Mapping the Structure and Evolution of World Wide Science

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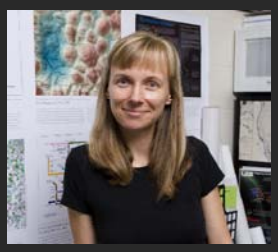
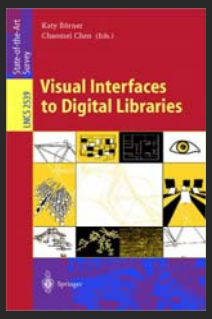


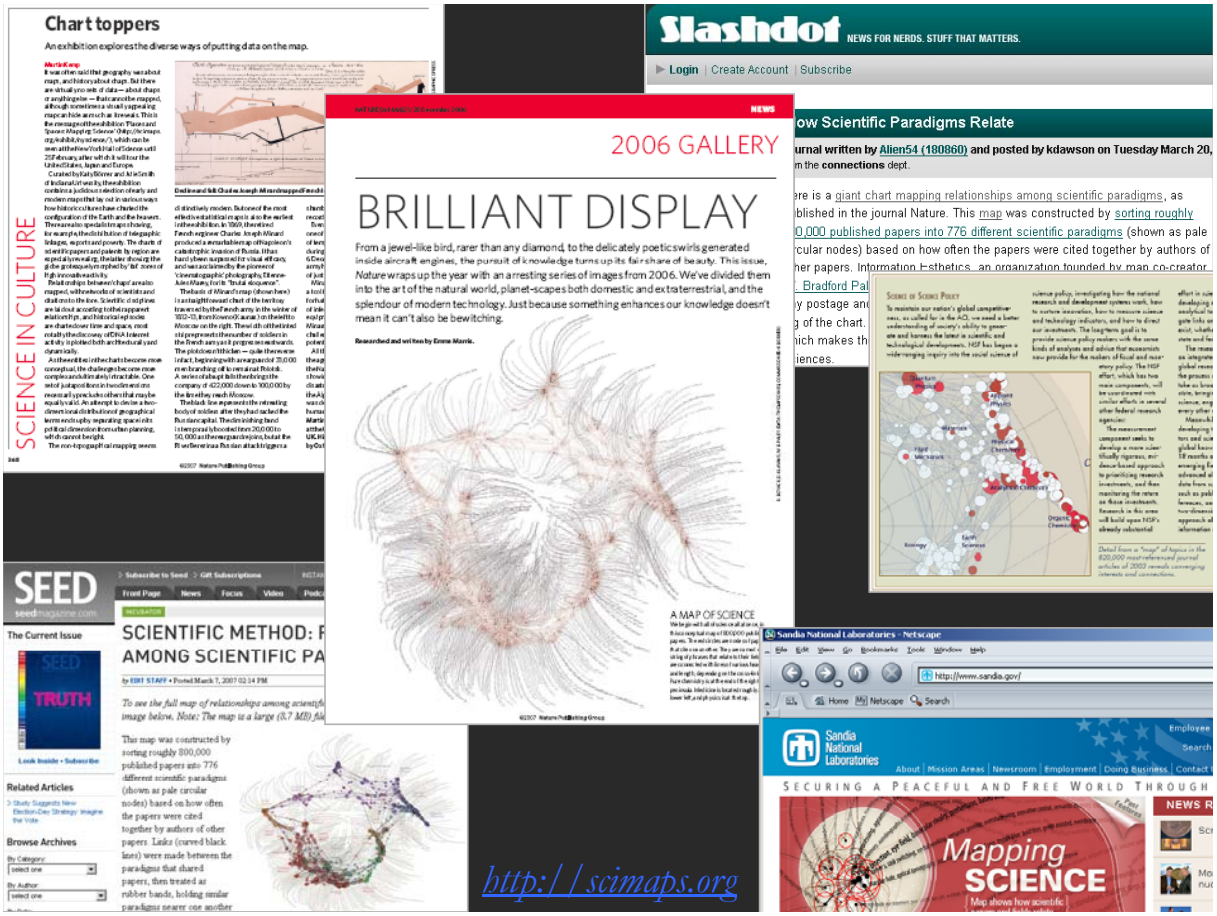
Meeting at FAPESP, São Paulo, Brazil
July 20, 2009

Computational Scientometrics: Studying Science by Scientific Means



- *Börner, Katy, Chen, Chaomei, and Boyack, Kevin. (2003).* ***Visualizing Knowledge Domains.*** *In Blaise Cronin (Ed.), Annual Review of Information Science & Technology, Medford, NJ: Information Today, Inc./American Society for Information Science and Technology, Volume 37, Chapter 5, pp. 179-255.* http://ivl.slis.indiana.edu/km/pub/2003-borner-arist.pdf
- *Shiffrin, Richard M. and Börner, Katy (Eds.) (2004).* ***Mapping Knowledge Domains.*** *Proceedings of the National Academy of Sciences of the United States of America, 101(Suppl_1).* http://www.pnas.org/content/vol101/suppl_1/
- *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

- ***Places & Spaces: Mapping Science*** *exhibit, see also http://scimaps.org.*



Computational Scientometrics Opportunities

Advantages for Funding Agencies

- Supports monitoring of (long-term) money flow and research developments, evaluation of funding strategies for different programs, decisions on project durations, funding patterns.
- Staff resources can be used for scientific program development, to identify areas for future development, and the stimulation of new research areas.

Advantages for Researchers

- Easy access to research results, relevant funding programs and their success rates, potential collaborators, competitors, related projects/publications **(research push).**
- More time for research and teaching.

Advantages for Industry

- Fast and easy access to major results, experts, etc.
- Can influence the direction of research by entering information on needed technologies **(industry-pull)**.

Advantages for Publishers

- Unique interface to their data.
- Publicly funded development of databases and their interlinkage.

For Society

- Dramatically improved access to scientific knowledge and expertise.

Process of Computational Scientometrics

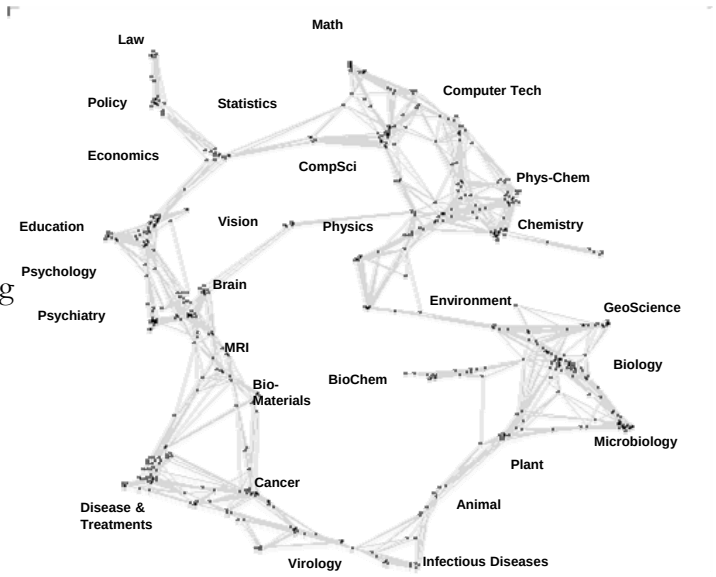
DATA EXTRACTION	UNIT OF ANALYSIS	MEASURES	LAYOUT (often one code does both similarity and ordination steps)		DISPLAY
			SIMILARITY	ORDINATION	
SEARCHES ISI INSPEC Eng Index Medline ResearchIndex Patents etc. BROADENING By citation By terms	COMMON CHOICES Journal Document Author Term	COUNTS/FREQUENCIES Attributes (e.g. terms) Author citations Co-citations By year THRESHOLDS By counts	SCALAR (unit by unit matrix) Direct citation Co-citation Combined linkage Co-word / co-term Co-classification VECTOR (unit by attribute matrix) Vector space model (words/terms) Latent Semantic Analysis (words/terms) incl. Singular Value Decomp (SVD) CORRELATION (if desired) Pearson's R on any of above	DIMENSIONALITY REDUCTION Eigenvector/ Eigenvalue solutions Factor Analysis (FA) and Principal Components Analysis (PCA) Multi-dimensional scaling (MDS) LSA, **Topics** Pathfinder networks (PFNet) Self-organizing maps (SOM) includes SOM_ET-maps, etc. CLUSTER ANALYSIS SCALAR Triangulation Force-directed placement (FDP)	INTERACTION Browse Pan Zoom Filter Query Detail on demand ANALYSIS

Börner, Katy, Chen, Chaomei, and Boyack, Kevin. (2003) Visualizing Knowledge Domains. In Blaise Cronin (Ed.), Annual Review of Information Science & Technology, Volume 37, Medford, NJ: Information Today, Inc./American Society for Information Science and Technology, chapter 5, pp. 179-255.

Latest 'Base Map' of Science

Kevin W. Boyack, Katy Börner, & Richard Klavans (2007). Mapping the Structure and Evolution of Chemistry Research. 11th International Conference on Scientometrics and Informetrics. pp. 112-123.

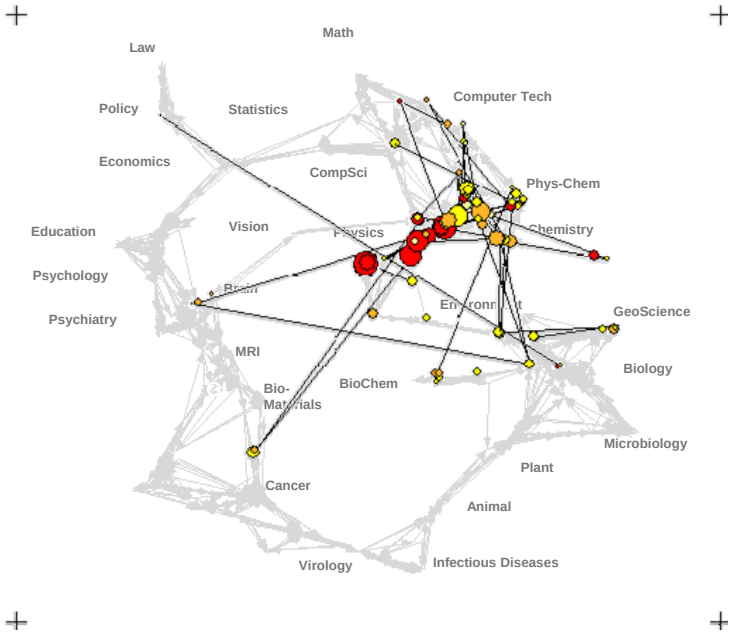
- Uses combined SCI/SSCI from 2002
  - 1.07M papers, 24.5M references, 7,300 journals
  - Bibliographic coupling of papers, aggregated to journals
- Initial ordination and clustering of journals gave 671 clusters
- Coupling counts were reaggregated at the journal cluster level to calculate the
  - (x,y)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



Science map applications: Identifying core competency

Kevin W. Boyack, Katy Börner, & Richard Klavans (2007).

Funding patterns of the US Department of Energy (DOE)



Science map applications: Identifying core competency

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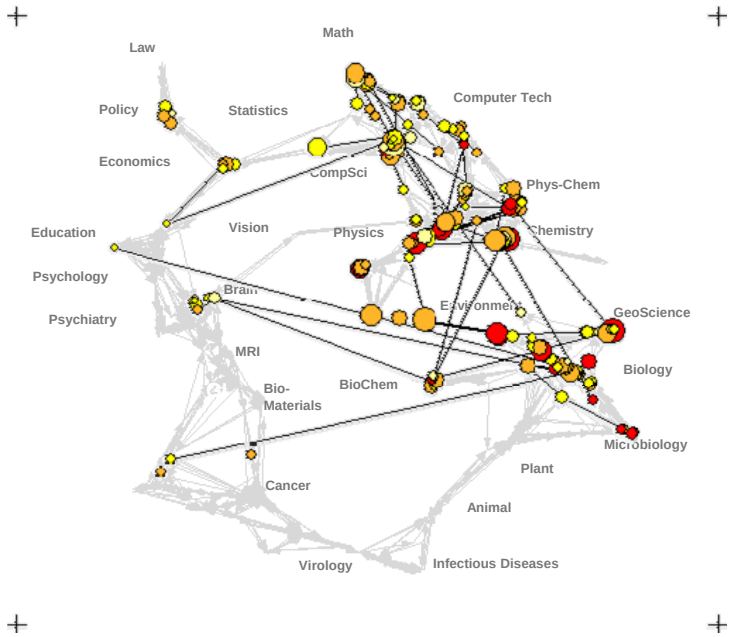
Funding Patterns of the National Science Foundation (NSF)



Science map applications: Identifying core competency

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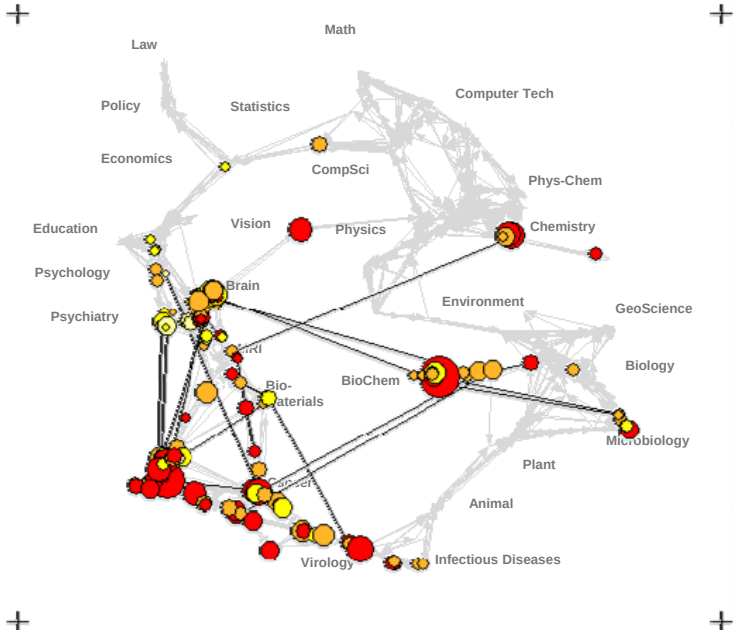
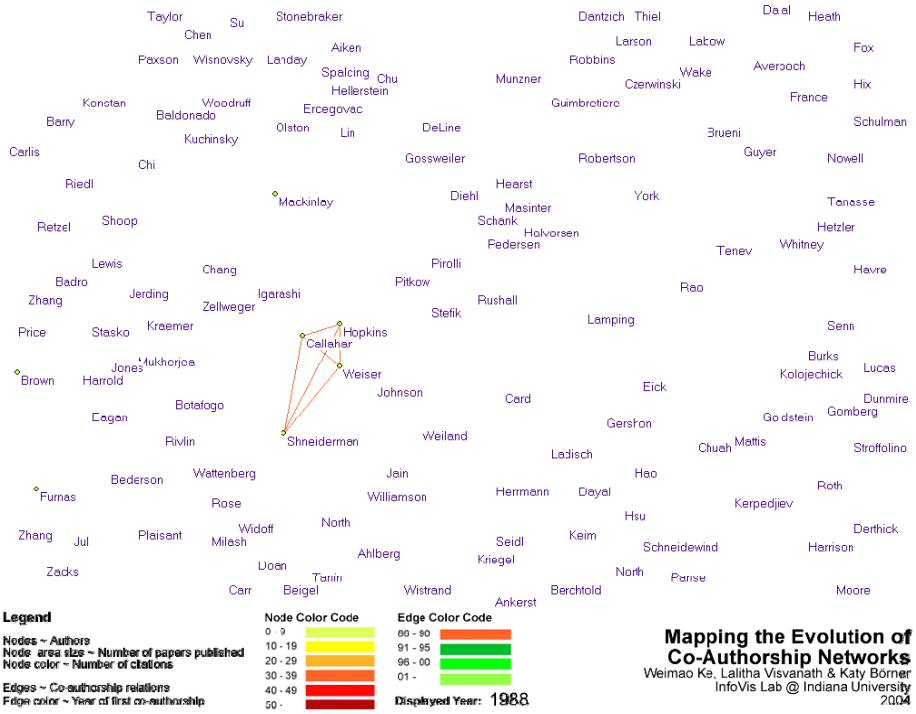
Funding Patterns of the National Institutes of Health (NIH)



Sample Science Studies

Mapping the Evolution of Co-Authorship Networks

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



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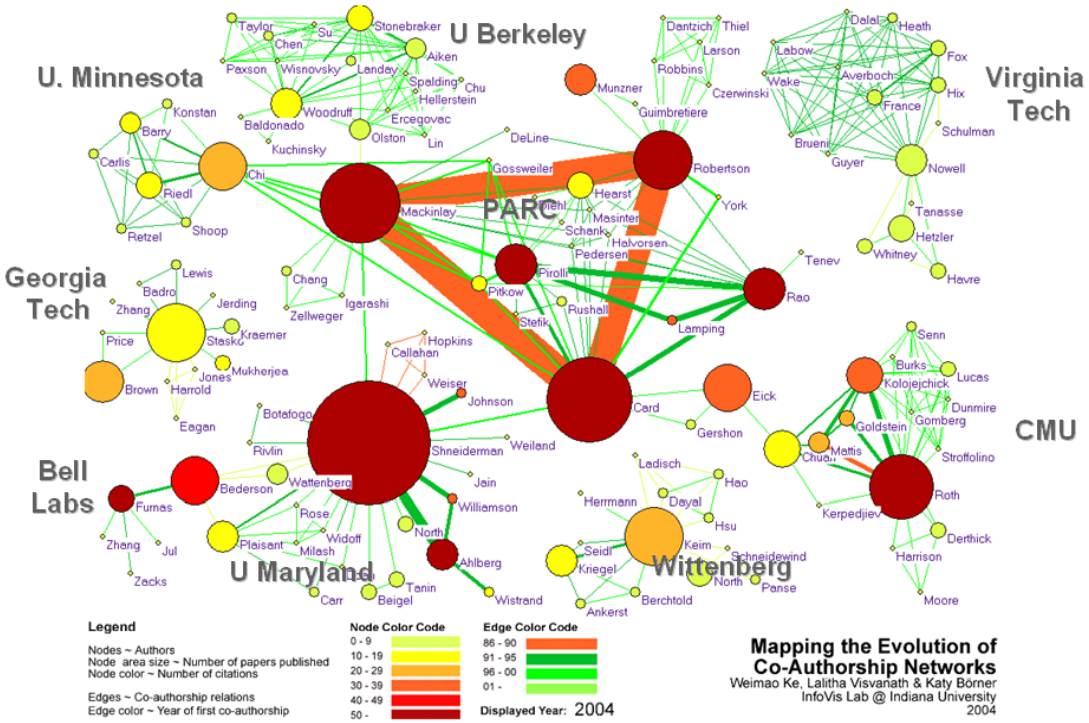


Studying the Emerging Global Brain: Analyzing and Visualizing the Impact of Co-Authorship Teams

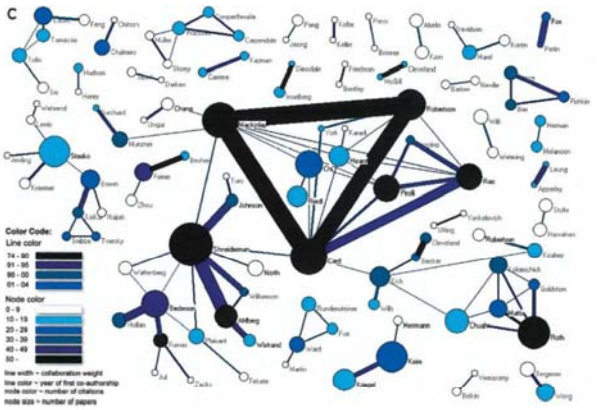
Börner, Dall'Asta, Ke & Vespignani (2005) Complexity, 10(4):58-67.

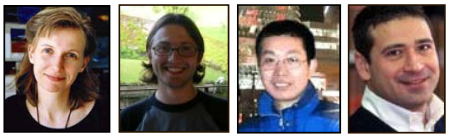
Research question:

- Is science driven by prolific single experts or by high-impact co-authorship teams?

Contributions:

- New approach to allocate citational credit.
- Novel weighted graph representation.
- Visualization of the growth of weighted co-author network.
- Centrality measures to identify author impact.
- Global statistical analysis of paper production and citations in correlation with co-authorship team size over time.
- Local, author-centered entropy measure.

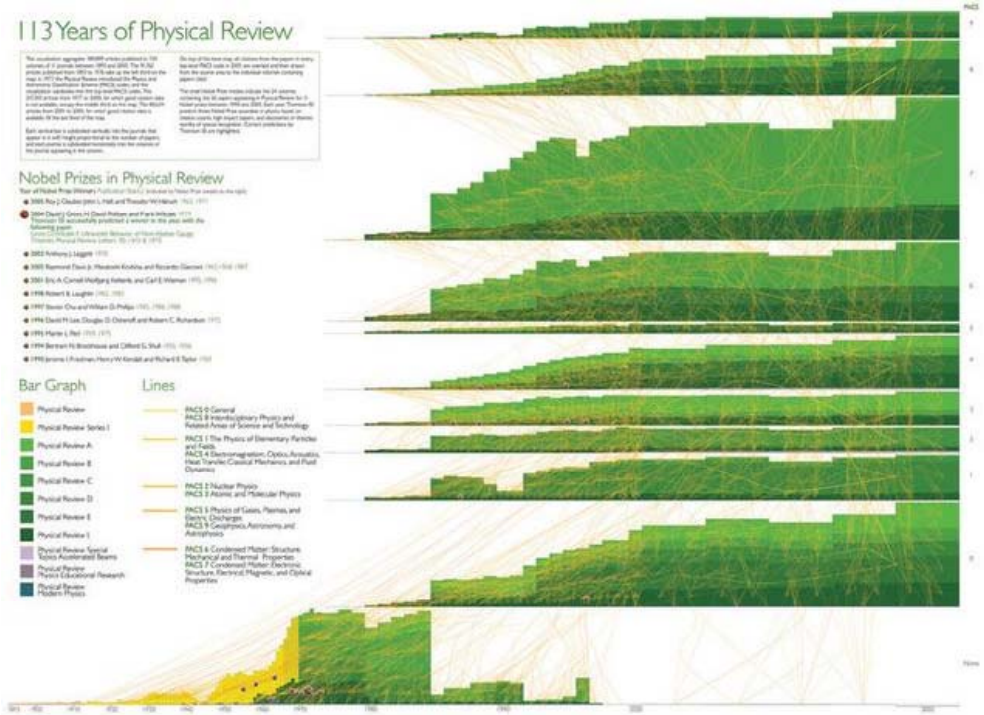




113 Years of Physical Review

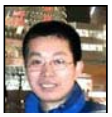
http://scimaps.org/dev/map_detail.php?map_id=171

Bruce W. Herr II and Russell Duhon (Data Mining & Visualization), Elisha F. Hardy (Graphic Design), Shashikant Penumarthy (Data Preparation) and Katy Börner (Concept)



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

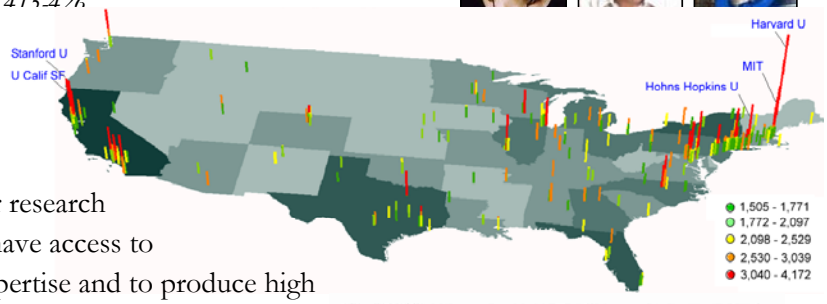


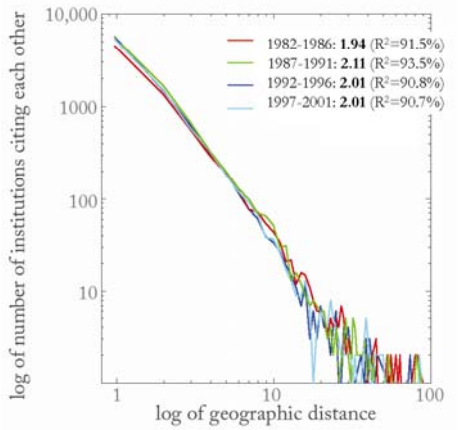


Börner, Katy, Penumarthy, Shashikant, Meiss, Mark and Ke, Weimao. (2006) Mapping the Diffusion of Scholarly Knowledge Among Major U.S. Research Institutions. Scientometrics. 68(3), pp. 415-426.

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 instructions?

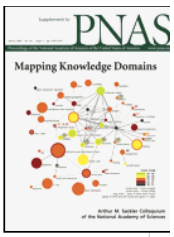




Contributions:

- 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



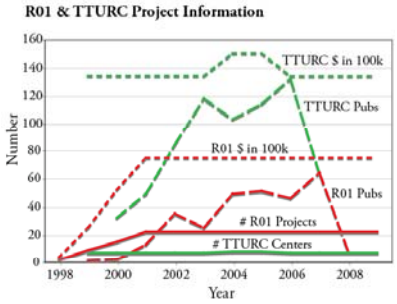
Co-word space of the top 50 highly frequent and bursty words used in the top 10% most highly cited PNAS publications in 1982-2001.

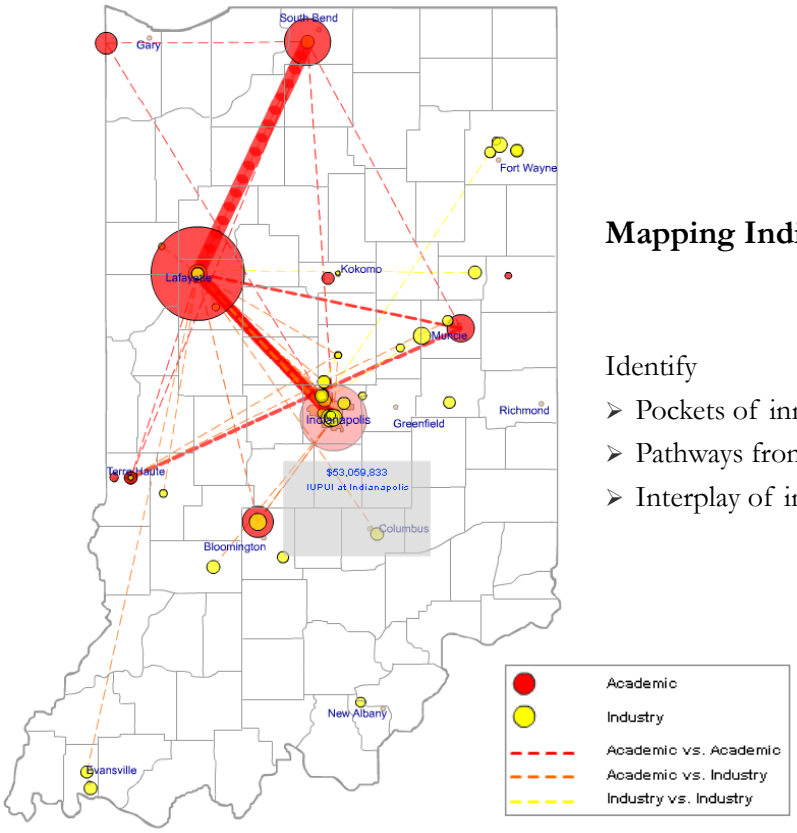
Mane & Börner. (2004) PNAS, 101(Suppl. 1): 5287-5290.

Mapping Transdisciplinary Tobacco Use Research Centers Publications

Compare R01 investigator based funding with TTURC Center awards in terms of number of publications and evolving co-author networks.

Zoss & Börner, forthcoming.

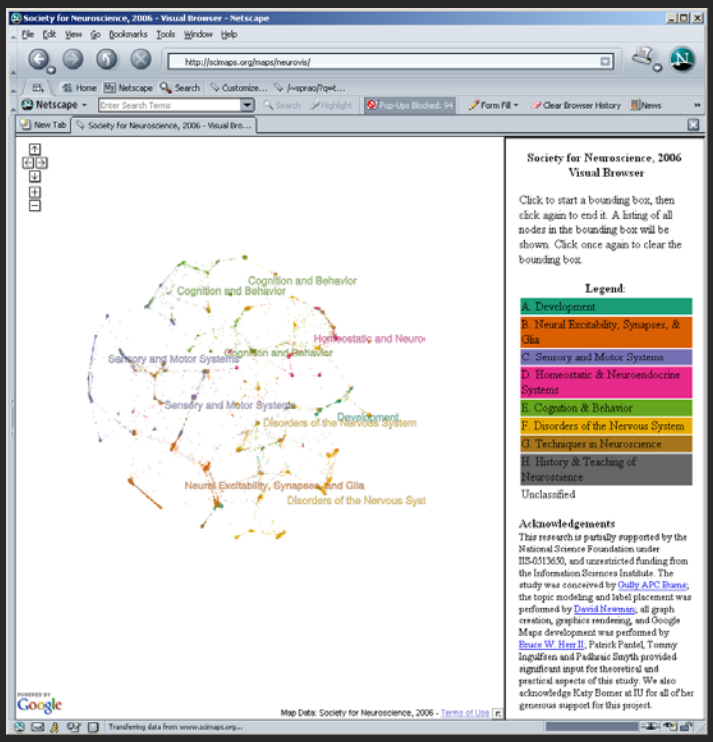




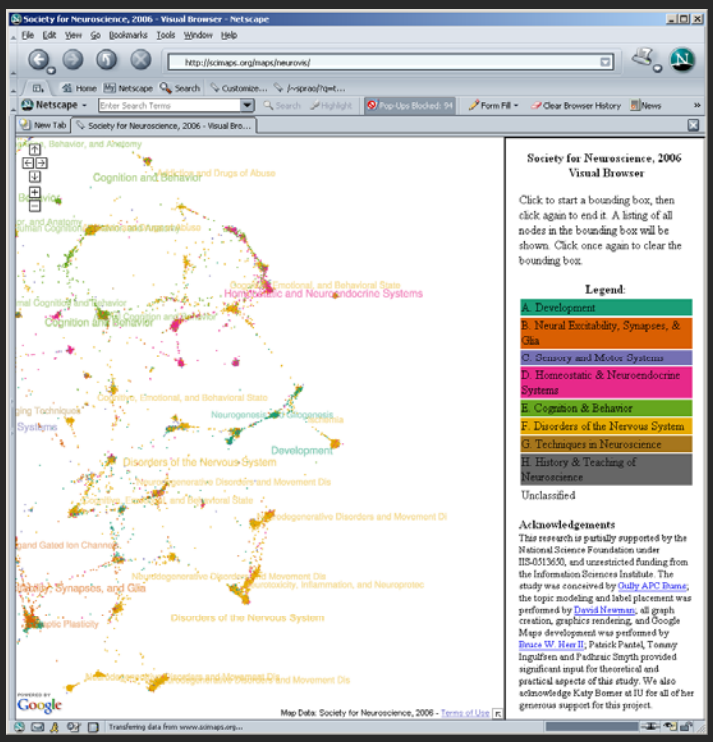
Mapping Indiana's Intellectual Space

Identify

- Pockets of innovation
- Pathways from ideas to products
- Interplay of industry and academia



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



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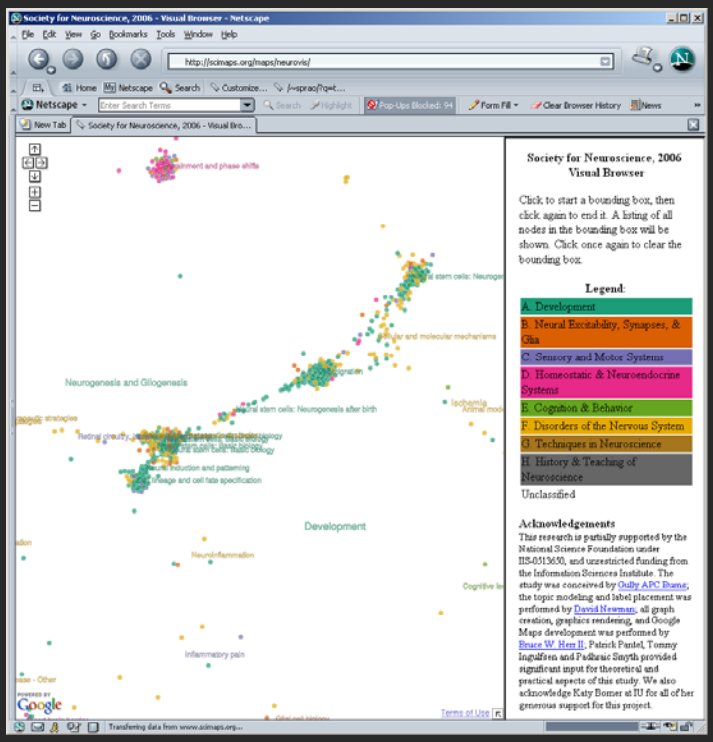

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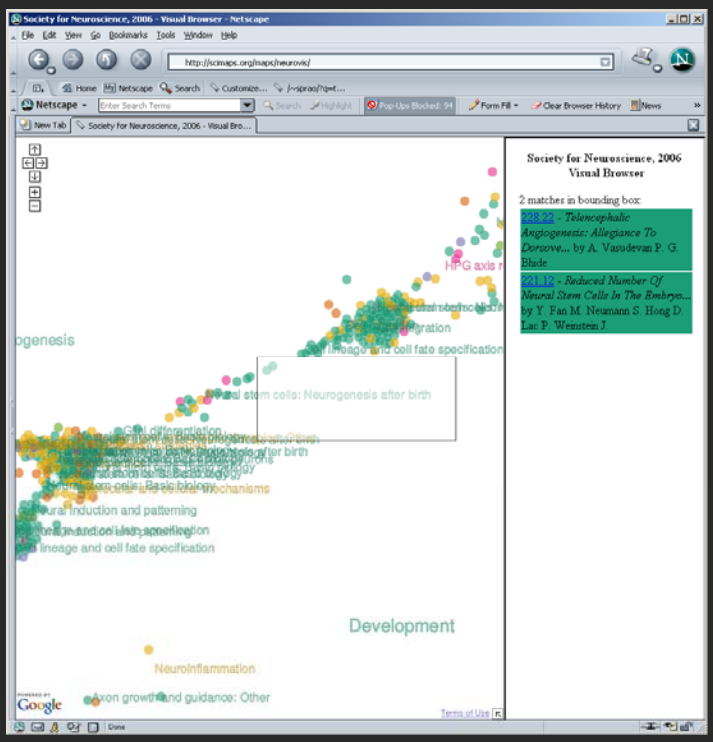

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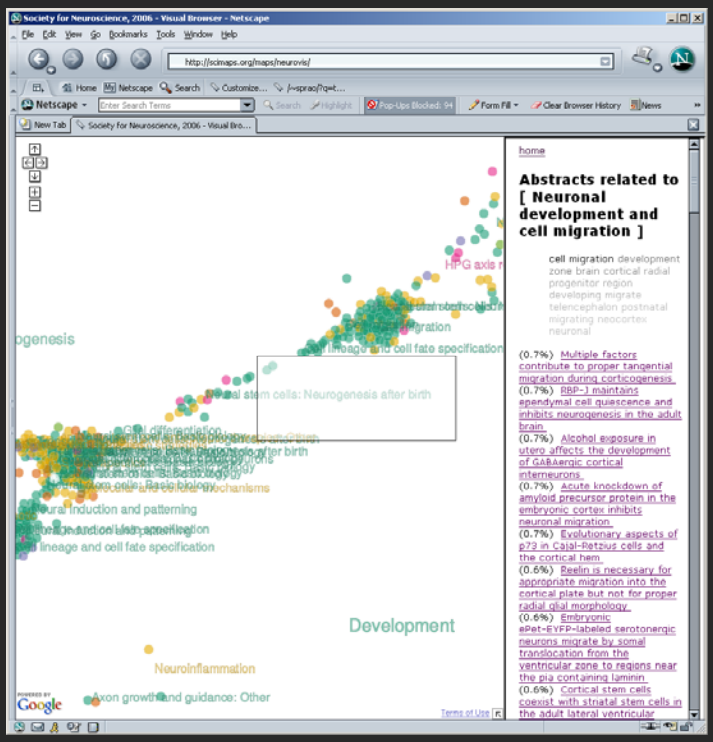


Bruce W. Herr II, Gully Burns (USC), David Newman (UCI), Society for Neuroscience, 2006 Visual Browser, 2007, http://scimaps.org/maps/neurovis/

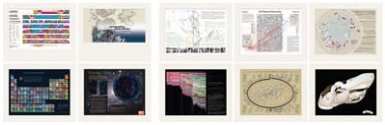
Mapping Science Exhibit

Mapping Science Exhibit – 10 Iterations in 10 years

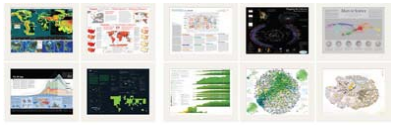
http://scimaps.org/

The Power of Maps (2005)

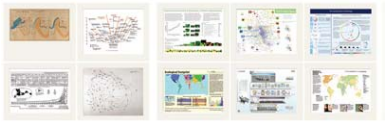
The Power of Reference Systems (2006)



The Power of Forecasts (2007)



Science Maps for Economic Decision Makers (2008)



Science Maps for Science Policy Makers (2009)

Science Maps for Scholars (2010)
Science Maps as Visual Interfaces to Digital Libraries (2011)
Science Maps for Kids (2012)
Science Forecasts (2013)

How to Lie with Science Maps (2014)

Exhibit has been shown in 52 venues on four continents. Also at
- NSF, 10th Floor, 4201 Wilson Boulevard, Arlington, VA.
- Chinese Academy of Sciences, China, May 17-Nov. 15, 2008.
- University of Alberta, Edmonton, Canada, Nov 10-Jan 31, 2009
- Center of Advanced European Studies and Research, Bonn, Germany, Dec. 11-19, 2008.

Illuminated Diagram Display

W. Bradford Paley, Kevin W. Boyack, Richard Kalvans, and Katy Börner (2007) Mapping, Illuminating, and Interacting with Science. SIGGRAPH 2007.

Large-scale, high resolution prints illuminated via projector or screen.

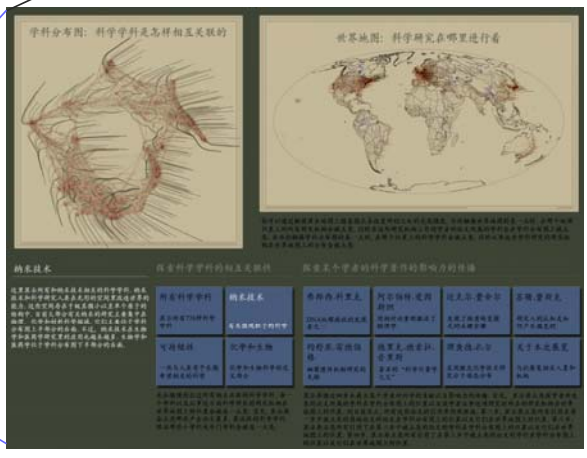
Questions:

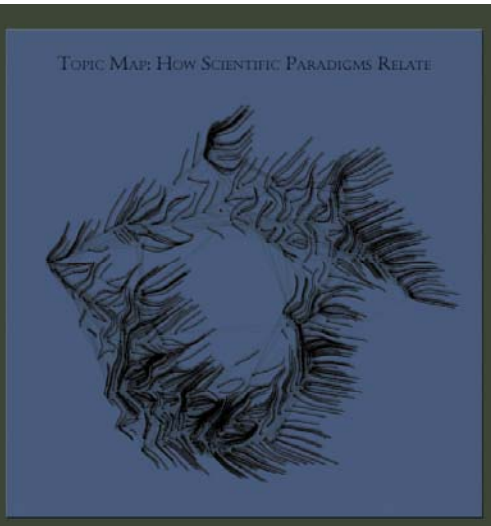
- Who is doing research on what topic and where?
- What is the 'footprint' of interdisciplinary research fields?
- What impact have scientists?

Interactive touch panel.

Contributions:

- Interactive, high resolution interface to access and make sense of data about scholarly activity.





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.

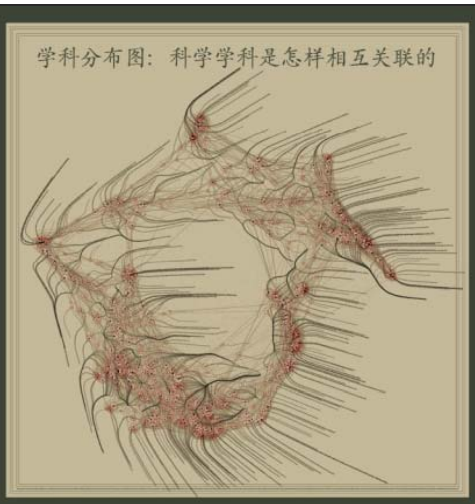
Nanotechnology

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

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 shapshot lights science that cites the second; and the fourth lights science that cites the third.



你可以通过触摸屏在地图上随意指点来改变所到之处的光亮强度。当你触摸世界地图的某一点时，在那个地理位置上的所有研究机构会被点亮。同时在这些研究机构工作的学者的论文所属的学科会在学科分布图上被点亮。而当你触摸学科分布图的某一点时，在那个位置上的科学学科会被点亮。同时从事这些学科研究的研究机构在世界地图上的分布会被点亮。

纳米技术

这里显示所有和纳米技术相关的科学学科。纳米技术和科学研究人类在无形的空间里改造世界的能力。这些空间寿在于极其微小以至单个原子的结构中。目前大部分有关纳米的研究主要集中在物理、化学和材料科学领域。它们主要位于学科分布图上半部分的右面。不过，纳米技术在生物学和医药学研究里的应用也越来越多。生物学和医药学位于学科分布图下半部分的右面。

所有科学学科 显示所有776种科学学科	**纳米技术** 有关微观粒子的科学	**弗郎西.科里克** DNA双螺旋状的发现者之一	**阿尔伯特.爱因斯坦** 用相对论重新激活了物理学	**迈克尔.费舍尔** 发现了物质转变模式的关键步骤	**苏珊.费斯克** 研究人的认知是如何产生偏见的
可持续性 一些与人类寄予长期希望相关的科学	**化学和生物** 化学和生物科学的交叉部分	**约舒亚.雷德伯格** 细菌遗传机制研究的先驱	**德里克.德索拉.普里斯** 著名的"科学计量学之父"	**理查德.扎尔** 采用激光化学技术研究分子动态分布	**关于本次展览** 与此展览相关人员和机构

探索科学学科的相互关联性

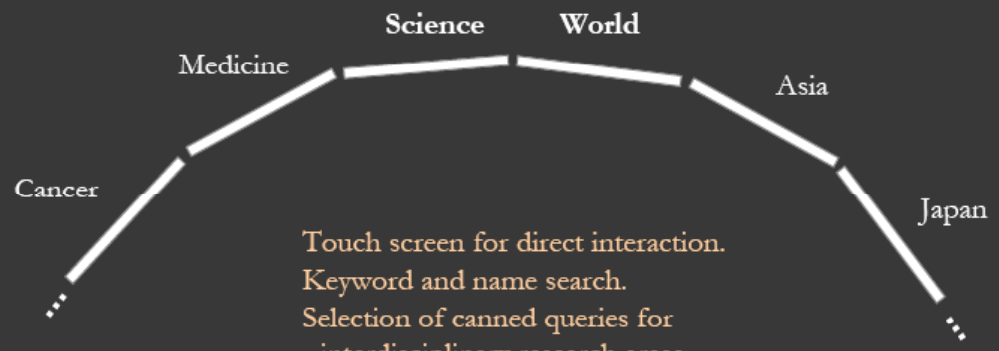
光柱缓慢的扫过所有相互关联的科学学科，每一个学科以及从事这方面科学研究的研究机构在世界地图上的位置会被逐一点亮。首先，显示屏会点亮那些产出论文最多、最活跃的科学学科，然后那些小学科或冷门学科会被逐一点亮。

探索某个学者的科学著作的影响力的传播

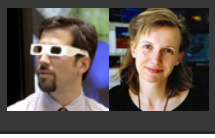
显示屏通过四步来展示某个学者对科学的贡献以及影响力的传播。首先，显示屏点亮该学者所发表的论文所属的学科在学科分布图上的位置以及该学者从事这项研究时所在的研究机构在世界地图上的位置。到目前为止，所有这些论文的引用率仍然很高。第二步，显示屏点亮所有引用在第一步中被点亮的原始论文的论文在学科分布图上的位置以及它们在世界地图上的位置。第三步，显示屏点亮所有引用了在第二步中被点亮的论文的学科在学科分布图上的位置以及它们在世界地图上的位置。第四步，显示屏点亮所有引用了在第三步中被点亮的论文的学科在学科分布图上的位置以及它们在世界地图上的位置。

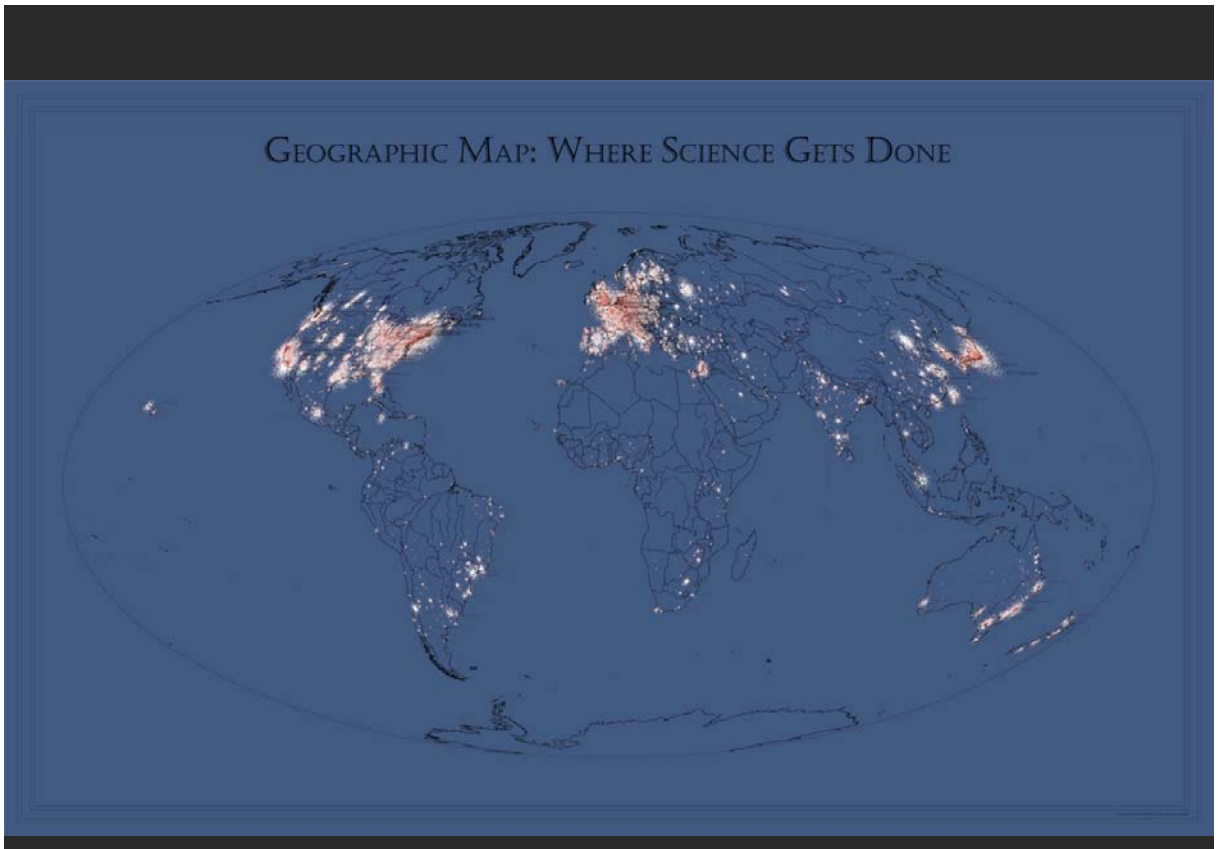
Re-implementation of Illuminated Diagram Software
by Advanced Visualization Lab, Indiana University

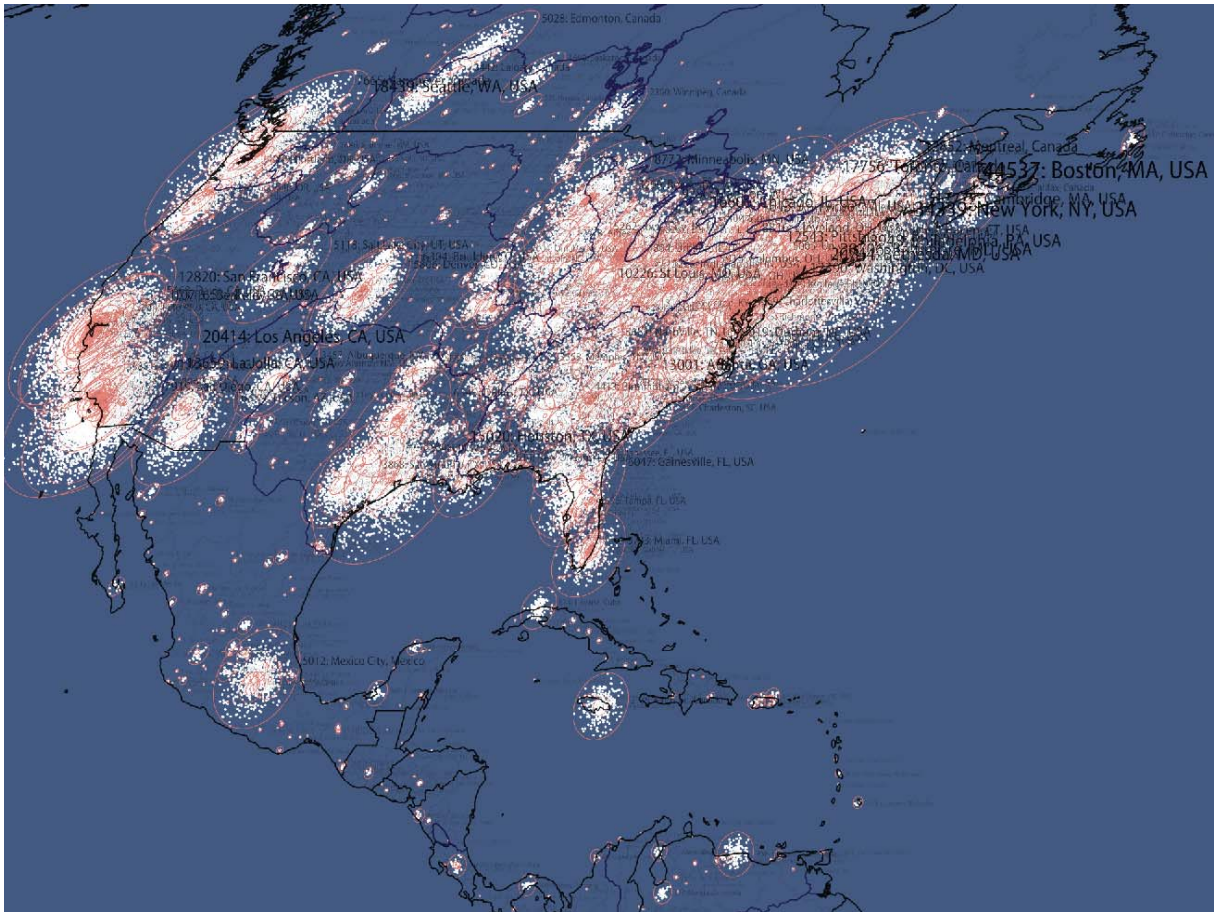
Drives unlimited number of ID screens.

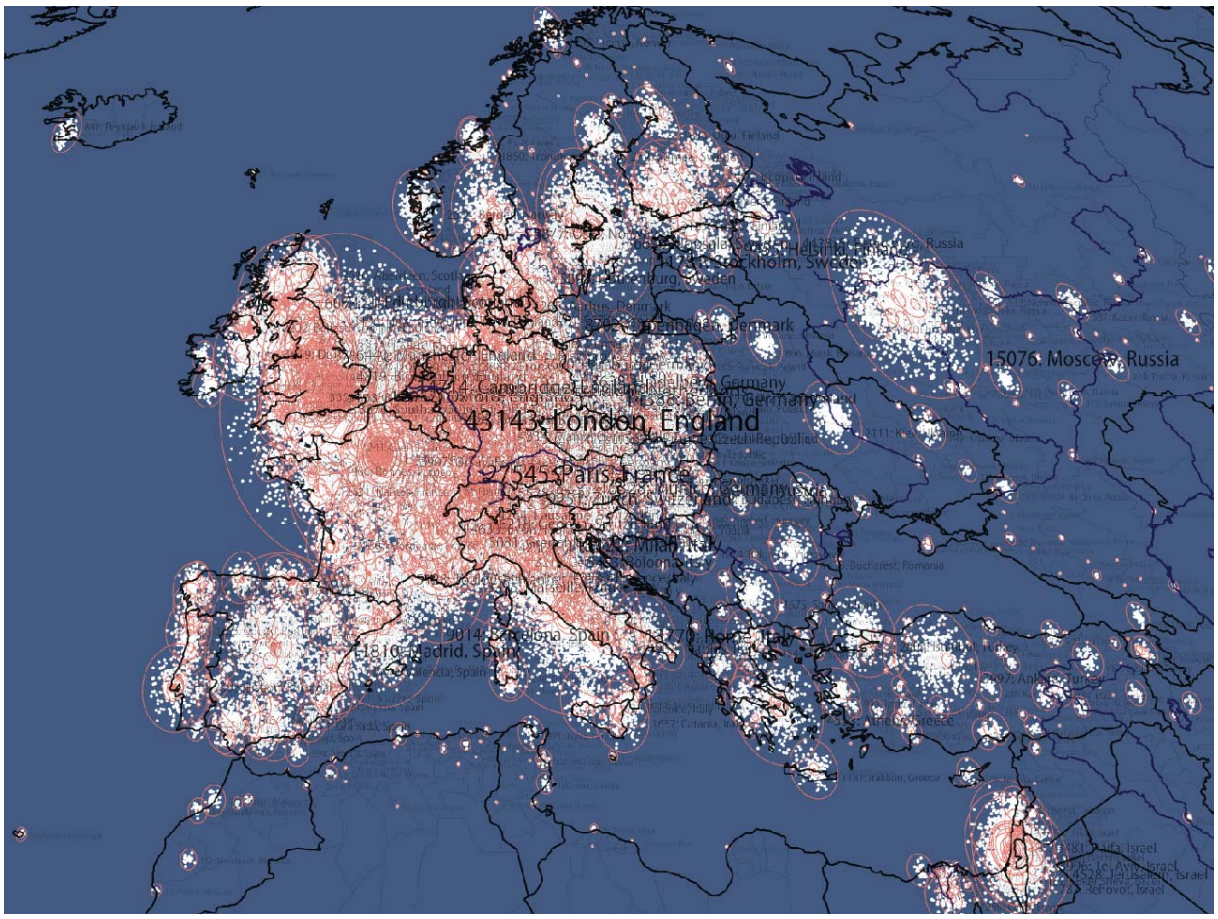


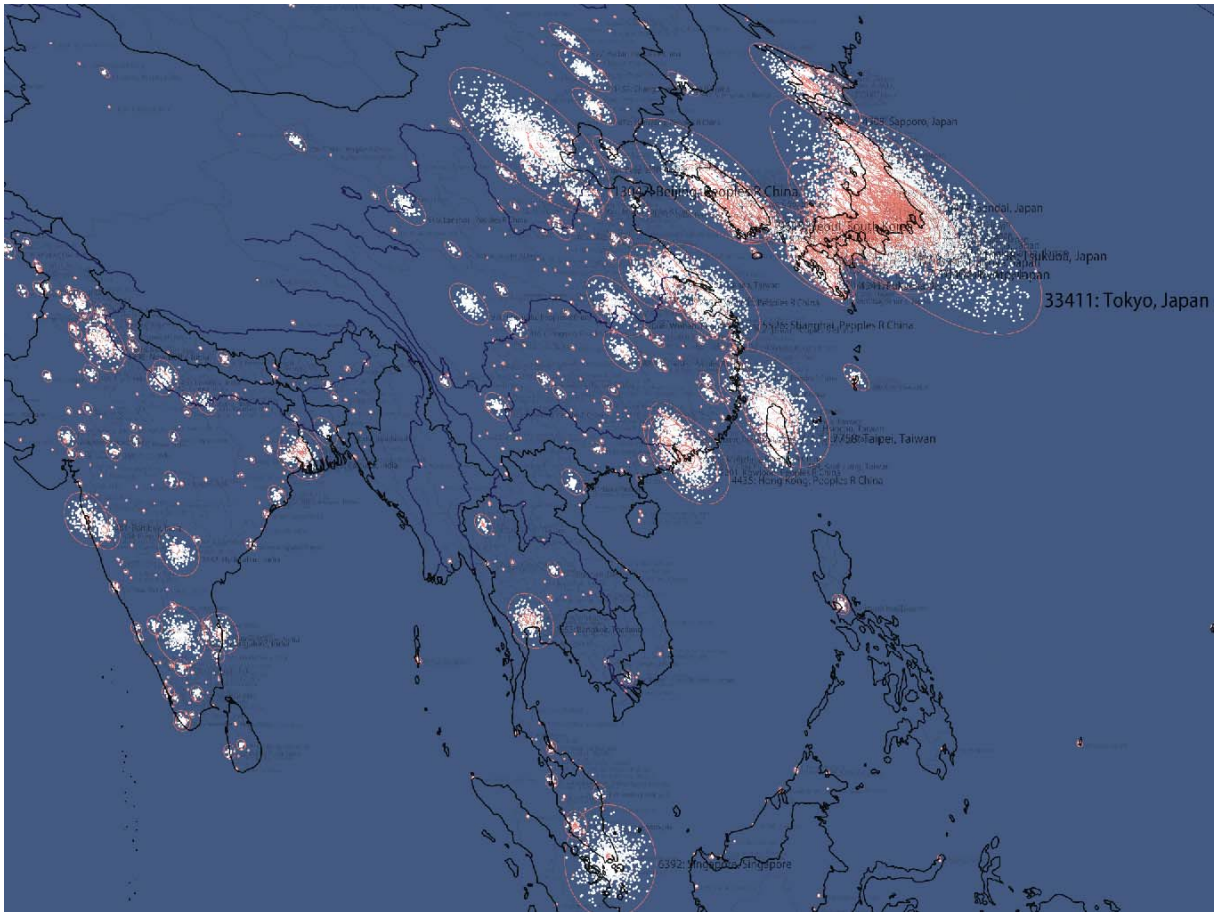
Touch screen for direct interaction.
Keyword and name search.
Selection of canned queries for
- interdisciplinary research areas
- famous people
- activity patterns, e.g., bursts, trends, etc.



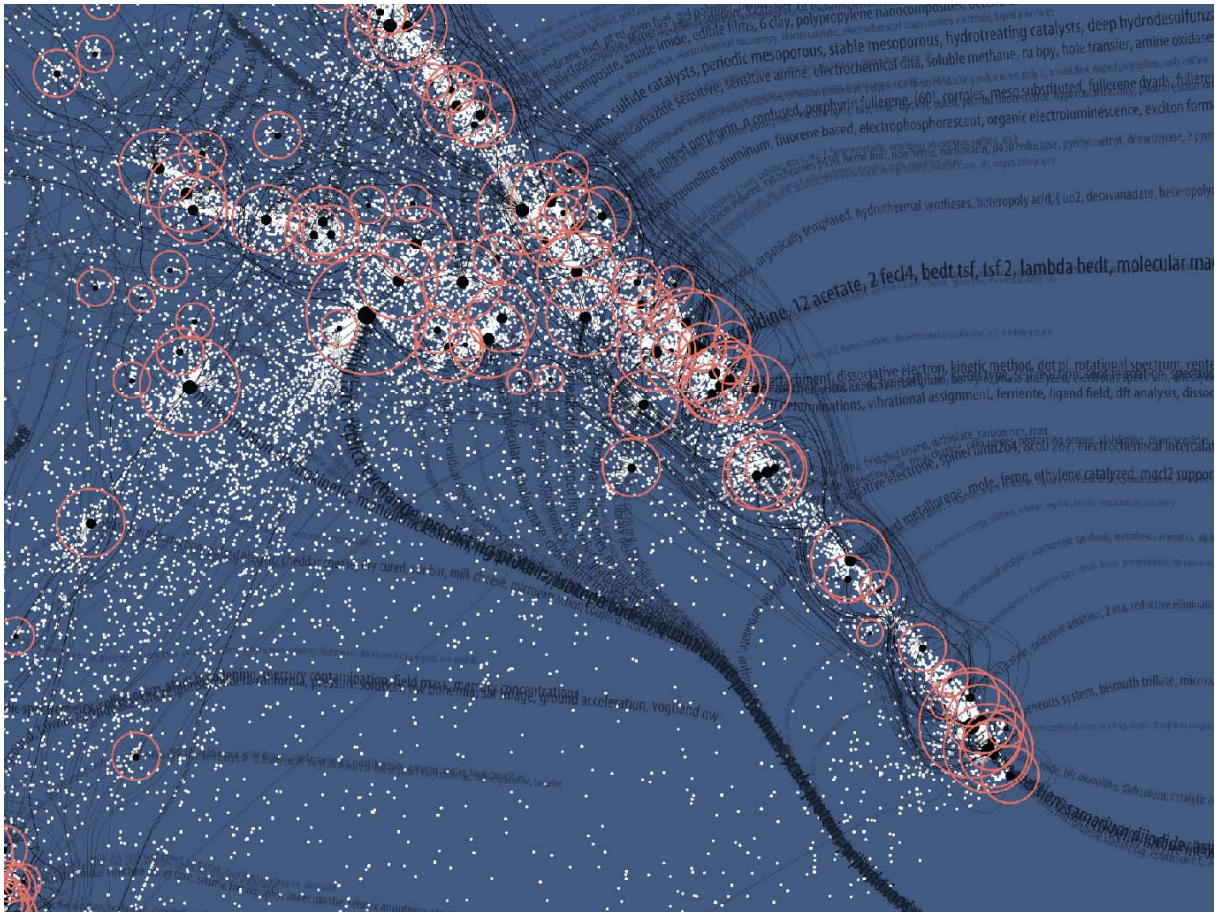



5028: Edmonton, Canada
18439: Seattle, WA, USA
4537: Boston, MA, USA
New York, NY, USA
20414: Los Angeles, CA, USA
5012: Mexico City, Mexico


15076: Moscow, Russia
4313: London, England
27545: Paris, France
Rome, Italy
Madrid, Spain


33411: Tokyo, Japan

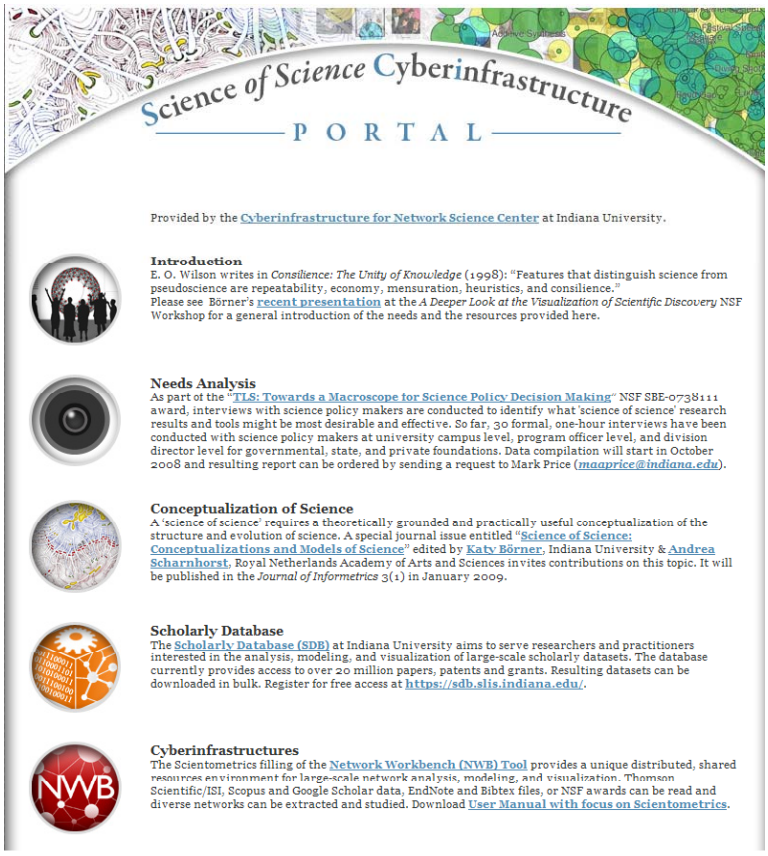

Topic Map: How Scientific Paradigms Relate



Debut of 5th Iteration of Mapping Science Exhibit at MEDIA X on May 18, 2009
at Wallenberg Hall, Stanford University
http://mediax.stanford.edu
http://scaleindependentthought.typepad.com/photos/scimaps

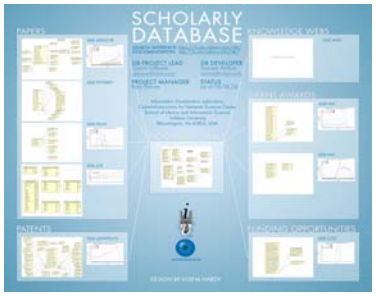
Science Maps in "Expedition Zukunft" science train visiting 62 cities in 7 months
12 coaches, 300 m long
Opened on April 23rd, 2009 by German Chancellor Merkel
http://www.expedition-zukunft.de

Science of Science Cyberinfrastructure



http://sci.slis.indiana.edu

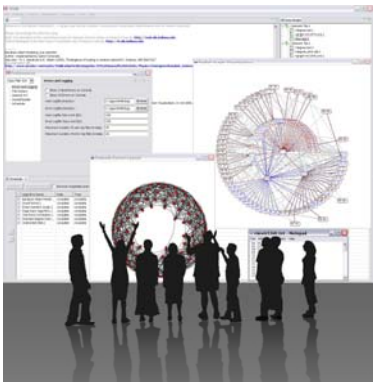
Cyberinfrastructures for a Science of Science



Scholarly Database of 23 million scholarly records
https://sdb.slis.indiana.edu

James S. McDonnell Foundation

Information Visualization Cyberinfrastructure
http://iv.slis.indiana.edu

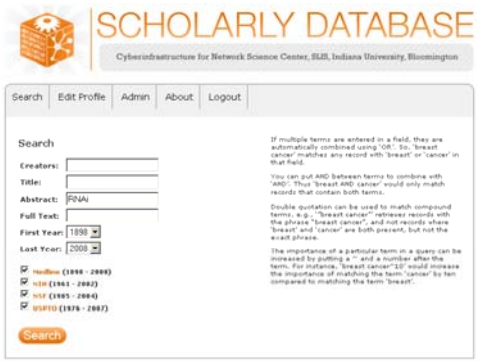


Network Workbench Tool and Community Wiki
***NEW* Scientometrics plugins**
http://nwb.slis.indiana.edu

Epidemics Cyberinfrastructure
http://epic.slis.indiana.edu/

Scholarly Database: Web Interface

Search across publications, patents, grants.
Download records and/or (evolving) co-author, paper-citation networks.



Register for free access at http://sdb.slis.indiana.edu

Scholarly Database: # Records & Years Covered

Datasets available via the Scholarly Database

Dataset	#Records	Years Coverage	updated	Restricted Access
Medline	16,053,495	1898-2008	Yes	
PhysRev	398,005	1893-2006		Yes
PNAS	16,167	1997-2002		Yes
JCR	59,078	1974,1979,1984,1989,1994-2004		Yes
USPTO	3,710,952	1976-2007	Yes	
NSF	174,835	1985-2003	Yes	
NIH	1,043,804	1972-2002	Yes	
Total	**21,456,336**	**1893-2008**	**4**	**3**

Aim for comprehensive temporal, geospatial, and topic coverage.

Network Workbench (NWB) Project

Investigators: Katy Börner, Albert-Laszlo Barabasi, Santiago Schnell, Alessandro Vespignani & Stanley Wasserman, Eric Wernert

Software Team: Lead: Micah Linnemeier

Members: Patrick Phillips, Russell Duhon, Tim Kelley & Ann McCranie

Previous Developers: Weixia (Bonnie) Huang, Bruce Herr, Heng Zhang, Duygu Balcan, Bryan Hook, Ben Markines, Santo Fortunato, Felix Terkhorn, Ramya Sabbineni, Vivek S. Thakre & Cesar Hidalgo

Goal: Develop a large-scale network analysis, modeling and visualization toolkit for physics, biomedical, and social science research.

Amount: $1,120,926, NSF IIS-0513650 award

Duration: Sept. 2005 - Aug. 2009

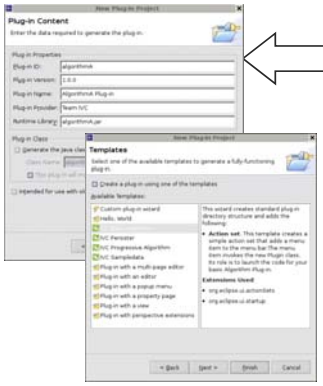
Website: http://nwb.slis.indiana.edu

Serving Non-CS Algorithm Developers & Users

Developers

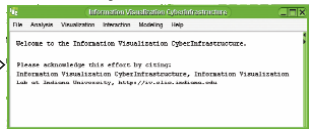
Users

CIShell Wizards

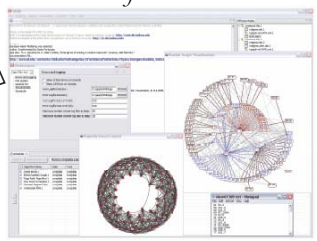


CIShell

IVC Interface



NWB Interface



See https://nwb.slis.indiana.edu/community July 1st, 2008

Algorithms Currently Available

Preprocessing Edit

- **Remove Nodes**
  - Extract Top Nodes
  - Extract Nodes Above or Below Val
  - Delete High Degree Nodes
  - Delete Random Nodes
  - Delete Isolates
- **Remove Edges**
  - Extract Top Edges
  - Extract Edges Above or Below Val
  - Remove Self Loops
  - Trim By Degree[2]
  - Pathfinder Network Scaling
- **Sampling**
  - Snowball Sampling (n nodes)
  - Node Sampling
  - Edge Sampling
- **Transformations**
  - Symmetrize
  - Dichotomize
  - Multipartite Joining

Modeling Edit

- **General**
  - Random Graph
  - Watts-Strogatz Small World
  - Barabási-Albert Scale-Free
- **Structured**
  - CAN
  - Chord
- **Unstructured**
  - Hypergrid
  - PRU
- **Other**
  - TARL
  - Discrete Network Dynamics

Analysis Edit

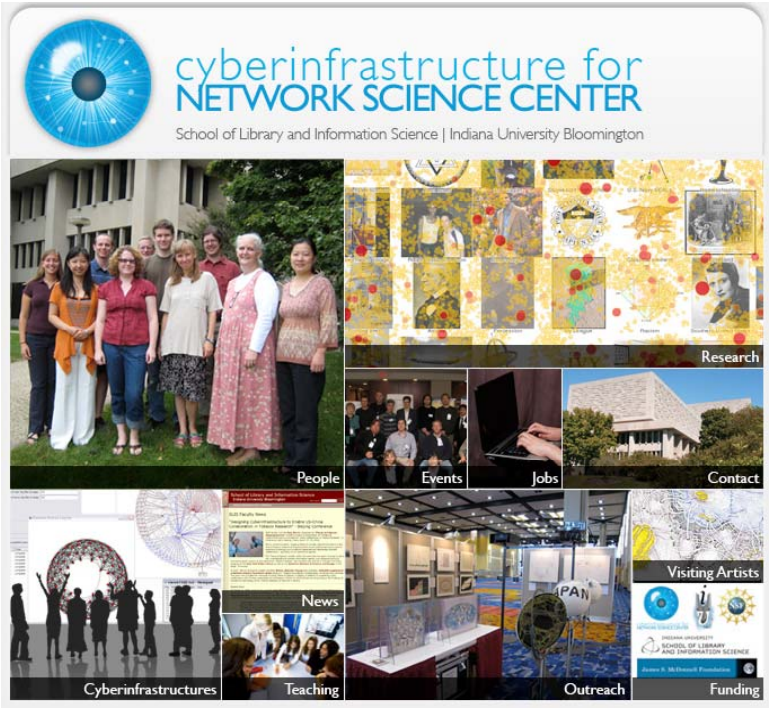
- **General Purpose**
  - Network Analysis Toolkit[2]
- **Unweighted & Undirected**
  - **Based on degree/**
    - Node Degree
    - Node Distribution
  - **Based on clustering**
    - k-Nearest Neighbor
    - Watts Strogatz Clustering Coefficie
    - Watts Strogatz Clustering Coefficie
  - **Based on path**
    - Diameter
    - Average Shortest Path
    - Shortest Path Distribution
    - Node Betweenness Centrality
  - **Based on components**
    - Connected Components
    - Weak Component Clustering
  - **K-Core**
    - Extract K-Core[2]
    - Annotate K-Coreness[2]
- **Unweighted & Directed**
  - **Based on degree**
    - Node Indegree
    - Node Outdegree
    - Indegree Distribution
    - Outdegree Distribution
  - **Based on local graph structure**
    - k-Nearest Neighbor
    - Single Node In-Out Degree Correla
  - **Unnamed Category?**
    - Page Rank
  - **Based on local graph structure**
    - Dyad Reciprocity[2]
    - Arc Reciprocity[2]
    - Adjacency Transitivity[2]
  - **Based on components**
    - Weak Component Clustering
    - Extract Attractors[2]

Visualization Edit

- **Tools**
  - GUESS
  - GnuPlot[2]
- **Predefined Positions Layout**
  - DrL (VxOrd)
  - Pre-defined Positions (prefuse beta)[2]
- **Move**
  - Circular
- **Tree Layouts**
  - Radial Tree (prefuse alpha)
  - Radial Tree with Annotations (prefuse beta)[2]
  - Tree Map
  - Tree View
  - Balloon Graph (prefuse alpha)[2]
- **Network Layouts**
  - Force Directed with Annotation (prefuse beta)
  - Kamada-Kawai (JUNG)
  - Fruchterman-Reingold (JUNG)
  - Fruchterman-Reingold with Annotation (prefuse beta)
  - Spring (JUNG)
  - Small World (prefuse alpha)
- **Other Layouts**
  - Parallel Coordinates (demo)[2]
  - LaNet (k-Core Decomposition)

Scientometrics Edit

- **Extract Network From Table**
  - Extract Co-Authorship Network
  - Extract Co-Occurrence Network From Table[2]
  - Extract Directed Network From Table[2]
- **Extract Network From Another Network**
  - Extract Bibliographic Coupling Similarity Network
  - Extract Co-Citation Similarity Network[2]
- **Cleaning**
  - Remove ISI Duplicate Records
  - Detect Duplicate Nodes
  - Remove Rows With Multitudinous Fields[2]



http://cns.slis.indiana.edu