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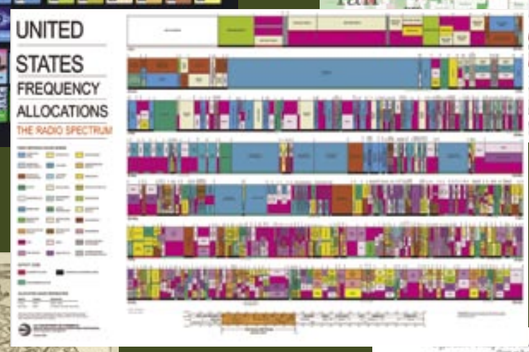

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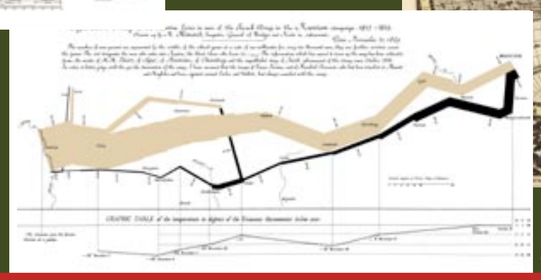

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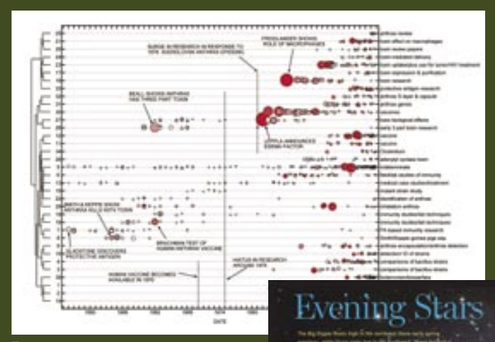

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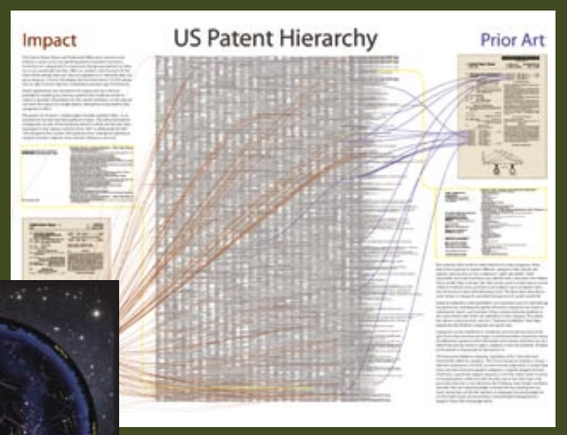

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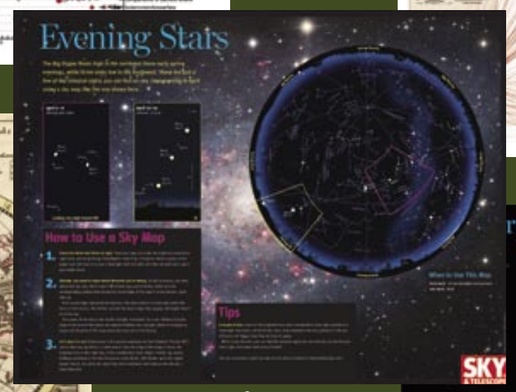

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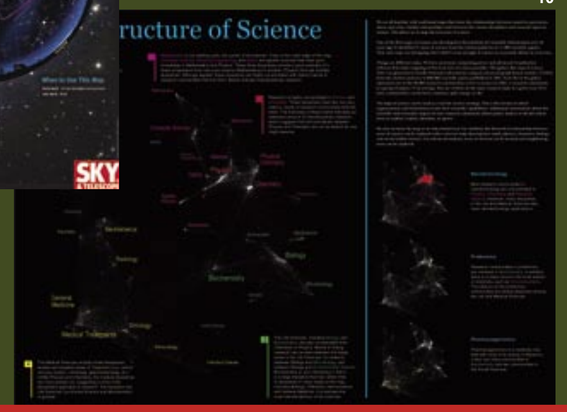

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1 **Visual Elements Periodic Table, by Murray Robinson (Illustrator) and John Emsley (Chemist). London, 2005.** *Courtesy of the Royal Society of Chemistry. Images © Murray Robertson 1999–2006*

2 **Cosmographia World Map, by Ptolemy. Ulm, Germany, 1482.** *Courtesy of the James Ford Bell Library, University of Minnesota, Minneapolis*

3 **U.S. Frequency Allocations Chart, by the National Telecommunications and Information Administration. Washington, D.C., 2003.** *Courtesy of the Office of Spectrum Management*

4 **Treemap View of 2004 Usenet Returnees, by Marc Smith. Redmond, Washington, 2005.** *Courtesy of the Community Technologies Group, Microsoft Research*

5 **Napoleon's March to Moscow, by Charles Joseph Minard. Paris, 1869.** *Courtesy of Edward Tufte, Graphics Press, Cheshire, Connecticut*

6 **A New Map of the Whole World with the Trade Winds According to the Latest and Most Exact Observations, by Herman Moll. London, 1736.** *Courtesy of the David Rumsey Map Collection, Cartography Associates, San Francisco, California*

7 **Timeline of 60 Years of Anthrax Research Literature, by Steven A. Morris. Stillwater, Oklahoma, 2005.** *Courtesy of Steven A. Morris, Oklahoma State University, Stillwater*

8 **Taxonomy Visualization of Patent Data, by Katy Börner, Elisha Hardy, Bruce Herr, Todd Holloway, and W. Bradford Paley. Bloomington, Indiana, and New York, 2006.** *Courtesy of Indiana University and W. Bradford Paley*

9 **Sky Chart of New York City in April 2006, by Roger W. Sinnott and Interactive Factory. Cambridge, Massachusetts, 2006.** *Courtesy of Sky & Telescope*

10 **The Structure of Science, by Kevin W. Boyack and Richard Klavans. Albuquerque, New Mexico, and Berwyn, Pennsylvania, 2005.** *Courtesy of Kevin W. Boyack, Sandia National Laboratories and Richard Klavans, SciTech Strategies, Inc.*

Today, mankind's scholarly knowledge is stored in an exponentially increasing number of papers, books, emails, and other formats. Neither man nor machine can process this enormous amount of data.

Hence, most knowledge gets reinvented, is duplicated across sciences, or is simply lost forever after a short period of time. To survive as a species, we need to utilize our collective knowledge to preserve our planet. Our aim beyond survival should be to enable every human being to live a healthy, productive, and fulfilling life.

Search engines help us retrieve facts from a vast and growing sea of information. Yet many questions remain: How big is this sea? How can we efficiently navigate to the useful islands of knowledge? How is knowledge interlinked on a global scale? In which areas is it worth investing resources? Answers to questions such as these are not readily apparent.

Cartographic maps of physical places have guided mankind's explorations for centuries. They enabled the discovery of new worlds while also marking territories inhabited by the unknown. Without maps, we would be lost.

Domain maps of abstract semantic spaces aim to serve today's explorers navigating the world of science. These maps are generated through a scientific analysis of large-scale scholarly datasets in an effort to connect and make sense of the bits and pieces of knowledge they contain. They can be used to identify objectively major research areas, experts, institutions, collections, grants, papers, journals, and ideas in a domain of interest. Science maps can provide overviews of "all-of-science" or of a specific area. They can show homogeneity vs. heterogeneity, cause and effect, and relative speed. They allow us to track the emergence, evolution, and disappearance of topics and help to identify the most promising areas of research.

The *Places & Spaces* exhibit has been created to demonstrate the power of maps. The exhibit has two components. The physical component is available for display at conferences and education centers and allows for close visual inspection through high-quality prints. It is meant to inspire cross-disciplinary discussion on how best to track and communicate human activity and scientific progress on a global scale. The online counterpart at **http://vw.indiana.edu/places&spaces** provides links to a selected series of maps and their makers along with detailed explanations of why these maps work. Ten iterations of the exhibit are planned as part of a larger effort to develop maps of science for both experts and the general public alike. We welcome your feedback and comments.

The exhibition here in Healy Hall at The New York Public Library, Science, Industry and Business Library (SIBL) shows the first and second iterations of the exhibit as well as collaborative works by New York–based artists W. Bradford Paley, Digital Image Design Inc. and Columbia University, and Ingo Günther.

Places & Spaces is curated by Dr. Katy Börner, School of Library and Information Science at Indiana University, and Deborah MacPherson, Projects Director of the nonprofit organization Accuracy&Aesthetics in Vienna, Virginia. *Places & Spaces* also receives input from the Advisory Board listed on the website. John Ganly, Assistant Director for Collections at SIBL, is adviser for the exhibit.

Places & Spaces is sponsored by National Science Foundation awards IIS-0238261 and CHE-0524661; Thomson Scientific; The New York Public Library, Science, Industry and Business Library; InfoUSA; Thomson Gale; the Cyberinfrastructure for Network Science Center, University Information Technology Services, and the School of Library and Information Science, all three at Indiana University. Much of the data used to generate the science maps is from Thomson ISI.

TO SEE MORE MAPS, visit the newly renovated Lionel Pincus and Princess Firyal Map Division at The New York Public Library's Humanities and Social Sciences Library, Fifth Avenue and 42nd Street, and the special exhibition *Treasured Maps*, on view until May 14, 2006. For more information, visit **www.nypl.org**.

HOURS Sunday and Monday: Closed
Tuesday–Thursday: 10 a.m.–8 p.m.
Friday–Saturday: 10 a.m.–6 p.m.

The New York Public Library
Science, Industry and Business Library
188 Madison Avenue, New York, NY 10016

The exhibit is in Healy Hall, on the Lower Level.

The New York Public Library
www.nypl.org

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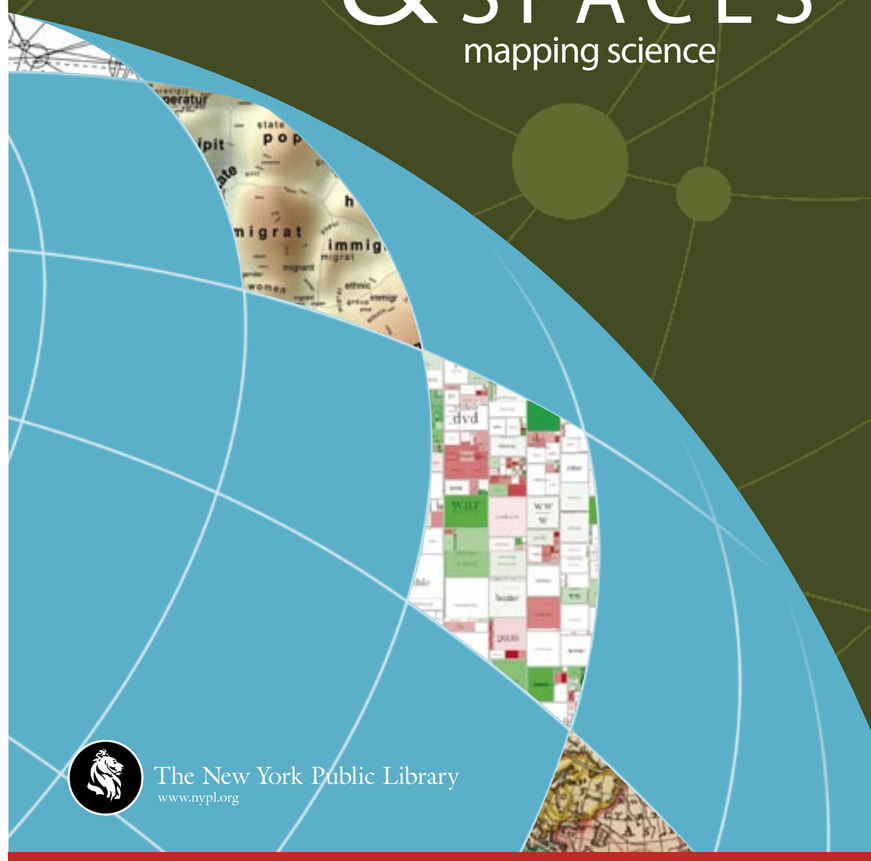
places & SPACES
mapping science



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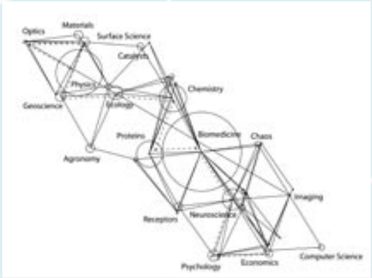
Ph.D. Thesis Map, by Keith V. Nesbitt. Newcastle, Australia, 2004. *Courtesy of IEEE and Keith V. Nesbitt, Charles Sturt University, Australia. © 2004 IEEE*

DR. KEITH V. NESBITT is a lecturer in the School of Information Technology at Charles Sturt University in Bathurst, Australia. This hand-drawn map, based on the *London Metro Map*, shows the interconnecting ideas that run through his Ph.D. thesis. Each separate "track of abstract thought" is given in a different color. Related ideas correspond to category stations along that track. Overlapping ideas are shown as connected stations. The thesis concerns the design of multisensory displays of abstract data with the motivation of mining this abstract data. The familiarity of metro maps makes the diagram easy for readers to interpret. The space in which the tracks are laid out has no meaning, so it is possible to read the map in any direction. However, there is a cultural bias for the tracks to be followed from left to right and top to bottom.

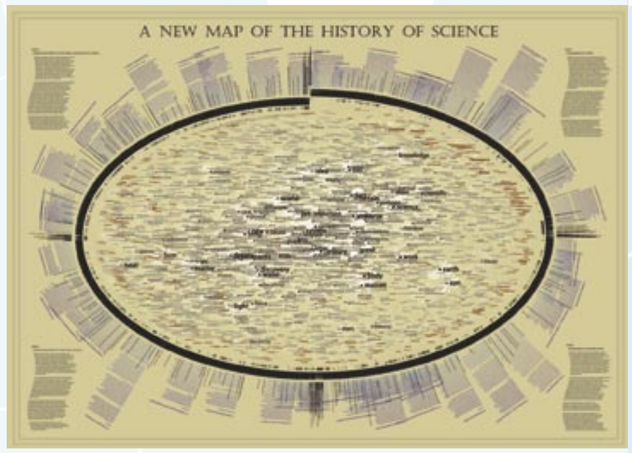
1996 Map of Science: A Network Representation of the 43 Fourth-Level Clusters Based on Data from the 1996 Science Citation Index, by Henry Small. Philadelphia, 1999. *Courtesy of Henry Small, Thomson ISI*

DR. HENRY SMALL has pioneered an approach to mapping the structure of science, year by year, based on scholarly publications yet independent of existing disciplinary categories. The very first map of all of science is shown here. A combination of fractional citation counting and co-citation clustering via multidimensional scaling was used to extract four nested levels of clustering via single and complete linkage. Major disciplines of science emerge from a bottom-up aggregation of highly cited papers. They are displayed in two dimensions, using an order-dependent, geometric triangulation process that produces a unified hierarchical arrangement of documents. Each circle contains a map of similar construction at a lower level of aggregation. Circle size corresponds to the number of citations received by documents in each cluster. Links among circles represent aggregate document co-citations. The original map facilitated the interactive exploration of the nested hierarchy of scientific disciplines.



TextArc Visualization of "The History of Science," by W. Bradford Paley. New York, 2006. *Courtesy of W. Bradford Paley*

W. BRADFORD PALEY approached making a map of science indirectly, by making a map of a book describing *The History of Science*. In this way, he leveraged the intelligent organization by Henry Smith Williams (the history's author): this map was created more to take advantage of a culturally recognized way of organizing science than to invent a new one. The history's first two volumes are organized strictly historically, so as the book wraps around the right side of the ellipse it is organized as a time line. The next two volumes distinguish two major domains—making two time lines—for more recent scientific exploration: the physical sciences (along the bottom left) and the life sciences (top left). Since the scattered words are pulled toward the places where they are used in the text (see the map itself for a better description of the layout), structure emerges: names of individuals appear along the outside, as they are usually mentioned in only one or two places, and concepts that are common to science of all eras (e.g., system, theory, experiment) are pulled to the center, as they are mentioned everywhere. Even more fascinating, subjects that provided the main focus for certain eras float not near the specific edges nor the general center, but in a local, topical band between the two (e.g., mind, knowledge, and conception during the philosophic beginnings of science; moon, Earth, sun, and stars somewhat later; electricity, light, and forces in the recent physical sciences; and animals, disease, development, and brain in the recent life sciences).



Nova Anglia, Novvm Belgivm et Virginia, by Jan Jansson. Amsterdam, Holland, 1642. *Courtesy of the Library of Congress, Geography and Map Division, Washington, D.C.*

JAN JANSSON was one of the first Europeans to create maps of the New World. Two maps from this era became prototypes, the 1612 map of Virginia by John Smith and the 1651 map of New England by Jansson. Their general layouts were extensively copied from one mapmaker to another. This map is based on De Laet's rare map of 1630 and is actually the third iteration of Jansson's 1636 *Nova Anglia, Novvm Belgivm et Virginia*. This map was influential because it showed all of the current Dutch holdings from New England to Virginia. It is widely considered to be one of the first maps to contain the place name "Masachusets." It also depicts "New Amsterdam" (New York), which was founded less than 20 years prior. Europeans' increased interest after 1600 in the colonization of North America is concisely shown in this map and developed partially *because of* it.

In Terms of Geography, by André Skupin. New Orleans, Louisiana, 2005. *Courtesy of André Skupin. University of California, San Diego*

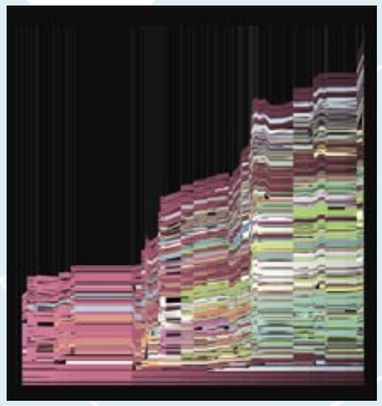
DR. ANDRÉ SKUPIN is an Assistant Professor of Geography at the University of California, San Diego. His research interests focus on geographic visualization, cartographic generalization, data mining, and information visualization. This map is a visualization derived from more than 22,000 abstracts submitted to the Annual Meetings of the Association of American Geographers during a ten-year period, 1993–2002. The methodology is centered around the representation of each document as an n-dimensional vector of terms. These vectors are used to construct a neural network model of the geographic knowledge domain using the Self-Organizing Map (SOM) method. The neural network is then transformed into two types of information: (1) a landscape in which elevation indicates the degree to which a single, focused topic is addressed; and (2) multilevel text labels associated with regions in the visualization. The final rendering was executed in standard geographic information systems (GIS) software.

HistCite™ Visualization of DNA Development, by Eugene Garfield (HistCite), Elisha Hardy and Katy Börner (Graphic Design), Ludmila Pollock (Images), and Jan Witkowski (Text). Philadelphia; Bloomington, Indiana; and New York, 2006. *Courtesy of Eugene Garfield, Thomson ISI, Indiana University, and Cold Spring Harbor Laboratory*

DR. EUGENE GARFIELD, founder of the Institute for Scientific Information (ISI), introduced "The Use of Citation Data in Writing the History of Science" in 1964. Forty years later, his HistCite™ tool automatically generates chronological tables and historiographs of topical paper collections. It helps researchers, librarians, and others to identify core papers on a topic in question; to understand the impact of specific authors, papers, and journals; and to make sense of the history of old and new research topics. The HistCite tables support the interactive display and permit sorting of papers chronologically as well as by journal, volume, issue number and page, and citation scores. In addition, the tool helps to find papers missing from the initial search and gives easy access to full citation records. The historiographic view reveals citation patterns among major core papers. Nodes on the maps represent papers and are displayed in chronological order. Node sizes denote the relative number of citations each core paper has received. Edges represent citation linkages. The colored map shows his 1964 rendering of key articles in the history of DNA from Gregor Mendel in 1865, to Marshall Nirenberg in 1961, to the Watson-Crick paper on the helical structure of DNA in 1953. The manually compiled Historiograph is contrasted with an automatically generated HistCite graph of key papers citing the 1953 primordial Watson-Crick paper. The interactive version and other HistCite examples can be found at **www.histcite.com**.

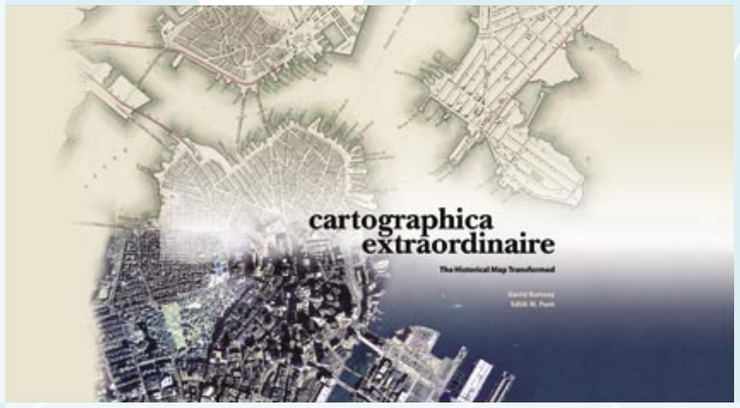
History Flow Visualization of the Wikipedia Entry on "Evolution," by Martin Wattenberg and Fernanda B. Viégas. Cambridge, Massachusetts, 2006. *Courtesy of Martin Wattenberg, Fernanda B. Viégas, and IBM Research*

DR. MARTIN WATTENBERG, at IBM Watson Research Center in Cambridge, Massachusetts, and Dr. Fernanda B. Viégas, formerly with MIT Media Laboratory and now at IBM, designed the History Flow visualization technique. History Flow provides a clear view of complex records of contributions and collaboration. Among other uses, it can be applied to show the evolution of documents, e.g., Wikipedia entries created by people all over the world. The map shows the edit history of the Wikipedia entry on "Evolution." The left column lists all authors who contributed to the entry and their assigned color codes. The right column shows the final version of the entry, color-coded according to the author of the final edit. The middle column gives the History Flow visualization. Each vertical line represents a version of the entry. The length of the line reflects the length of the entry. Line color-coding indicates which author edited the page. Entry versions are sorted in time, from left to right. As can be seen, the page has gone through many minor and major changes over time and is continuously growing in length.



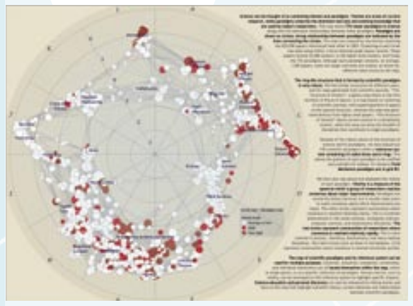
***Cartographica Extraordinaire: The Historical Map Transformed*, by David Rumsey and Edith M. Punt. San Francisco, California, and Montreal and Nova Scotia, Canada, 2004.** *Courtesy of ESRI Press. Copyright © 2004 David Rumsey, ESRI, DigitalGlobe Inc., MassGIS. All rights reserved*

DAVID RUMSEY'S collection of historical maps is one of the largest and most complete of its kind. Focused for the most part on North and South America in the 18th and 19th centuries, the collection comprises more than 150,000 items: maps, atlases, and contextual supporting documents. Unlike similar collections, the delicacy and rarity of which necessitate careful storage and restricted-use policies, maps in the David Rumsey Collection are available in growing numbers on the Web at **www.davidrumsey.com**. The conjunction of old and new technologies is the heart of *Cartographica Extraordinaire*. The maps selected for *Cartographica Extraordinaire* tell a hundred distinct, exciting, important, and sometimes controversial stories, along two main paths of inquiry: how did a continental wilderness become a civilization, and how has the development of cartographic science changed the ways we perceive, describe, study, and use that land? Geographic information systems (GIS) have come, as part of the digital revolution, to dominate the cartography of today. But GIS didn't leap into being out of nothing; all its processes and capabilities have precursors in historical maps. Old maps can therefore tell us not only the stories of their subject matter, but stories about the nature of mapmaking as well: its exigencies and limitations, trends and developments—its theory and practice and what that tells us about the people we were, are, and will be. The book is available from ESRI Press at **www.esri.com**.



Map of Scientific Paradigms, by Kevin W. Boyack and Richard Klavans. Albuquerque, New Mexico, and Berwyn, Pennsylvania, 2006. *Courtesy of Kevin W. Boyack, Sandia National Laboratories and Richard Klavans, SciTech Strategies, Inc.*

DR. KEVIN W. BOYACK is in the Computation, Computers, and Mathematics Center at Sandia National Laboratories. Richard Klavans is with SciTech Strategies, Inc. They are interested in the mapping of science as a platform for planning and evaluation on the national, corporate, and personal levels. Science can be thought of as containing themes and paradigms; themes are current areas of research, while paradigms comprise the dominant tool sets and existing knowledge that are used by current researchers. To generate this map, Boyack and Klavans recursively clustered (using the VxOrd graph layout tool) the 820,000 most important papers referenced in 2003, resulting in 776 paradigms. The most dominant relationships between paradigms were also



calculated and are shown as lines between paradigms. The map of scientific paradigms comprises a reference system that can be used for multiple purposes. Countries, industries, companies, and individual researchers can all locate themselves within the map, either as single points, or as a specific collection of paradigms. Science education and discovery can also be enhanced by linking to the map stories and facts that highlight content and relationships between scientific paradigms.

WORLDPROCESSOR: Zones of Invention—Patterns of Patents, by Ingo Günther. New York, 2006. *Courtesy of Ingo Günther*

INGO GÜNTHER, a sculptor and media artist, is a visiting professor at the Tokyo National University for Art and Music. Over the last 15 years he has mapped social, scientific, political, and economic data on globes as navigational guides in a globalized world. The Worldprocessor-globe here plots the total number of patents granted worldwide, beginning in 1883 with just under 50,000, hitting 650,000 in 1993 (near the North Pole), and (shifting the scale to the southern hemisphere) continuing to 2002 on a rapid climb toward 1 million. Geographic regions where countries offer environments conducive to fostering innovation are represented by topology. Additionally, nations where residents are granted an average of 500 or more U.S. patents per year are called out in red by their respective averages in the years after 2000.