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# Mapping Scientific Frontiers

## Ivars Peterson

How does a scientific field grow?

Several decades ago in his book *The Structure of Scientific Revolutions*, Thomas S. Kuhn argued that scientific discovery is characterized by several distinct stages. He defined "normal" science as a period in which the scientific community assumes that it "knows what the world is like." Scientists take great pains to defend these models of the world and tend to reject novel findings that appear to challenge the underlying assumptions.

At some point, challenges to the prevailing wisdom become strong enough to put science in crisis. The crisis is finally resolved with a transition from the old paradigm to a new, more compelling model. A scientific revolution occurs.

Looking centuries into the past, scientists and historians can readily identify significant paradigm shifts—turning points that put science on a new footing. It's much more difficult to detect and monitor such revolutionary changes in understanding as they happen amidst the hurly-burly of daily scientific exchange.

One way to try to get a handle on what's happening in a scientific field is to study citations in research papers. The idea is to look at which papers are cited together, then to represent those data as a network of nodes (articles) and links (articles appearing in the same reference list).

In a visualization of a complex network with many links, however, it can be very difficult to recognize significant patterns amid the clutter. Chaomei Chen of Drexel

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University in Philadelphia has developed a method for effectively visualizing such networks by reducing the number of links that must be shown and appropriately weighting the remaining ones while still preserving a given network's basic structure. Animation then allows him to study the evolution of these networks over time.

Consider the specialty of botulinum toxin research. The botulinum toxin is a potent poison produced by the bacterium *Clostridium botulinum*. Botulism, the medical condition caused by the toxin, was first systematically studied in the 1820s by a German medical officer, Justinus Kerner (1786–1862). The bacterium itself was first isolated and its toxin identified by Emile van Ermengen in 1897. Modern toxin research began with the culturing of the bacterium and isolation of the toxin in 1944, followed by the discovery in 1949 that the botulinum toxin blocks neuromuscular transmission.

Using citation records from 1945 to 2002, Chen found that he could characterize botulinum toxin research as a network that includes 516 nodes (papers cited together 10 or more times) and 19,631 links, for example. Another network that he derived from the data focused on prolific authors. Using such network representations, Chen could then identify various clusters, showing how the field has branched over the years, from early toxin research to medical uses of the toxin, gene studies, botulism disease and food spoilage, and so on.

Animated visualizations of the 58-year history of the field's growth vividly illustrate how these research clusters have emerged, spread, and branched out. Color coding and other techniques help spotlight research frontiers and significant changes in research direction.

"Intellectual structures of a knowledge domain before and after a major conceptual revolution are likely to be fundamentally different as new theories and evidence become predominant," Chen writes in an upcoming *Proceedings of the National Academy of Sciences*. In this paper, Chen describes further advances in his visualization techniques, implemented in a computer program he calls CITESPACE, that emphasize progressively visualizing the

evolution of network structures.

"In comparison to other methods for detecting changes of networks over time, our approach simplifies cognitively demanding tasks of comparing a sequence of network snapshots," Chen says. "The progressive visualization method allows us to focus on much simpler tasks of locating pivot nodes and cluster centers."

To show how his method works, Chen applied it to the field of superstring theory in physics, looking at citations from 1985 to 2002 (and a part of 2003). His panoramic visualizations, highlighting landmark or pivotal papers in the field, can be seen at
http://www.pages.drexel.edu/~cc345/citespace/Figure2.png, http://www.pages.drexel.edu/~cc345/citespace/Figure3.png, and
http://www.pages.drexel.edu/~cc345/citespace/Figure4.png.

Chen's visualizations successfully spotlighted groundbreaking articles that triggered two revolutions in superstring theory.

"The progressive visualization method introduced here has practical implications," Chen concludes. "It provides scientists with a roadmap of their own field."

It's a bit like watching a movie instead of reading the novel to get the gist of what's hot and what's not.

References and sources for this article

### References:

Chen, C. In press. Searching for intellectual turning points: Progressive knowledge domain visualization. *Proceedings of the National Academy of Sciences*. Abstract available at
http://www.pnas.org/cgi/content/abstract/0307513100v1.

_____. 2003. *Mapping Scientific Frontiers: The Quest for Knowledge Visualization*. New York: Springer Verlag.

Chen, C., and S. Morris. 2003. Visualizing evolving networks: Minimum spanning trees versus pathfinder networks. IEEE Symposium of Information Visualization. Oct. 19-21. Seattle. Available at http://www.pages.drexel.edu/~cc345/papers/infovis03.pdf.

Kuhn, T.S. 1962. *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press.

Chaomei Chen has a Web site devoted to his CITESPACE project at http://cluster.cis.drexel.edu/~cchen/citespace/.

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A collection of Ivars Peterson's early *MathTrek* articles, updated and illustrated, is now available as the Mathematical Association of America (MAA) book *Mathematical Treks: From Surreal Numbers to Magic Circles*. See http://www.maa.org/pubs/books/mtr.html.

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Comments are welcome. Please send messages to Ivars Peterson at ip@sciencenews.org.

Ivars Peterson is the mathematics/computer writer and online editor at *Science News* and *Science News for Kids*. He is the author of *The Mathematical Tourist*, *Islands of Truth*, *Newton's Clock*, *Fatal Defect*, *The Jungles of Randomness*, and *Fragments of Infinity*. He also writes for the children's magazine *Muse*. He is coauthor of the children's books *Math Trek: Adventures in the MathZone* and *Math Trek 2: A Mathematical Space Odyssey*.

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