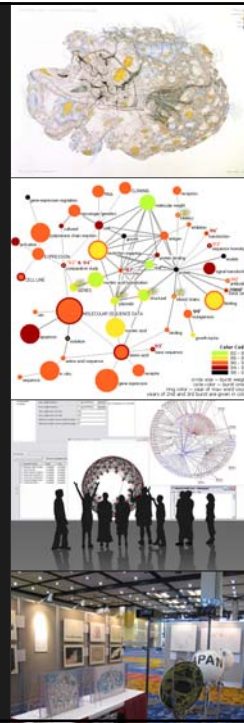


Mapping the Evolution of Science



Dr. Katy Börner
Cyberinfrastructure for Network Science Center, Director
Information Visualization Laboratory, Director
School of Library and Information Science
Indiana University, Bloomington, IN
katy@indiana.edu

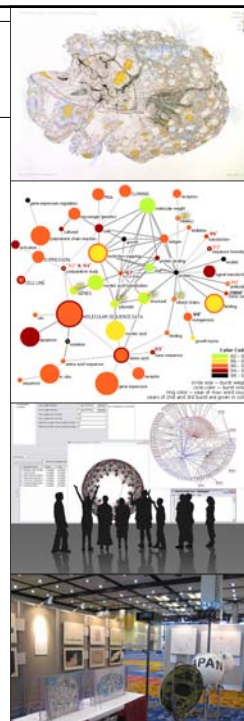
*Heraeus Seminar on the Evolution of Physics, Bad Honnef, Germany
January 22, 2008*


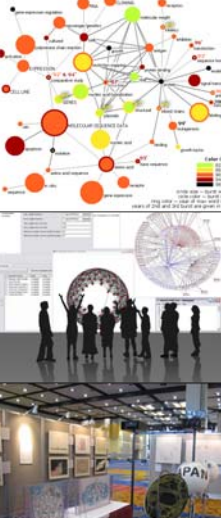


Overview

- Concepts -> Conceptualization
- Models -> Descriptive Models
-> Process Models
- CI Design -> IVC, NWB, SDB
- Communication -> "Mapping Science" Exhibit

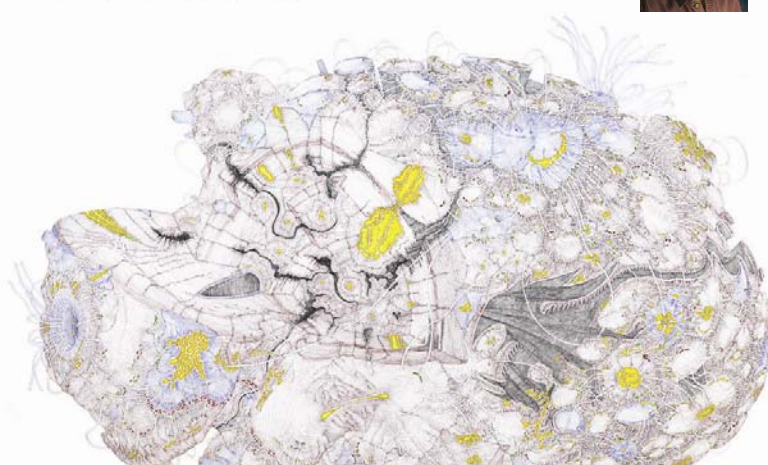
Börner: "Mapping the Evolution of Science"




<p>Overview</p>	
<ul style="list-style-type: none"> ➤ Concepts -> Conceptualization ➤ Models -> Descriptive Models -> Process Models ➤ CI Design -> IVC, NWB, SDB ➤ Communication -> “Mapping Science” Exhibit 	
<p>Borner: "Mapping the Evolution of Science"</p>	

Conceptualizing Science

Hypothetical Model of the Evolution and Structure of Science, by Daniel Zeller
On display in 3rd iteration of exhibit





Emergence

Continuity

Complexity

Stability

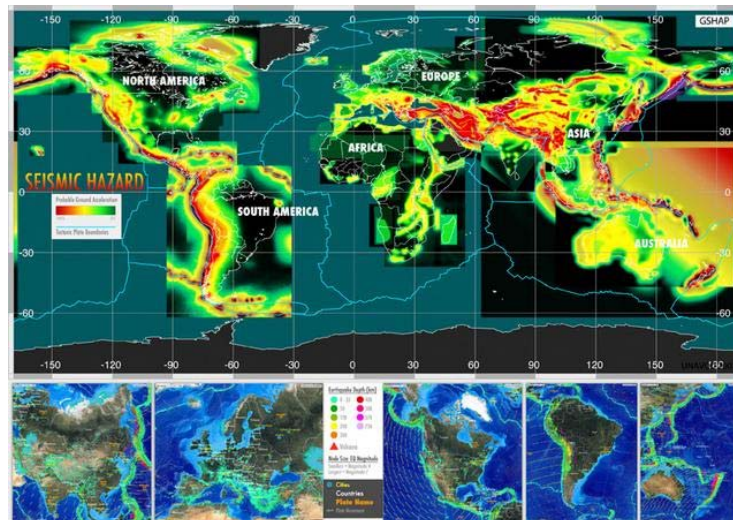
HYPOTHETICAL MODEL of the EVOLUTION and STRUCTURE of SCIENCE

Authors are mortal. Papers are immortal.
Densely knit communities. The importance of weak links.
Cumulative structure of science. Good and bad years. Monsters = 'the unknown' or voids.
Impact of funding on science (yellow).

Tectonic Movements and Earthquake Hazard Predictions

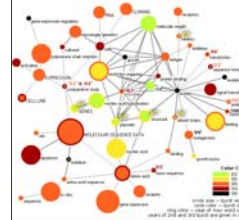
Michael W. Hamburger, Lou Estey, Chuck Meertens (Data & Visualization), Elisha Hardy (Graphic Design)

On display in 3rd iteration of exhibit.



Overview

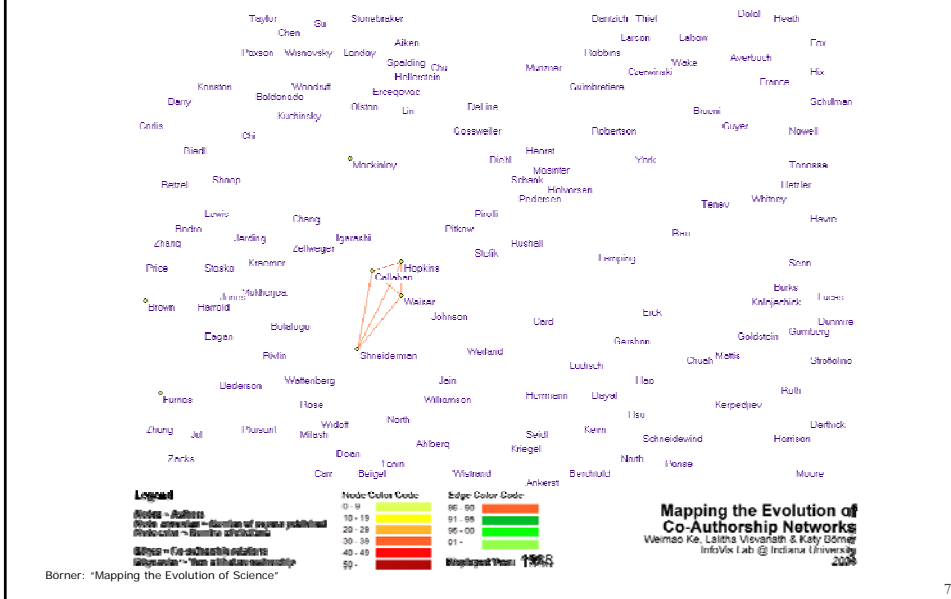
- Concepts -> Conceptualization
- **Models** -> **Descriptive Models**
-> Process Models
- CI Design -> IVC, NWB, SDB
- Communication -> "Mapping Science" Exhibit



Börner: "Mapping the Evolution of Science"

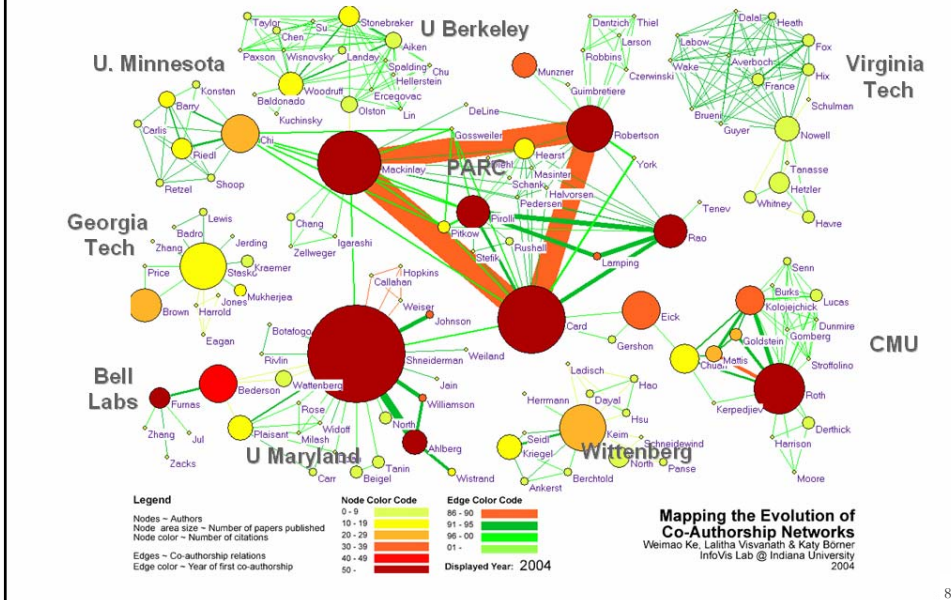
Mapping the Evolution of Co-Authorship Networks

Ke, Viswanath & Börner, (2004) Won 1st prize at the IEEE InfoVis Contest.



Mapping the Evolution of Co-Authorship Networks

Ke, Viswanath & Börner, (2004) Won 1st prize at the IEEE InfoVis Contest.



Spatio-Temporal Information Production and Consumption of Major U.S. Research Institutions

Börner, Katy, Penumarthy, Shashikant, Meiss, Mark and Ke, Weimao. (2006)
Mapping the Diffusion of Scholarly Knowledge Among Major U.S. Research Institutions. Scientometrics. 68(3), pp. 415-426.

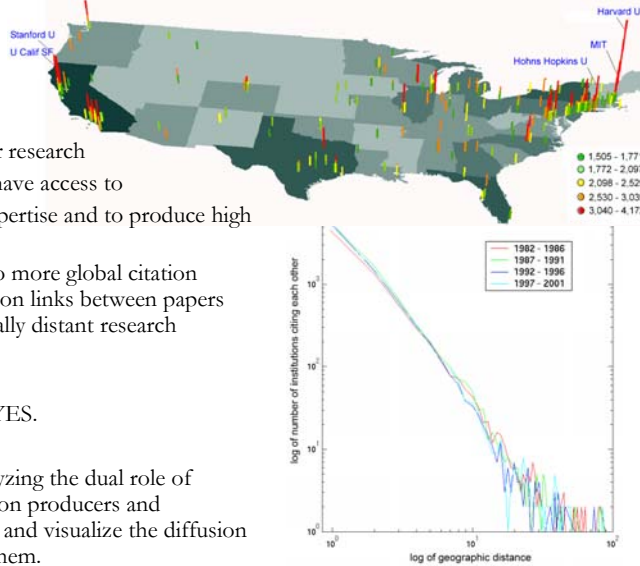


Research questions:

1. Does space still matter in the Internet age?
2. Does one still have to study and work at major research institutions in order to have access to high quality data and expertise and to produce high quality research?
3. Does the Internet lead to more global citation patterns, i.e., more citation links between papers produced at geographically distant research institutions?

Contributions:

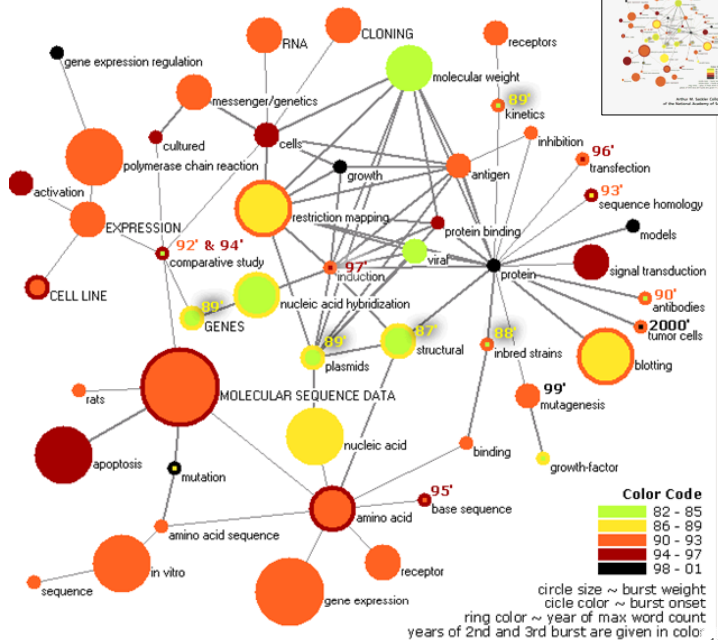
- Answer to Qs 1 + 2 is YES.
- Answer to Qs 3 is NO.
- Novel approach to analyzing the dual role of institutions as information producers and consumers and to study and visualize the diffusion of information among them.



Mapping Topic Bursts

Co-word space of the top 50 highly frequent and bursty words used in the top 10% most highly cited PNAS publications in 1982-2001.

Mane & Börner. (2004)
PNAS, 101(Suppl. 1): 5287-5290.



Wikipedian Activity
Studying large scale social networks such as Wikipedia

Vizzards 2007 Entry

Second Sight: An Emergent Mosaic of Wikipedian Activity, The NewScientist, May 19, 2007



Second sight

Image: Bruce W. Herr and Todd M. Holloway

Power struggle

How do you keep track of the bubbling mass of information that is Wikipedia? This chaotic-looking mosaic is one attempt to show which topics are



looked into the mood tools (locked pages at the time of writing include entries on Sheffield Wednesday football club, Mikhail Gorbachev and pigs). The mosaic has been commended in a competition for images that visualise network dynamics, coinciding with this week's International Workshop and Conference on Network Science in Bloomington.

www.newscientist.com

19 May 2007 | newscientist 19

Science Related Wikipedian Activity

http://scimaps.org/dev/map_detail.php?map_id=165

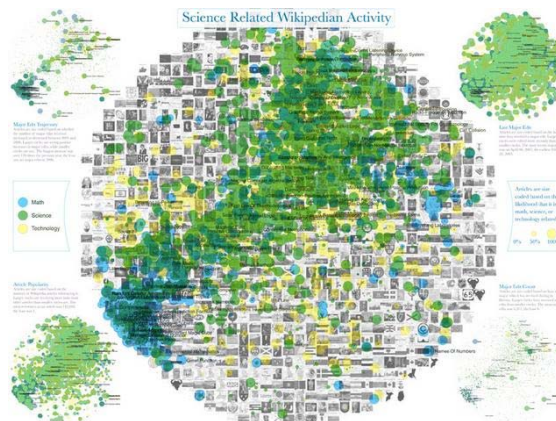
Same base map.

Overlaid are 3,599 math (blue), 6,474 science (green), and 3,164 technology relevant articles (yellow).

All other articles are given in grey.

Corners show articles size coded according to

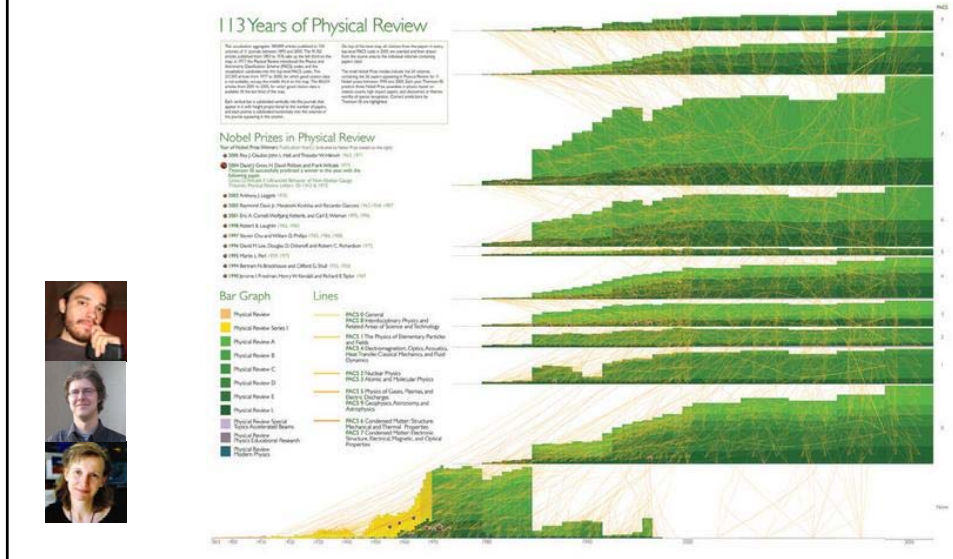
- article edit activity (top left),
- number of major edits (top right),
- number of bursts in edit activity (bottom, right)
- indegree (bottom left).



113 Years of Physical Review

http://scimaps.org/dev/map_detail.php?map_id=171

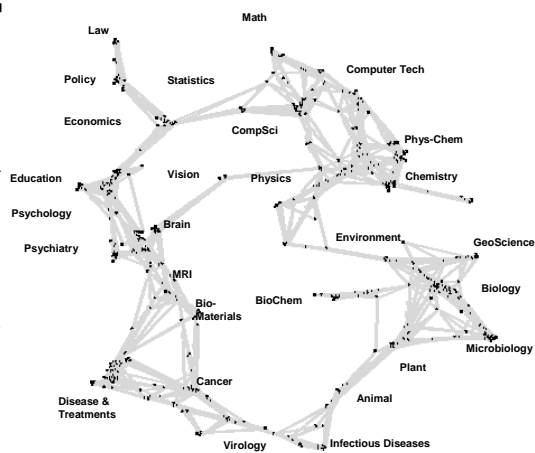
Bruce W. Herr II and Russell Dubon (Data Mining & Visualization), Elisba F. Hardy (Graphic Design), Sbashikant Penumarthy (Data Preparation) and Katy Börner (Concept)



'Base Map' of Science

Kevin W. Boyack & Richard Klavans,

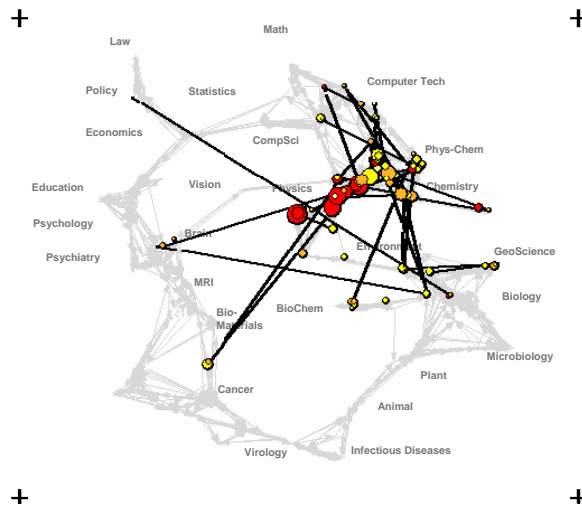
- Uses combined SCI/SSCI from 1975 to 2002
 - 1.07M papers, 24.5M references, 7,300 journals
 - Bibliographic coupling of papers, aggregated to journals
- Initial ordination and clustering of journals gave 671 clusters
- Coupling counts were reaggregated at the journal cluster level to calculate the
 - (x,y) positions for each journal cluster
 - by association, (x,y) positions for each journal



Science map applications: Identifying core competency

Kevin W. Boyack & Richard Klavans,

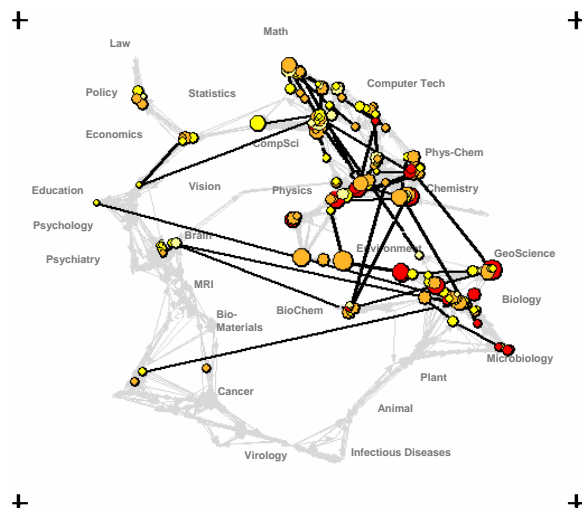
Funding patterns of the US Department of Energy (DOE)



Science map applications: Identifying core competency

Kevin W. Boyack & Richard Klavans,

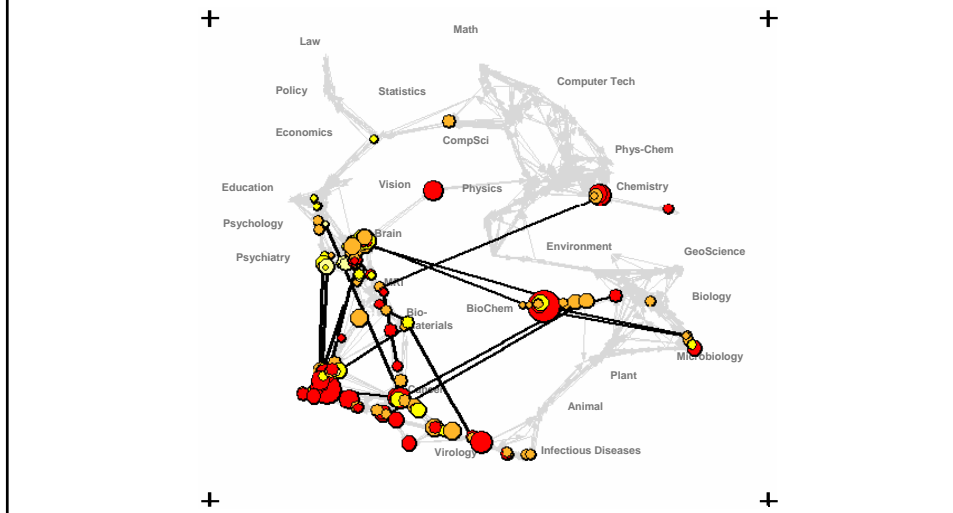
Funding Patterns of the National Science Foundation (NSF)



Science map applications: Identifying core competency

Kevin W. Boyack & Richard Klavans,

Funding Patterns of the National Institutes of Health (NIH)



Society for Neuroscience, 2006 - Visual Browser

Click to start a bounding box, then click again to end it. A listing of all nodes in the bounding box will be shown. Click once again to clear the bounding box.

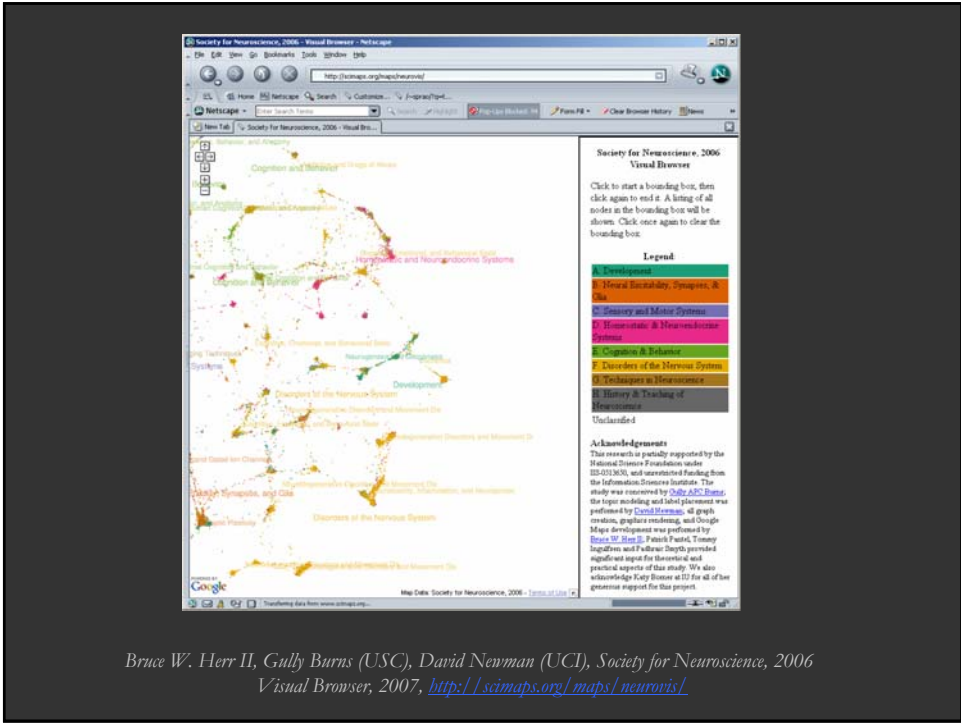
Legend

- A. Development
- B. Neural Excitability, Synapses, & Ions
- C. Sensory and Motor Systems
- D. Homeostasis & Neuroendocrine System
- E. Cognition & Behavior
- F. Disorders of the Nervous System
- G. Technological Neuroscience
- H. History & Teaching of Neuroscience
- Unclassified

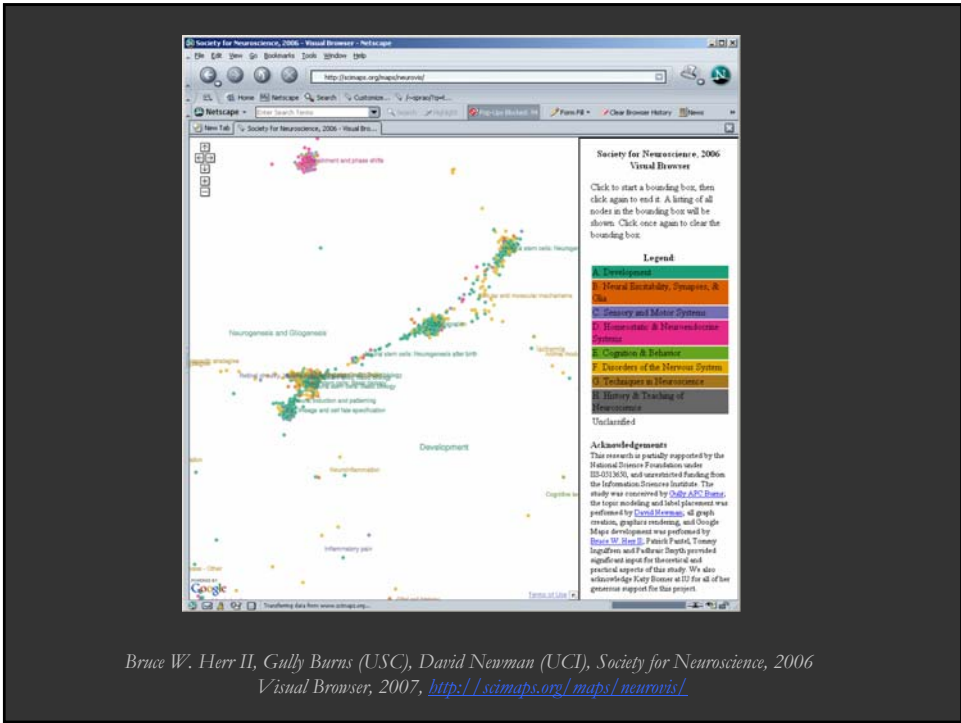
Acknowledgements
 This research is partially supported by the National Science Foundation under IO-0130636, and a National Fellowship from the Information Science Institute. The study was conceived by Gully Burns. The logo modeling and label placement was performed by David Newman, all graph creation, graph rendering, and Google Maps development was performed by Bruce W. Herr II. Patrick Patten, Tommy Ingoldson, and Federico Dotti provided significant input for theoretical and practical aspects of this study. We also acknowledge Kelly Burrell at ISI for all of her generous support of this project.

Map Data: Society for Neuroscience, 2006. Terms of Use

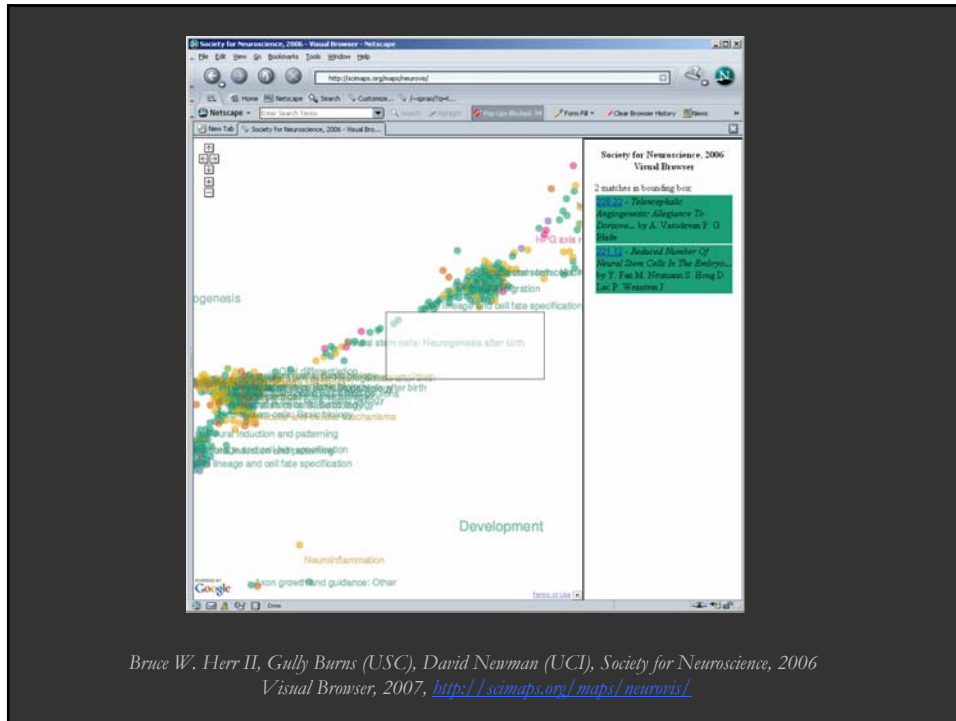
Bruce W. Herr II, Gully Burns (USC), David Newman (UCI), Society for Neuroscience, 2006
 Visual Browser, 2007, <http://scimaps.org/maps/neurovis/>



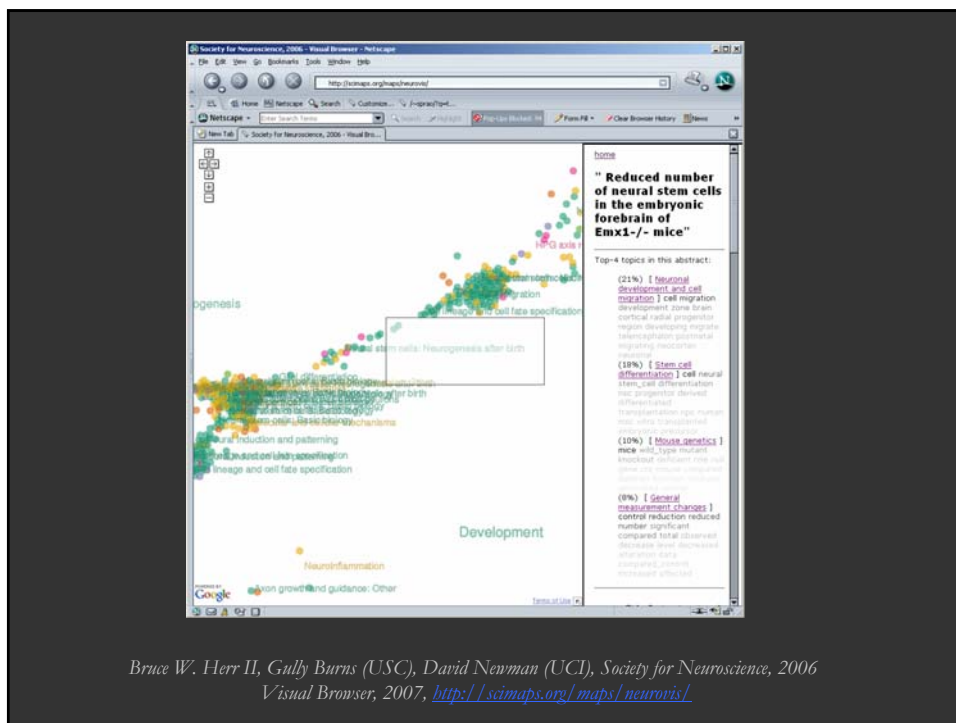
Bruce W. Herr II, Gully Burns (USC), David Newman (UCI), Society for Neuroscience, 2006
 Visual Browser, 2007, <http://scimaps.org/maps/neurovis/>



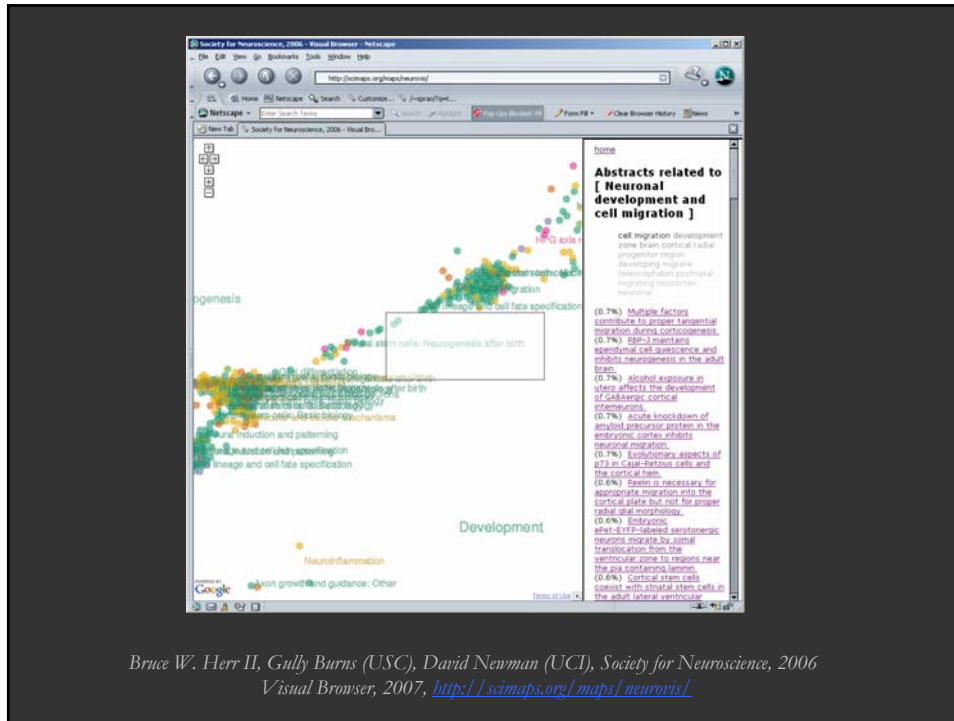
Bruce W. Herr II, Gully Burns (USC), David Newman (UCI), Society for Neuroscience, 2006
 Visual Browser, 2007, <http://scimaps.org/maps/neurovis/>




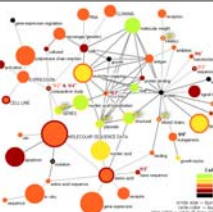


Bruce W. Herr II, Gully Burns (USC), David Newman (UCI), Society for Neuroscience, 2006
 Visual Browser, 2007, <http://scimaps.org/maps/neurovis/>



Bruce W. Herr II, Gully Burns (USC), David Newman (UCI), Society for Neuroscience, 2006
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 Visual Browser, 2007, <http://scimaps.org/maps/neurovis/>

Overview		
➤ Concepts	-> Conceptualization	  
➤ Models	-> Descriptive Models -> Process Models	
➤ CI Design	-> IVC, NWB, SDB	
➤ Communication	-> “Mapping Science” Exhibit	
Börner: “Mapping the Evolution of Science”		

The TARL Model (Topics, Aging, and Recursive Linking)

Börner, Katy, Maru, Jeegar & Goldstone, Robert. (2004). *The Simultaneous Evolution of Author and Paper Networks*. *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 101(Suppl. 1), 5266-5273.



Basic Assumptions

- Co-author and paper-citation networks co-evolve.
- Authors come and go. Papers are forever.
- Only authors that are 'alive' are able to co-author.
- All existing (but no future) papers can be cited.

Unique Features

- Author and paper networks grow simultaneously.
- Preferential attachment is modeled as an emergent property of the elementary, local networking activity of authors reading and citing papers, but also the references listed in papers.
- The number of topics is linearly correlated with the clustering coefficient of the resulting network and can be determined from the cluster coefficient observed in real world networks.
- The model incorporates aging, i.e., a bias for authors to cite recent papers and hence papers are not only clustered by topic, but also in time.

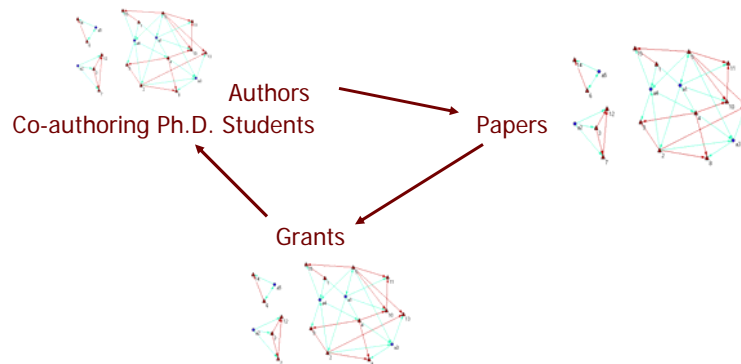
pseudo code

```
// Initialization
generate #_papers papers and assign a random topic to each paper;
generate #_authors authors and assign a random topic to each author;
randomly assign #_co-authors+1 authors to papers of the same topic;
// Simulation
for each year do {
  add #_new_authors new authors, deactivate authors older than #_author_age;
  for each topic do {
    randomly partition set of authors into author_groups of size #_co-authors+1;
    for each author_group do {
      for each new_paper to be produced, do {
        generate new_paper;
        randomly select #_read_papers from existing papers;
        get all references of read_papers up to #_reference_path_length;
        for each new_paper_reference do {
          select a time_slice from (start year to cur_year-1) with probability given in aging;
          randomly select a paper published or cited in this time_slice as a new_paper_ref;
          add the new_paper_reference to new_paper;
        }
      }
    }
  }
  add all new papers to the set of existing papers;
  add new links to author and paper information;
}
```


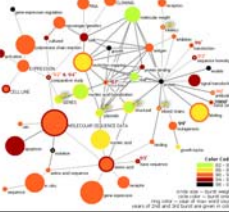


The TARL Model (Topics, Aging, and Recursive Linking)

Modeling Network Ecologies

Most real world networks exist within a delicate ecology of networks.



To fully understand, e.g., the 'rich get richer effect' or the 'diffusion of knowledge', different networks need to be considered simultaneously and the interplay of network structure and network dynamics has to be studied.

<p>Overview</p>	
<ul style="list-style-type: none"> ➤ Concepts -> Conceptualization ➤ Models -> Descriptive Models -> Process Models ➤ CI Design -> IVC, NWB, SDB ➤ Communication -> “Mapping Science” Exhibit 	  
<p>Borner: “Mapping the Evolution of Science”</p>	

Information Visualization CyberInfrastructure

The InfoVis CyberInfrastructure provides access to data, software code and learning modules as well as computing resources in support of the analysis, modeling and visualization of diverse data sets.

DATABASES
An Oracle database provides access to publications, papers, grants and grant opportunities. The database is continuously and automatically updated.

SOFTWARE
An open source IVC framework was designed to facilitate the integration of diverse data analysis, modeling and visualization algorithms. The algorithmic data processing methods, tools and tools for the analysis and visualization can be easily “plugged in” or “unplugged” from the framework.


COMPUTING RESOURCES
The InfoVis CyberInfrastructure is hosted at Indiana University's Research Database Complex, consisting of three Sun E10K servers with 12 TB disks, 48 GB of RAM and 100 Gbps network. A Sun X86 server acts as a proxy and IVC resources are accessible with those and by the database server.

LEARNING MODULES
A set of associated learning modules aims to equip learners with a practical skill set in providing code and advice to quickly identify and use different algorithms and diverse data sets techniques and data visualization tools for the generation and comparison of network visualizations.

SDB SCHOLARLY DATABASE

Scholarly Database
<http://sdb.shis.indiana.edu>


CAREER: Visualizing Knowledge Domains. NSF IIS-0238261 award (Katy Börner, \$451,000) Sept. 03-Aug. 08.
<http://iv.shis.indiana.edu/>



NetworkWorkbench

A Workbench for Network Scientists

SEI: Network Workbench: A Large-Scale Network Analysis, Modeling and Visualization Toolkit for Biomedical, Social Science and Physics Research. NSF IIS-0513650 award (Katy Börner, Albert-László Barabási, Santiago Schnell, Alessandro Vespignani & Stanley Wasserman, Eric Werner) (Senior Personnel), \$1,120,926) Sept. 05 - Aug. 08.
<http://nwb.shis.indiana.edu>




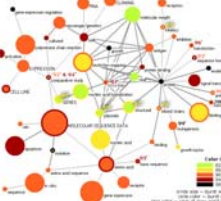


<p>Overview</p>	
<ul style="list-style-type: none"> ➤ Concepts -> Conceptualization ➤ Models -> Descriptive Models -> Process Models ➤ CI Design -> IVC, NWB, SDB ➤ Communication -> “Mapping Science” Exhibit <p style="font-size: small; margin-top: 20px;">Borner: "Mapping the Evolution of Science"</p>	  



Chart toppers

An exhibition explores the diverse ways of putting data on the map.

From the simple pie chart to the complex network diagram, the exhibition explores the diverse ways of putting data on the map. It features a variety of maps, including a world map showing the distribution of scientific publications, a map of the human genome, and a map of the world's climate zones.

Slashdot

NEWS FOR NERDS. STUFF THAT MATTERS.

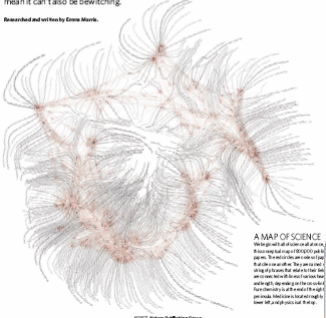
[Login](#) | [Create Account](#) | [Subscribe](#)

2006 GALLERY

BRILLIANT DISPLAY

From a jewel-like bird, rarer than any diamond, to the delicately poetic swirls generated inside aircraft engines, the pursuit of knowledge turns up its fair share of beauty. This issue, *Nature* wraps up the year with an arresting series of images from 2006. We've divided them into the art of the natural world, planet-scapes both domestic and extraterrestrial, and the splendour of modern technology. Just because something enhances our knowledge doesn't mean it can't also be bewitching.

Researched and written by Emma Murch.




A MAP OF SCIENCE
This map is a network of relationships between scientific paradigms. It is based on a database of 100,000 scientific papers. The map shows how different scientific ideas are related to each other, and how they have evolved over time. The map is a complex network of nodes and edges, with nodes representing scientific paradigms and edges representing relationships between them. The map is a beautiful and intricate work of art, and it is a testament to the power of data visualization.

SEED

Scientific Method: Among Scientific Paradigms

2006 March 16, 2007 12:19 PM

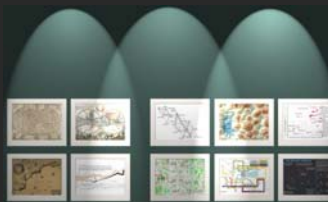
This map was constructed by sorting roughly 100,000 published papers into 776 different scientific paradigms. The map shows how different scientific ideas are related to each other, and how they have evolved over time. The map is a complex network of nodes and edges, with nodes representing scientific paradigms and edges representing relationships between them. The map is a beautiful and intricate work of art, and it is a testament to the power of data visualization.



http://scimaps.org

The Power of Maps

Four Early Maps of Our World VERSUS Six Early Maps of Science



(1st Iteration of Places & Spaces Exhibit - 2005)

The Power of Reference Systems

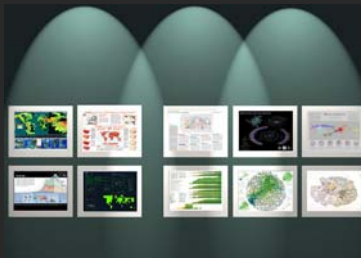
Four Existing Reference Systems
VERSUS
Six Potential Reference Systems of Science



(2nd Iteration of Places & Spaces Exhibit - 2006)

The Power of Forecasts

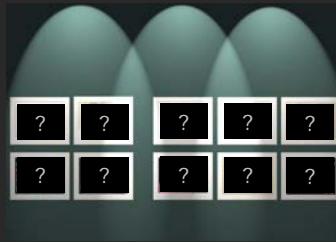
Four Existing Forecasts
VERSUS
Six Potential Science 'Weather' Forecasts



(3rd Iteration of Places & Spaces Exhibit - 2007)

Science Maps for Economic Decision Making

Four Existing Maps
VERSUS
Six Science Maps



(4th Iteration of Places & Spaces Exhibit - 2008)



"Places & Spaces: Mapping Science"
on display at on display at the American Museum of Science
and Energy, Oak Ridge, TN,
September 7, 2007- January 7, 2008.

TOPIC MAP: HOW SCIENTIFIC PARADIGMS RELATE

GEOGRAPHIC MAP: WHERE SCIENCE GETS DONE

You may run your finger over each of these maps to control the lighting on the other; touching a place on the world map will light up topics studied in that place; touching a paradigm on the topic map will light up the places that study that topic.

Nanotechnology

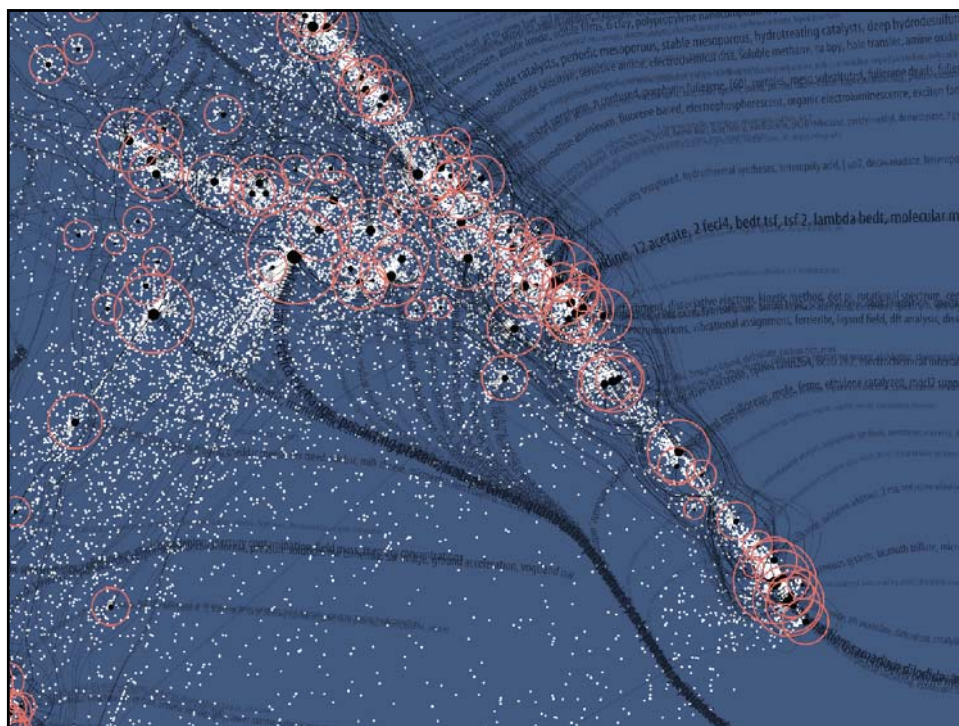
This overlay shows the distribution of nanotechnology within the paradigms of science. The majority of current work in nanotechnology takes place in physics, chemistry, and materials science, at the upper right portion of the map. However, an increasing amount of nanotechnology is being applied in the biological and medical sciences, at the lower right.

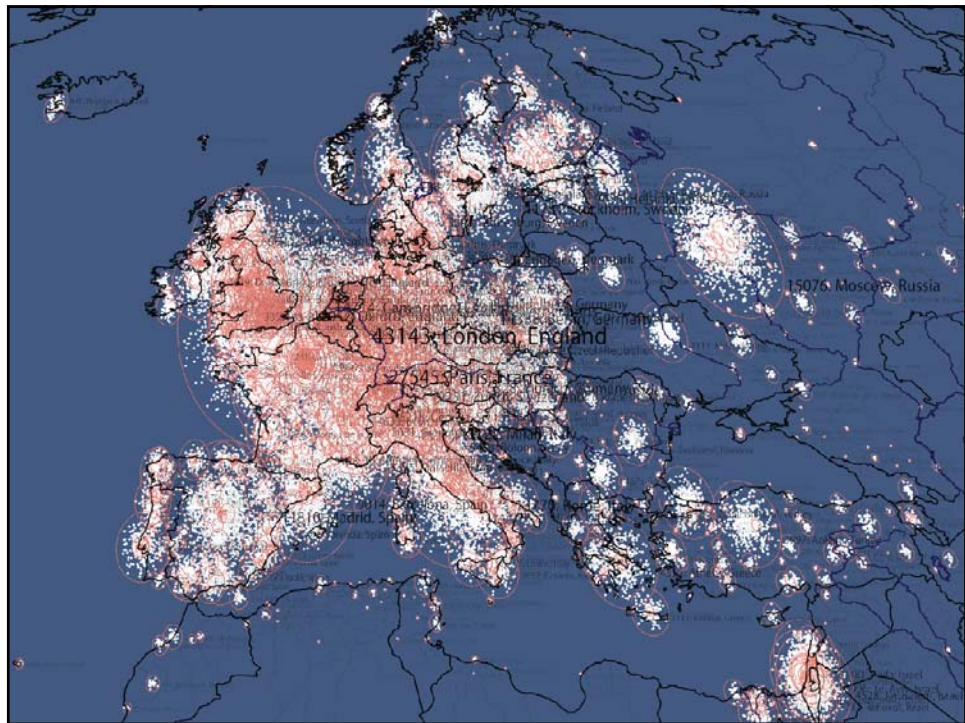
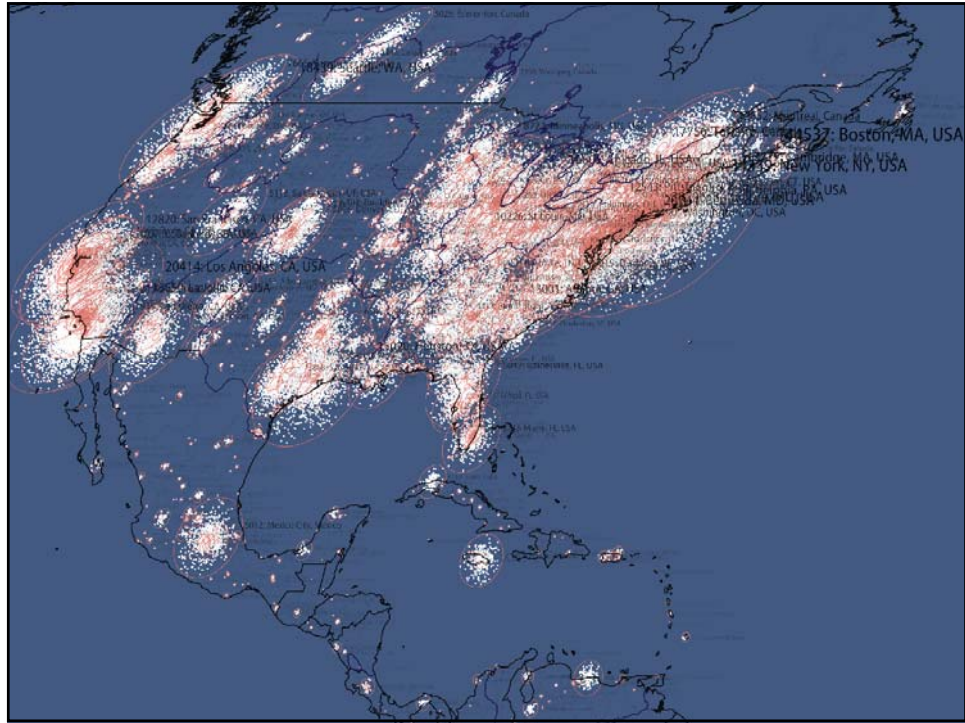
All Topics <small>Sweep through all 776 scientific paradigms</small>	Nanotechnology <small>Science on the tiny scale of molecules</small>	Francis H. C. CRICK <small>Co-discovered DNA's double helix</small>	Albert EINSTEIN <small>Revitalized physics with Relativity theories</small>	Michael E. FISHER <small>Models critical phase transitions of matter</small>	Susan T. FISKE <small>Connects perception and stereotypes</small>
Sustainability <small>The science behind our long-term hopes</small>	Biology & Chemistry <small>The interface between these two vital fields</small>	Joshua LEDERBERG <small>Pioneer in bacterial genetic mechanisms</small>	Derek J. de Solla PRICE <small>Known as the "Father of Scientometrics"</small>	Richard N. ZARE <small>Uses laser chemistry in molecular dynamics</small>	About this display <small>People & organizations that helped create it</small>

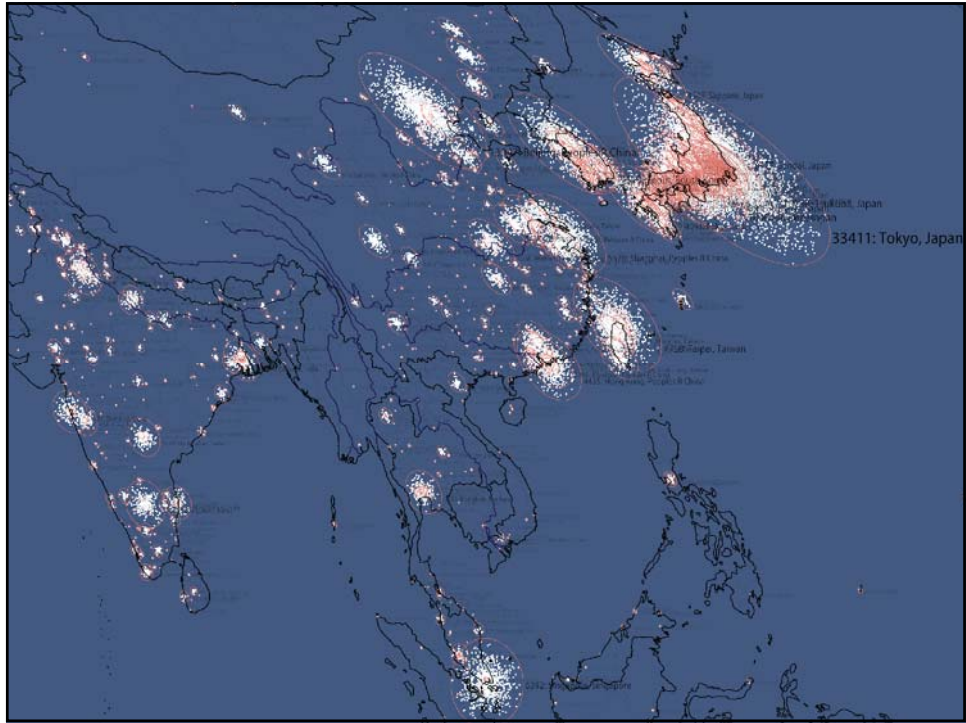
We sweep slowly through adjoining related topics, lighting up the places in the world that study each topic. You may select a subset of the topics that deal with these three interesting subjects by touching it.

A single person's spreading influence is shown as a series of four snapshots. First, we light only topics and places relating to that person's papers—papers that are still highly cited today. The second lights everything that cites that original work. Note that this first-generation impact extends to far more topics than did the original work. The third snapshot lights science that cites the second, and the fourth lights science that cites the third.









References

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- Börner, Katy, Sanyal, Soma and Vespignani, Alessandro (2007). **Network Science**. In Blaise Cronin (Ed.), *Annual Review of Information Science & Technology*, Information Today, Inc./American Society for Information Science and Technology, Medford, NJ, volume 41, chapter 12, pp. 537-607. <http://ivl.slis.indiana.edu/km/pub/2007-borner-arist.pdf>
- Boyack, Kevin W., Börner, Katy & Klavans, Richard. (2007). Mapping the Structure and Evolution of Chemistry Research. *Proceedings of the 11th International Conference on Scientometrics and Informetrics (ISSI 2007)*, Madrid, Spain, June 25-27, pp. 112-123.
- Boyack, Kevin W., Klavans, Richard and Börner, Katy. (2005). Mapping the Backbone of Science. *Scientometrics*. 64(3), 351-374.

These and more papers are linked from <http://ivl.slis.indiana.edu/publications/>

Börner: "Mapping the Evolution of Science"

45

The End.