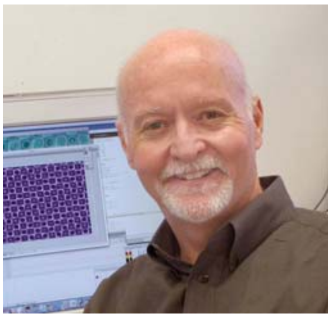
Brian Evans

Paper: **A Substrate for Creativity**



Topic: creativity, cognition, computation

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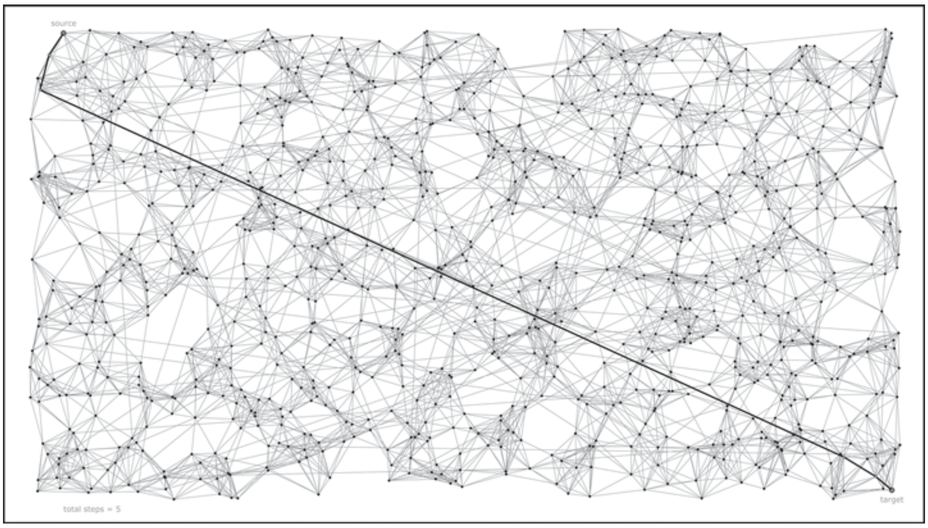
Abstract:

Hofstadter tells us that, “in regards to cognition analogy is everything.” [1] It follows then that creativity, a subset of cognitive processes, is also an exercise of analogic thinking, a process of pattern matching, building conceptual metaphors, “mapping across conceptual domains.” This process is fundamental to creativity, novelty and knowledge building. [2]

Systems science tells us “structure determines behavior.” Creativity, a basic behavior arising from our neural structure, is “the act of noticing patterns…making them visible in some kind of model, or theory, or poem, or sculpture.” [3] Patterns are noticed across some conceptual divide and manifested/mapped into physical form. The maps, the objects we make, are also conceptual metaphors, analogs of the real.

There are computational models that afford us the opportunity to see this structure, a substrate for the mechanisms of creativity. We can model and explore that substrate at many stages or levels, stretching from the complexities of human culture to the simple material movement of electrons. Behavior begins as the movement of ions, electro-chemical activity—signals moving though the complex networks of our brains. Eventually those signals manifest as social structures, human networks of action in the world. Interestingly both our created culture and our neural signaling have at their base this same process—pattern matching—built on small-world networks. [4, 5]

By modeling and visualizing this network structure, within some new topographies, we can investigate the process of finding the novel within the known, and see how a new idea is nothing more than effective way-finding through a dense network of connections—with each link simply an association, a pattern match.



A model of a small-world network with 1000 nodes, 10 links per node. With 99% linking to nearest neighbors and 1% random links, it is both structured and connected, taking only four steps from source to target. That “short-cut” is a model for the “aha” moment when we make the familiar strange, and see something in a new way.

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The Substrate of Creative Thought

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Abstract

The structures and processes of creative thought mirror the structures and processes of our neural networks. In creating and learning, the fundamental process is conceptual metaphor, where ideas, like neurons, connect based on matching patterns. The connections exist in clustered networks. What allows the subtle connections needed for novelty is a small amount of randomness within the linking—a small-world network structure results. Small-world networks are explained and illustrated. A new model of small-world network topography is also described and visualized. The model offers a substrate upon which creativity, understood as a neural process, can occur.

1. Introduction

There is a mechanism for creativity. We can explore that mechanism at many stages or levels across a wide expanse, stretching from the complexities of human culture to the simple material movement of electrons. Human behavior, working from perception and cognition, manifests as culture. That behavior begins as the movement of ions, electro-chemical activity—signals moving though the complex networks of our brains. Eventually those signals manifest as human action in the world. Interestingly both our created culture and our neural signalling have at their base the same process—pattern matching.

We can define creativity as "the act of noticing patterns…making them visible in some kind of model, or theory, or poem, or sculpture, so that the insights gained don't just float away." And "creative people don't just express themselves in metaphor, in analogy, they see and think in metaphor and analogy…" [1] Patterns are noticed across some conceptual divide and expressed as metaphor.

Hofstadter tells us that, "in regards to cognition analogy is everything." [2] It follows then that creativity, a subset of cognitive processes, is also as an exercise of analogic thinking and conceptual metaphor, building from the idea that metaphor "the mapping across conceptual domains" is fundamental for creative practice, novelty and knowledge building. [3]

2. The Loop of Learning and Innovation

A metaphor is a pattern match found between conceptually unlike things. It exists for us as a loop of desire that is the essence of being cognitively alive. The loop parallels our more basic desires for food, sleep, etc. Our survival instincts (materially existing as genetic neural structures) 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 through our senses to signals stored in our memory, 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. 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 search for knowledge is ongoing.

“The relation between what we see and what we know is never settled.” [4] This is a relation of the strange and the familiar—the loop of learning and creativity (manifested as innovation). See Figure 1.

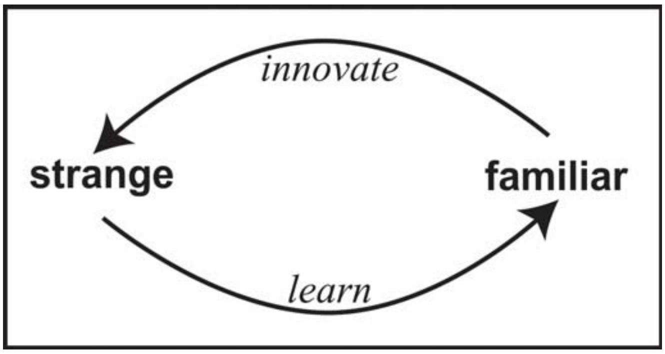

Figure 1: The metaphoric loop of learning (new knowledge from new information) and creating (new knowledge from known information). [5]

2.1 Learning

The tension inherent in desire is a motivation for learning. The fundamental mechanism for learning is analogic thinking through metaphor. 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.

The signals come from outside of us, entering through our senses. Signals are converted to data, stored in our short-term memory where the brain seeks to link the new patterns to patterns stored in memory. Pattern matches of new ideas, concepts and experiences become new network links, new synaptic structures in our plastic brains, allowing new paths for electro-chemical spikes to move from neuron to neuron. [6]

2.2 Creativity

Poet Stephen Spender reminds us, “All that you can imagine you already know.” Creativity is also a process in the metaphoric loop, but now the new connections are made within what we know. What is required is seeing the known in new ways—making the familiar strange. In developing “the creative habit…Metaphor is the lifeblood of all art, if it is not art itself.” [7]

A new idea is a new connection from old knowledge. Einstein saw light as a vehicle for space travel. Shakespeare compared his love to a rose. At the material level in the neuronal lattices within our cortex new links are made, built on the firing of a metaphor. New synapses create new pathways, connecting clusters of firing neurons—cognitive representations of things, ideas, objects and emotions.

3. Ideas, Neurons and Networks

There are models of signal flow and network structure that can help us understand how human activity demonstrates creativity. In particular is the small-world network structure, modeling well-connected and well-structured networks. Small-world networks use a small percentage of distant (random) connections among a large percentage of close, tightly clustered links. [8]

A clustered network is a model of ideas organized and incestuously linked within segregated conceptual domains. In an academic environment we can think of these clusters as disciplinary silos. To move beyond the closed thinking that can occur within these silos academic departments sometimes look outside, seeking the diversity of interdisciplinary connections—a social construction of a metaphoric link, with individuals as nodes in the network.

These connections to the outside can be modeled as a very small amount of random linking within the clustered structure. This small amount provides for a substantial increase in connectivity of the network, dramatically improving the odds of new connections (new ideas). This is the dual advantage of the small-world network structure—well organized and highly connected. Recent research in neuroscience indicates that this structure is present in our neural networks as well. [9,10] It would be a natural result of a selectionist model of brain morphology. [11] Computational approaches to this structure are also starting to appear, built primarily on the Watts and Strogatz model. [12]

The small world structure is a useful substrate for the creative linking of ideas and is also the structure of our brains. A small-world network of neurons is the material embodiment of idea flow, with the distant links allowing for novelty—“making the familiar strange.” The traces of signals through our neuronal networks are the materials of cognition. Conceptual metaphors are the key connectors at the cognitive level. These connectors exist as the distant links in the small-world substrate. This substrate can be easily modeled computationally.

3.1 Clustered Networks

Figure 2 is an illustration of a clustered graph or network built on a ring lattice. 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.

3.2 Random Networks

Figure 3 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.

3.3 Small World Networks

A small-world network is one that is clustered and so highly structured, but with a small amount of randomness. Figure 4 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 system, while nearly as structured as the original clustered graph. While most linking is clustered there are a very small number of random connections as well.

Hebb's law states that "cells that fire together wire together." [13] 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, which means structure. Sometimes 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 are linked and some essence of structure is recorded for later recall as metaphor. The brain learns.

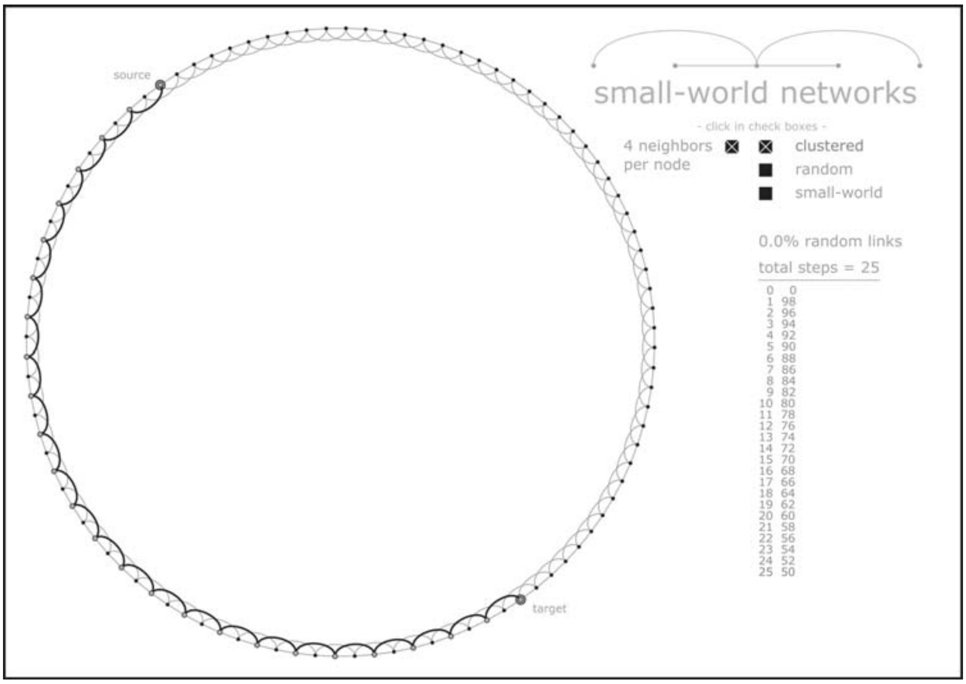

Figure 2: Graph of a 100-node clustered network, each node connected to its four closest neighbors. The bold line shows the 25 steps needed to traverse the network from the source to the target. Clustered networks are highly structured but poorly connected.

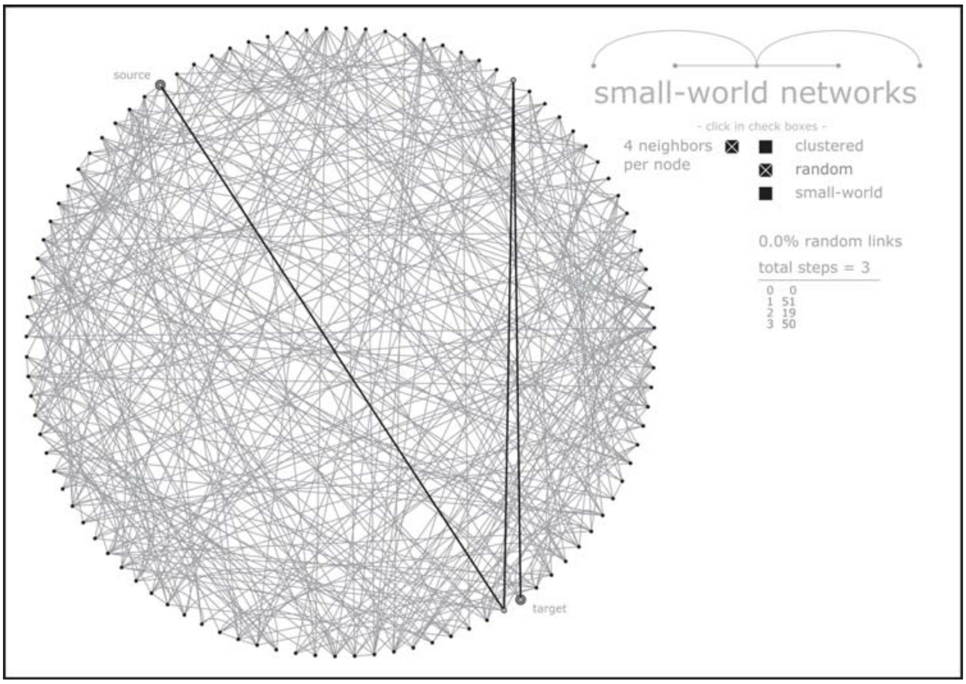

Figure 3: Graph of a 100 node random network with each node randomly linked to four others. This random network is poorly structured but highly connected, in this instance requiring only three steps to get from source to target.

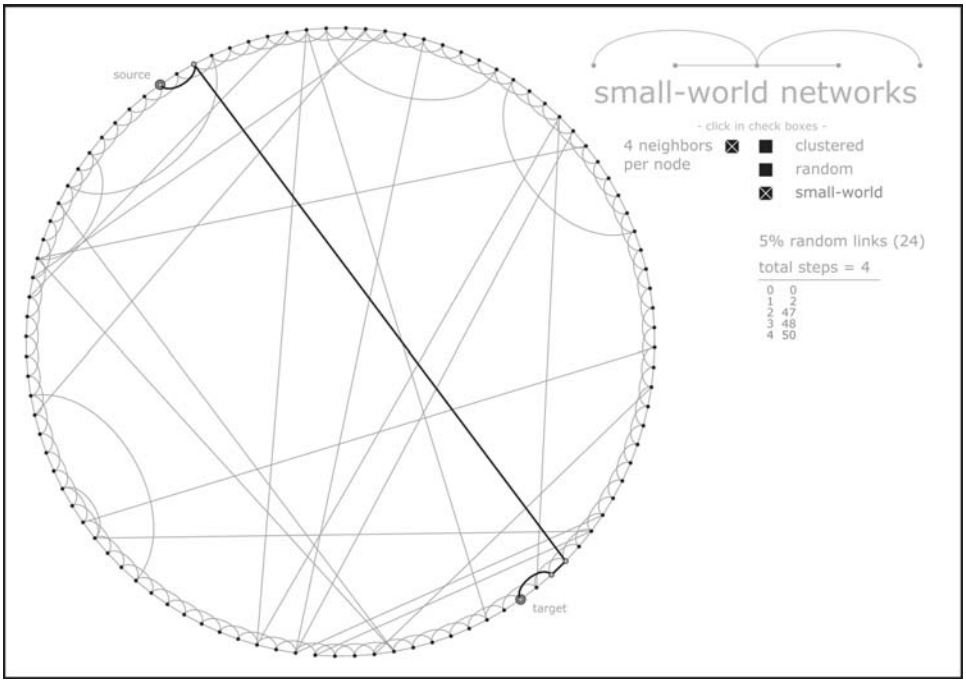

Figure 4: Graph of a 100 node small-world network, developed as a clustered network with approximately 5% random links. This network type provides all the benefits of a clustered (structured) network, with nearly the same connectivity as a random network. This instance requires only one link more that the random network to get from source to target.

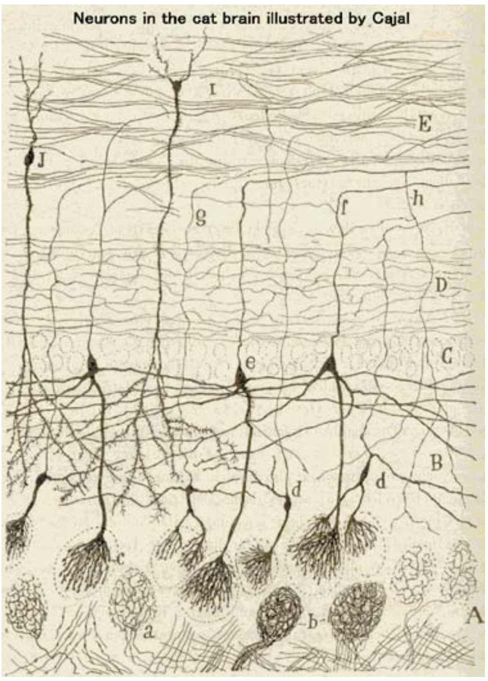

Figure 5: A rendering of a neuronal structure, illustrated by Ramón y Cahal nearly a century ago, that shows similarities to the ring lattice network topography.

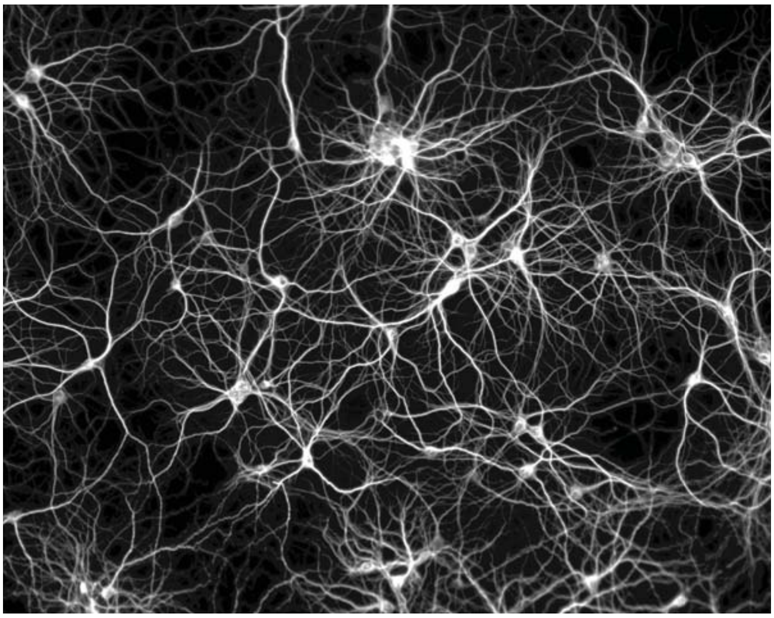

Figure 6: An illustration of neurons, evenly distributed in space. © Paul De Koninck, Laval University, www.greenspine.ca.

4. Creativity Substrates

The ring lattice is the basic topography used for the Watts and Strogatz network model. It is a convenient structure to illustrate the function of small-world networks, and it is possible to find the structure in the wiring of the brain, as illustrated by Ramón y Cahal's drawing of nearly a century ago, seen in Figure 5. [14] However, the simple geometry of the ring lattice is not the only useful structure from which to model and explore networks of conceptual domains or signalling neurons. There are other neuronal distributions within the brain to consider.

Figure 6 is microscopic picture of a neuronal tissue culture. While simple, it shows a more random (and oddly, as a result, more evenly spread) distribution of neurons. To build a clustered network, with nodes distributed in this way, the nodes link to other nodes in closest proximity. In a model of this topography, seen in Figure 7, there are 1000 nodes, placed randomly within the frame. Each node links to its ten nearest neighbors.

It is interesting to note in this model that, due to randomness in the topography of the nodes, the clustered network is more connected than the ring lattice. The clustered network illustrated requires thirty-three steps to get from the source to the target. If we built a ring lattice model with the same number of nodes and links it would require 100 steps to travel the same distance.

Figure 8 shows a rewiring of the network with 1% random links. The path from the source to the target is now only four steps! Again we see the effectiveness of adding a tiny amount of randomness into the network structure

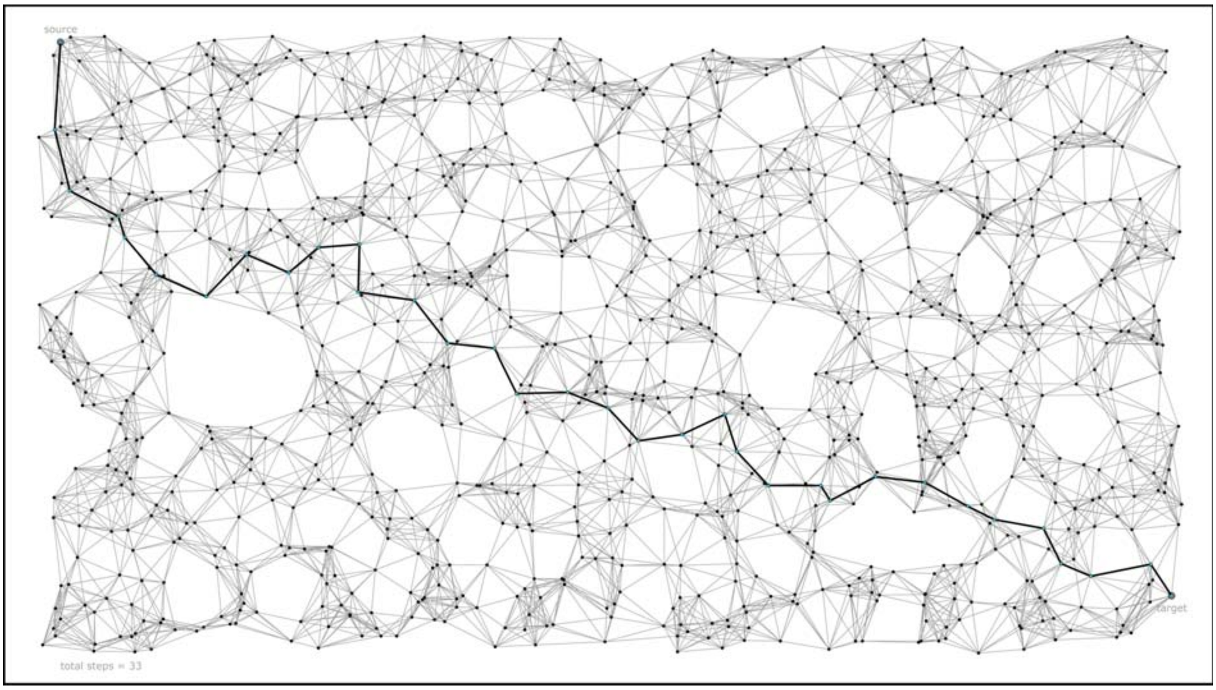

Figure 7: A clustered network of 1000 nodes, distributed randomly. Each node is linked to it 10 nearest neighbors. In the clustered network 33 steps are required to get from source to target—well structured, but not well connected.

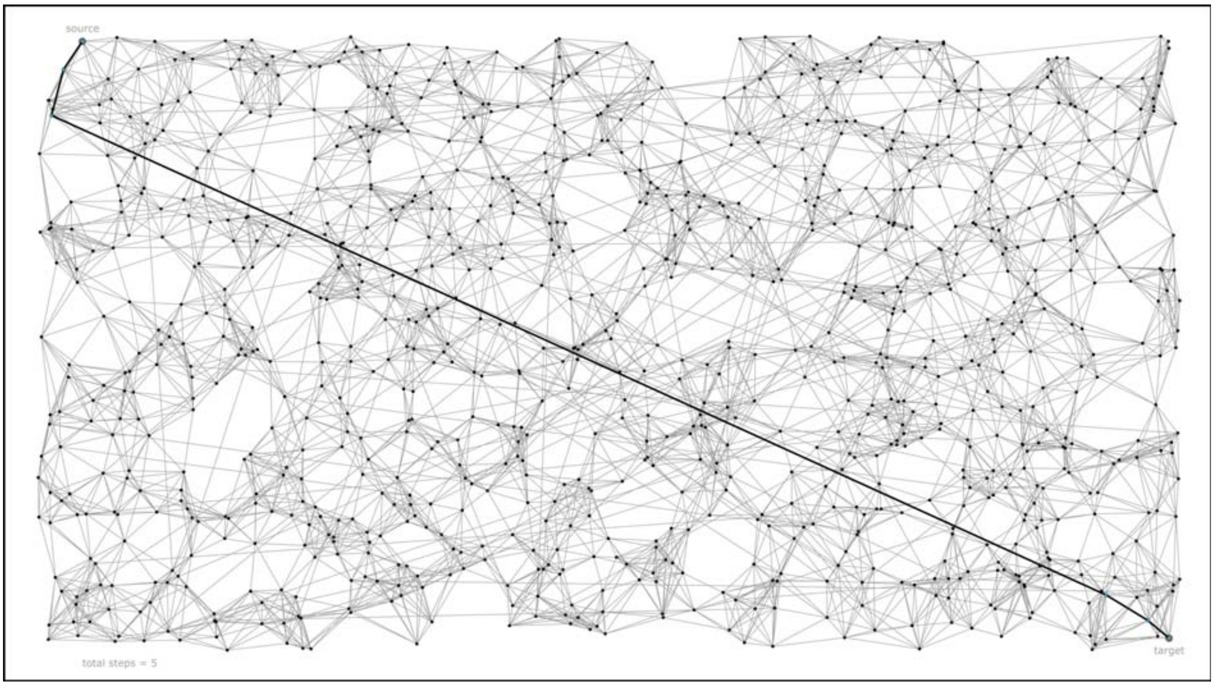

Figure 8: A small-world version of the 1000 node network. Both structured and connected, with 1% random links, it takes only 4 steps from source to target.

5. Way-finding in Small-worlds

These small-world networks illustrate a substrate upon which new metaphors can be found, and new neuronal connections can be made. Understanding this substrate is a first step in constructing models where not only a behavior of creativity can be emulated, but also the actual mechanisms for the behavior.

A big issue for further study is the fact that *having short paths through a network is not the same as knowing where those short paths are.* How might we parse this network structure to take advantage of its connectedness? How can we find our way through the tangles of the small-world? In considering the massive complexity of our brains the task is indeed daunting but necessary for creativity. Creative thought requires a substrate that allows for metaphor and then actually finding the metaphor (the proverbial “aha” moment). [15,16]

Neuroscience is paying new attention to other cells in the brain—the glia. [17,18] There are at least as many glia in the brain as there are neurons. Recent studies are finding that neuronal signals continue outside the synaptic gap and are carried as waves propagating through the brain outside the network of neurons. [19, 20] The external signals appear to be modulating neuronal activity throughout the network. Being able to impact the traversals of signals within a network from outside the network could significantly facilitate way-finding. As our models develop this points to one area of interest for future investigation.

6. Acknowledgements

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