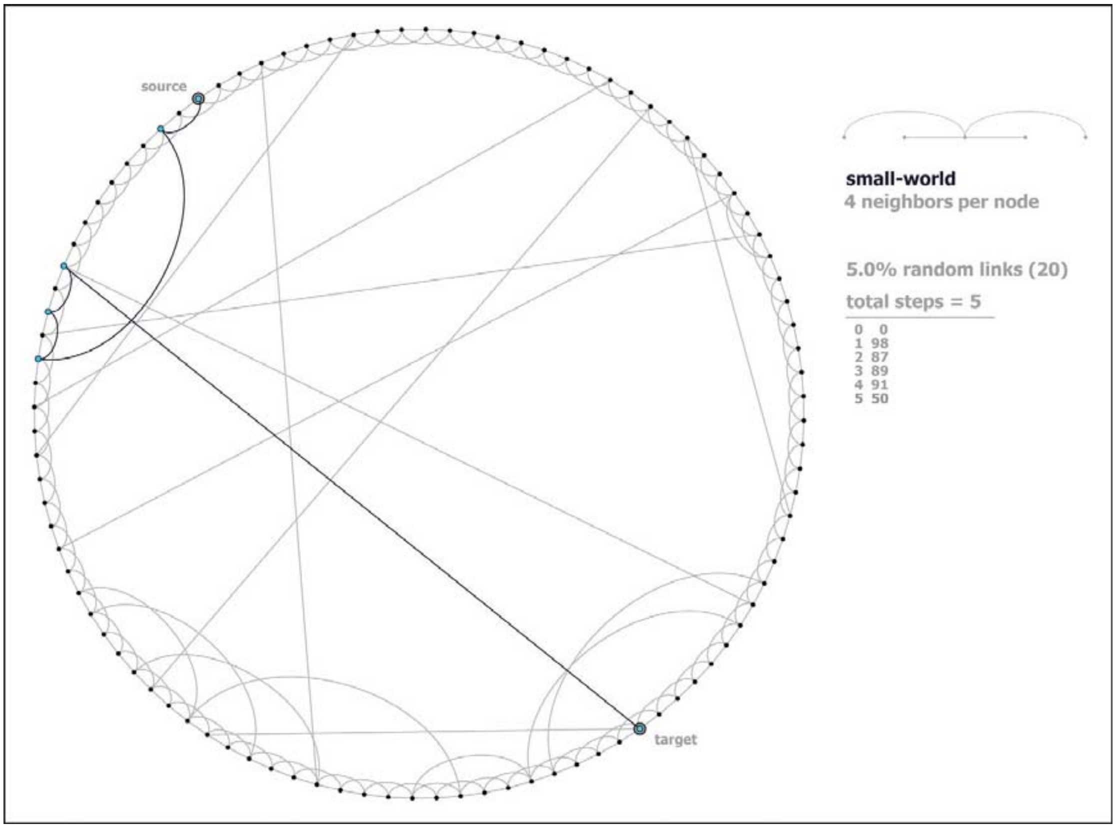
Figure 7 is an illustration of a random network, with properties that are exactly opposite those of a clustered network. Here each node is *randomly* linked to four other nodes. Linked neighbors will rarely have other nodes in common. Signals will move through this network with little coherence, but will traverse the network quickly as it is highly connected.

Small-World Networks (High Structure / High Communication)

A small-world network is one that is clustered and so highly structured, with just a small amount of randomness (Watts & Strogatz, 1998). Figure 8 is an illustration of a small-world network, based on the Watts and Strogatz model, with just 5% randomness in the links. Note that the network is nearly as effective as the random network in regards to moving a signal quickly through the network while nearly as structured as the original clustered graph. Evidence is growing that the neuronal networks of our brains are structured this way (Bassett & Bullmore, 2006). While most linking is clustered there are a small number of seemingly random connections as well.

Hebb's law states that "cells that fire together wire together" (LeDoux, 2002). Our brain's network is built on associations. Some associations have the appearance of randomness. However a connection is a pattern match. Pattern match means repetition, means structure. Some times what is repeating might be subtle, seemingly random when out of context. When two neurons are firing simultaneously a synaptic connection begins to form—two nodes of

Figure 8. Graph of a 100 node small-world network with 5% random links. This graph needs only 5 steps to traverse the network from the source to the target. This is an illustration of the unique nature of small-world networks, highly structured and highly connected



a network are linked and some essence of structure is recorded for later recall. The brain learns.

The Multi-Dimensional Utterance

A conceptual point on a picture plane requires at least six values to define it—the x,y coordinates of the diagonal of the plane and the x,y location of the point on the plane. If we are describing a visible point the number of defining dimensions needed grows dramatically. At a minimum we must specify color, shape, size, texture, location and so forth. *Any utterance is an expression in many, many quantifiable dimensions.*

As sensory information continues along the signal path any and all of the dimensions are potentially abstracted and they then traverse that path in parallel, eventually spreading through the dense networks in the brain. Any single dimension or combination of dimensions might fire another network of connections based on pattern matches. Maybe the color of the point is the color of a rose. Maybe it is egg-shaped, the size of a pinhead, a golf ball. Maybe it's rough like sandpaper, situated next to a similar point, but two inches to the right. Any one of the associations will set off their own unique set of neuronal connections.

Pattern matches are repetition hence they are structure. Patterns, dimensions, attributes, qualities, they are all mapped, as they are all processed along the experiential chain. They make other connections and other matches, which make more connections and more matches in the deeply recursive poetry that is the constant flow of human individual consciousness.

Metaphor as Connection and the Mechanism of Creativity

The human brain is made up of billions of neurons and trillions of synaptic connections (Edelman, 1992). We see in the structure of the small-world network the power of the metaphor as an efficient way to move signals through those trillions of connections in new configurations, showing us new ways to think about what we know. The "leap of intuition" the "aha moment" can be seen to be random links in our mostly clustered and highly structured brains. A primary means through which we can reason and through which we can imagine. A new idea is a neuronal circuit that we may not have noticed before (a forgotten memory, a weak link) or in our plastic brains a newly grown synaptic connection.

A pattern match fires through new or newly discovered circuits of neurons such that we attend to old knowledge in new ways or use new data to make new knowledge. As circuits fire the connections get stronger, firing more easily the next time. Eventually the wiring joins the cluster as part of the structured brain, no longer strange. New pattern matches or other forgotten memories continue to occur. These new associations, seemingly random links (to the clustered brain) empower us again to tap our creative potentials. The effectiveness of the small-world structure continues as long as we embrace the new and learn. Association, manifested within this small-world substrate, is recognized as an effective model of how we think and especially the neural process of "cognitive insight"—creativity (Schiller, 2005).

CONCLUSION

This brief excursion along the communication path shows the significance of abstraction and connection. These are the basis of the data map. Maps are metaphors and they provide a repetition of generalized aspects of an utterance across conceptual space. This repetition protects us from the phenomenological chaos around us. We are accosted by infinite amounts of data and information—way more that we can possibly process. Along the experiential chain what is useable for us in understanding the moment is a reduction and abstraction sent forward along the signal paths. We must make sense of things to function as living beings. Our sanity and survival depend on it.

A data map, manifested as a rich metaphor can enhance that process. We map the abstraction back into a sensory experience, making new metaphors and new maps. We make images. We make sounds. It is a constant process of feedback. Sometimes the feedback is loud and clear and necessary to make quick decisions or to excite quick action. Sometimes we see a more subtle mapping. We recognize the poetry of our existence as we find the resonances and understand the responsibilities we share with everyone and everything around us.

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