To Trace a 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 visualized. 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.

Introduction

There is a mechanism for creativity. We can explore that mechanism at many stages or levels across many scales, stretching from the complexities of human culture to the simple material movement of electrons. Collective 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.

Hofstadter tells us that, “in regards to cognition analogy is everything [1].” Patterns are noticed across some conceptual divide and expressed as metaphors, building from the idea that metaphor—“the mapping across conceptual domains”—is fundamental to creativity, novelty and knowledge building [2].

Learning and Creativity

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 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 [3] [4].

Poet Stephen Spender reminds us, “All you can imagine you already know [5].” Creativity is also a metaphoric process, but now new connections are made within what we know. What is required is seeing the known in new ways—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.

Ideas, Neurons and Networks

There are models of signal flow and network structure that can help us understand creativity, especially the small-world network structure, modeling well-connected and well-structured networks. Small-world

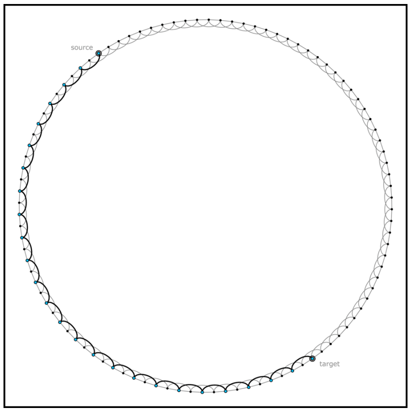

Figure 1: *clustered network*

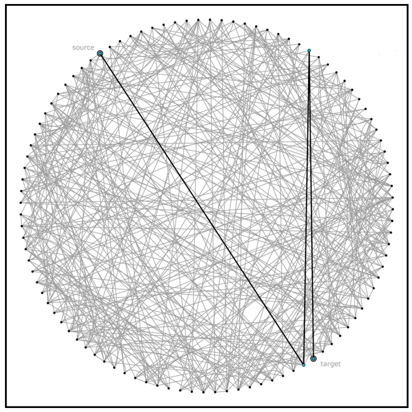

Figure 2: *random network*

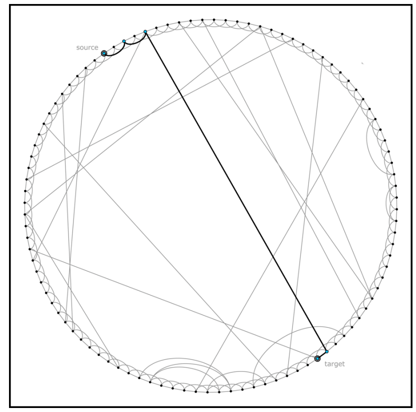

Figure 3: *small world network*

networks use a small percentage of distant (random) connections among a large percentage of close, tightly clustered links [6].

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 [7]. It would be a natural result of a selectionist model of brain morphology [8]. Computational approaches to this structure are also starting to appear, built primarily on the Watts and Strogatz model [9].

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.

Clustered networks. Figure 1 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 to the target node farthest away from the source, will take at minimum twenty-five steps.

Random Networks. Figure 2 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 can traverse the network quickly as it is highly connected.

Small world networks. A small-world network is one that is clustered and so highly structured, but with a small amount of randomness. Figure 3 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, "cells that fire together wire together [10]." 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 fire 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.

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 4 [11]. 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. One approach is to build a clustered network, with nodes distributed randomly in space and then linked to other nodes in closest proximity. Figure 5 shows a more random (and oddly, as a result, more evenly spread) distribution of neurons. In this model there are 1000 nodes, placed randomly within the frame. Each node links to its ten nearest neighbors. Again we see a high degree of structure but the network is not efficiently connected.

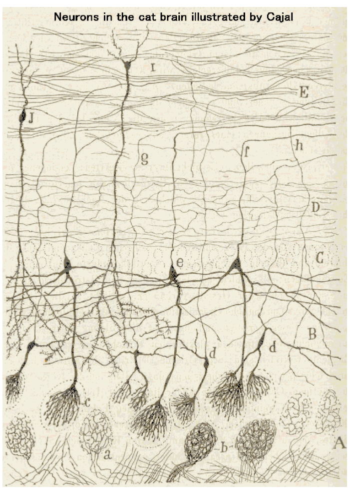

Figure 4: **a** *neuron drawing*

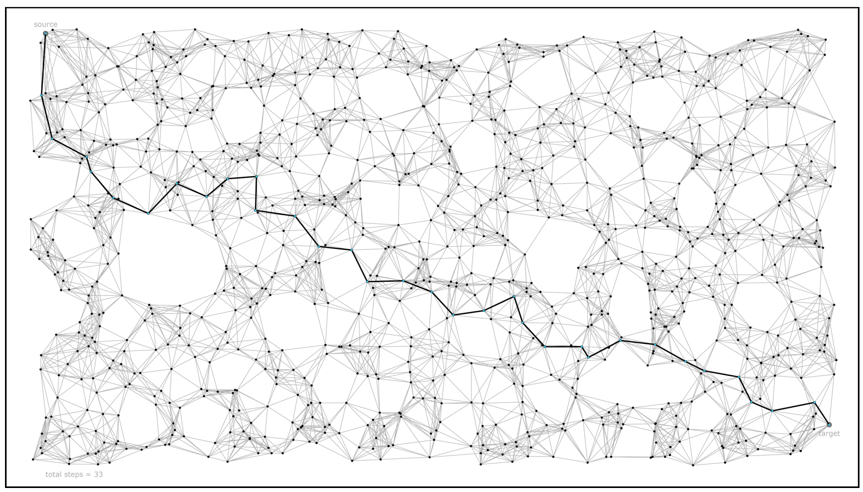

Figure 5: *a clustered network, 33 steps from source to target*

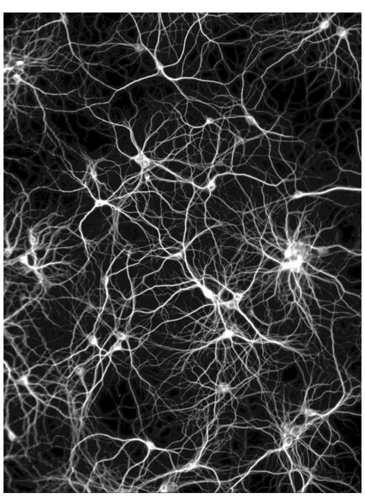

Figure 6: *a neural net*

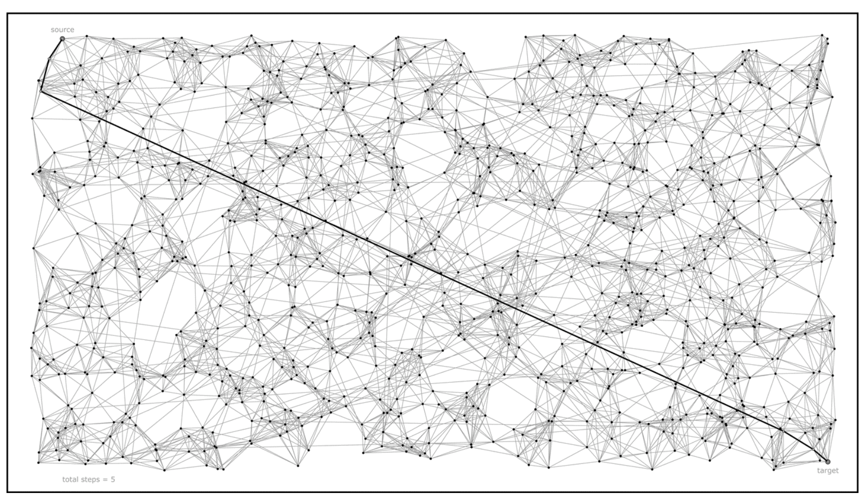

Figure 7: *small world network, 1% random links, 4 steps to the target*

It is interesting to note in this model that, due to the initial random placement 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. This topography is also a structure present in the brain, as seen by Figure 6 (© Paul De Koninck, Laval University, www.greenspine.ca).

Figure 7 shows a rewiring of this 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.

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 [12].

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 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) [13].

Acknowledgements

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