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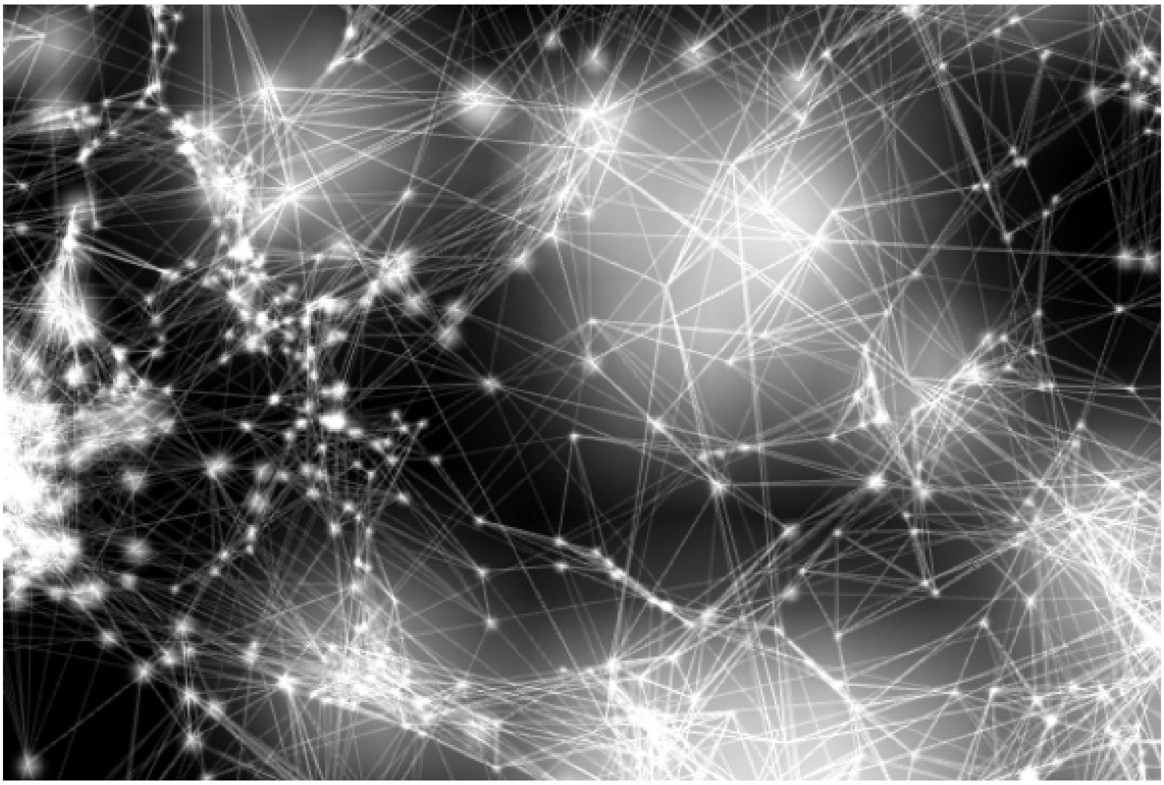
SA Visual

The Beautiful Complexity of the Cosmic Web

3D interactive visualization lets users explore the vast, hidden structure of the universe

STAFF | By Amanda Montañez on April 14, 2016



Scientists first discovered the so-called “cosmic web” less than a decade ago. Since then, various questions have lingered, perhaps foremost among them: What does the cosmic web look like? A new visualization by Kim Albrecht at the Center for Complex Network Research helps to address this intriguing mystery.

But first, let’s back up: What exactly is the cosmic web? In short, it is the vast network formed by all of the galaxies in the Universe and the web-like strands linking them together. Composed of invisible hydrogen gas filaments, these intergalactic connections make up the majority of ordinary matter in the Universe, and trace the distribution of dark matter as well.

To observe these cosmic threads directly is challenging, to say the least. Astrophysicists have managed to image enough pieces of the cosmic web that predicted models of its structure seem sufficiently reliable. Last year, the researchers behind the Illustris project used these models to construct a 2D simulation of the cosmic web, visualizing key data such as gas density, temperature, and velocity.

With Illustris as a foundation, visual researcher and information designer Kim Albrecht has now created an ambitious new 3D visualization of the cosmic web. Entitled “Network Universe,” Albrecht’s project builds on the Illustris simulation, taking it to a new level that is not just interactive, but immersive.

As I zoomed, panned, and rotated through Network Universe, I was immediately struck by the visual disparities among the three cosmic web “models” it presented. Where did these intriguing variations come from? The answer lay in the science on which the visualization was based.

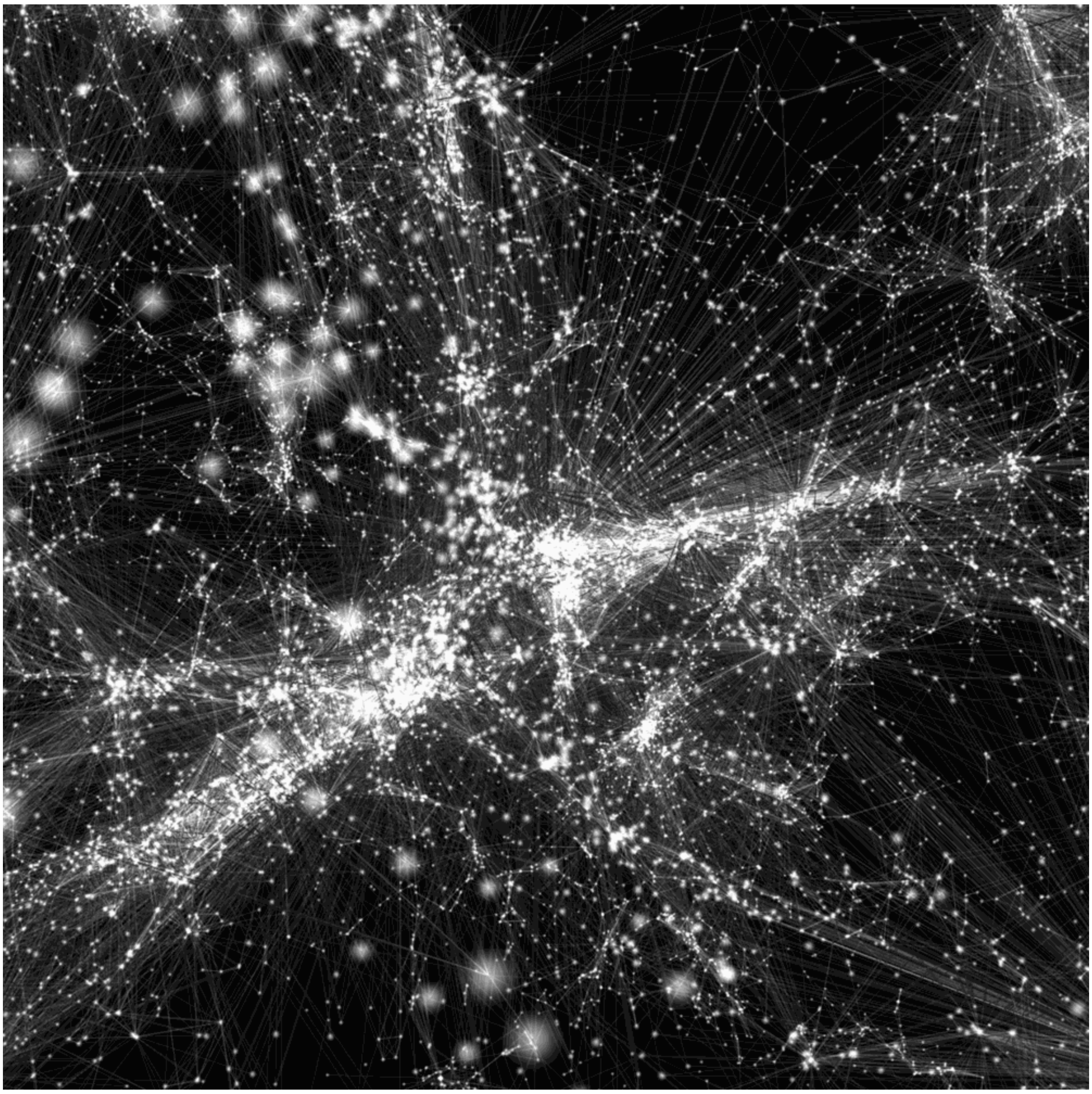
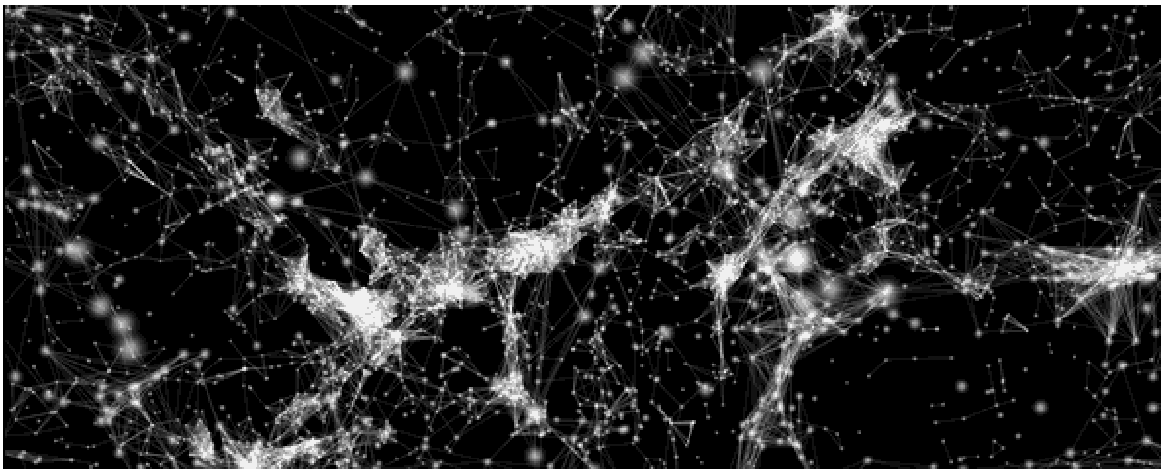
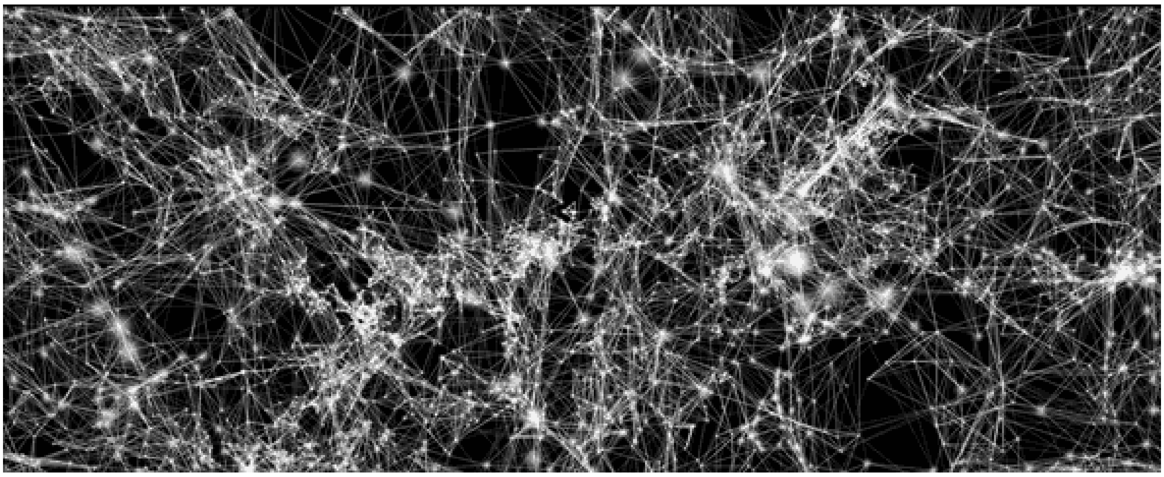


IMAGE FROM NETWORK UNIVERSE BY KIM ALBRECHT
CLICK IMAGE ABOVE TO LAUNCH



FIXED LENGTH MODEL

VARYING LENGTH MODEL



NEAREST NEIGHBORS MODEL

Albrecht's visualization was born of a collaborative research project aiming to evaluate various algorithms that might dictate the structure of the cosmic web. The three visual renditions of the network represent the three main models that were tested. The website offers a brief, one-sentence summary of each model, and the research paper breaks them down further into mathematical formulas. I'll admit, I glazed over when reading the formulas, and while the descriptions on the website were somewhat friendlier, I still struggled initially to understand the precise origin of what my eyes perceived. After some critical thought and an email exchange with Albrecht, answers began to solidify in my mind.

The Fixed Length Model is reasonably simple: All nodes (i.e. galaxies) within a given distance of one another are connected. Those nodes without any neighbors within that radius are on their own, while those with many neighbors have equally many connections. As a result, the visualization appears very dense in certain spots, where nodes are closely grouped, and quite sparse in others.

In the varying length model, things get a bit more complicated. Here, the larger the node, the longer its connections can reach. Smaller nodes can also form connections, but only to those relatively close to them. What results is a rich visual density characterized by extensive, overlapping strands and intense whiteness concentrated around the largest nodes.

Finally, according to the Nearest Neighbors Model, each node is limited to n links, and those links are shared only with those nodes closest to it. So, let's say $n = 3$. For some nodes, the three nearest neighbors will all be close by, while for others, they may be much farther. However, even for those with many neighbors, the number of connections cannot exceed three. Therefore, the visualization never becomes highly dense like either of its counterparts, and the distribution of white on black is relatively even throughout.

While all of the visualizations are beautiful and fun to explore, to me, there is something about Nearest Neighbors. The connection lines appear exceptionally clean, and there is a certain pleasant naturalness about the overall composition; a sense of randomness tempered by an overriding order. One might even compare it to certain structures in nature, such as neural networks in the brain, or a mesh of protein filaments.

Interestingly, as outlined in the research paper, it is the Nearest Neighbors Model that turns out to be the strongest in terms of its compatibility with actual observed characteristics of the cosmic web. While there is obviously much more science to explore around these results, the visual artist in me is satisfied with this outcome on its simple, poetic face. That which appears most beautiful to the human eye, and which indeed most closely resembles the stuff of which the human herself is made, just happens to be the truth.

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