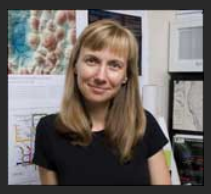
Mapping Science: Opportunities and Challenges



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

Expedition Workshop/Mapping Public Goods And Services Connecting To Science & Scholarly Knowledge
Office of Intergovernmental Solutions, D.C. (Susan B. Turnbull)
2007.08.14

Challenges & Opportunities

"Science.gov is a gateway to **50 million pages** of authoritative selected science information provided by U.S. government agencies, including research and development results." *(science.gov)*

The Scholarly Database at Indiana University supports cross-searching of publication, patent and grant databases, **18 million records** in total.

Some areas of science produce more than **40,000 scholarly papers each month.**

Challenges & Opportunities

No one human brain or man made machine can make sense and utilize so much data, information, knowledge, and expertise.

Search engines help us finding facts and navigating local neighborhoods of these facts. They do not support the discovery of (global) trends, patterns, outliers, etc.

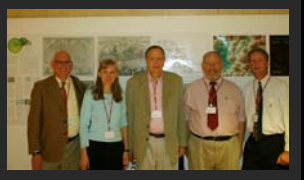
Maps have guided mankind's explorations for centuries. Can we use them to guide our scientific explorations?

Overview

- Mapping Science Exhibit
  - 1st Iteration in 2005: **The Power of Maps**
  - 2nd Iteration in 2006: **The Power of Reference Systems**
  - 3rd Iteration in 2007: **The Power of Forecasts**
- Science Map Making
  - General Process
  - Recent Insights
- Scholarly Marketplaces
  - Scholarly Database
  - Cyberinsfrastructure Shell
  - Network Workbench / EpiC Cyberinfrastructure

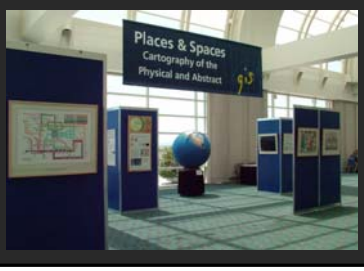
Overview

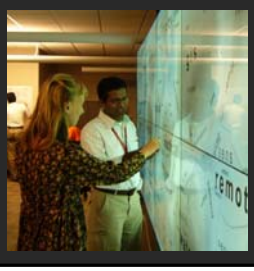
- Mapping Science Exhibit
  - 1st Iteration in 2005: **The Power of Maps**
  - 2nd Iteration in 2006: **The Power of Reference Systems**
  - 3rd Iteration in 2007: **The Power of Forecasts**
- Science Map Making
  - General Process
  - Recent Insights
- Scholarly Marketplaces
  - Scholarly Database
  - Cyberinsfrastructure Shell
  - Network Workbench / EpiC Cyberinfrastructure



Places & Spaces: Mapping Science
a science exhibit that introduces people to maps of sciences, their makers and users.
http://scimaps.org

Exhibit Curators:
Dr. Katy Börner &
Julie Smith, Indiana University





Illuminated Diagram Display

(VIDEO: 4:10-8:45)

Places & Spaces: Mapping Science *exhibit at NYPL, New York, 2006*

Places & Spaces: Mapping Science *exhibit at ACM in Chicago, 2007*

Places & Spaces: Mapping Science *exhibit at MCPL in Bloomington, IN, 2007*

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

Overview

- Mapping Science Exhibit
  - 1st Iteration in 2005: **The Power of Maps**
  - 2nd Iteration in 2006: **The Power of Reference Systems**
  - 3rd Iteration in 2007: **The Power of Forecasts**
- Science Map Making
  - General Process
  - Recent Insights
- Scholarly Marketplaces
  - Scholarly Database
  - Cyberinsfrastructure Shell
  - Network Workbench / EpiC Cyberinfrastructure

Mapping Science

- 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.
- 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).
- Börner, Katy, Sanyal, Soma and Vespignani, Alessandro (in press). **Network Science.** In Blaise Cronin (Ed.), Annual Review of Information Science & Technology, Information Today, Inc./American Society for Information Science and Technology, Medford, NJ.

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

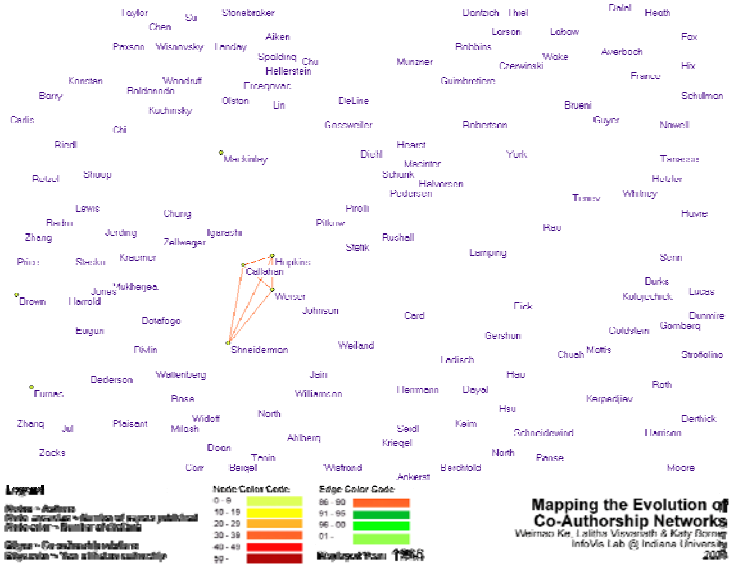
Process of Analyzing and Mapping Science

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, Chen & Boyack. (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.

Mapping the Evolution of Co-Authorship Networks

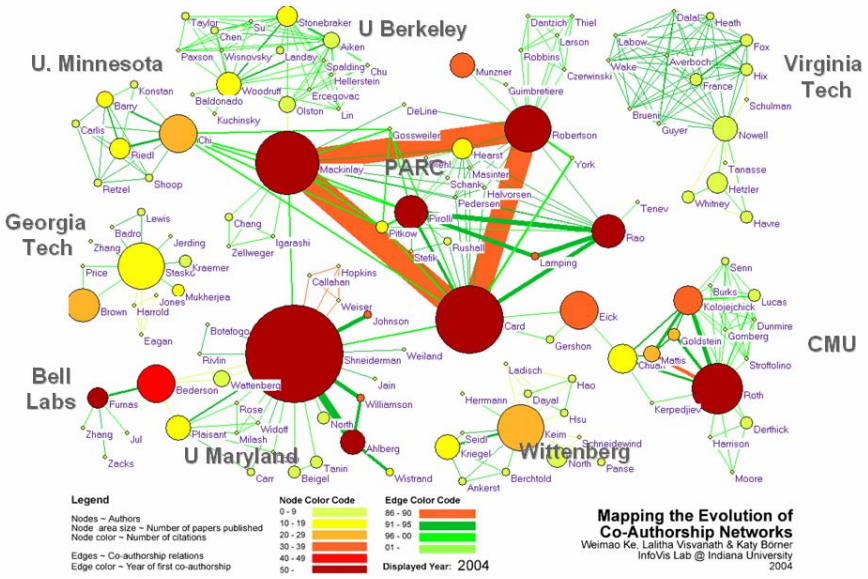
Ke, Visvanath & Börner, (2004) Won 1st price at the IEEE InfoVis Contest.



14

Mapping the Evolution of Co-Authorship Networks

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



15

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

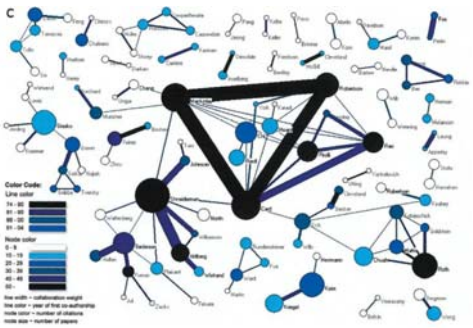
Börner, Dall'Asta, Ke & Vespignani (2005) Complexity, 10(4):58-67.

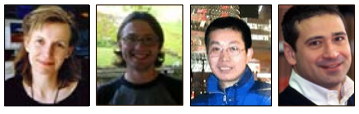
Research question:

- 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.





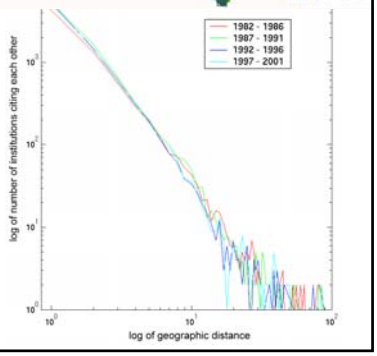
Spatio-Temporal Information Production and Consumption of Major U.S. Research Institutions



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.

Emergent Mosaic of Wikipedia Activity

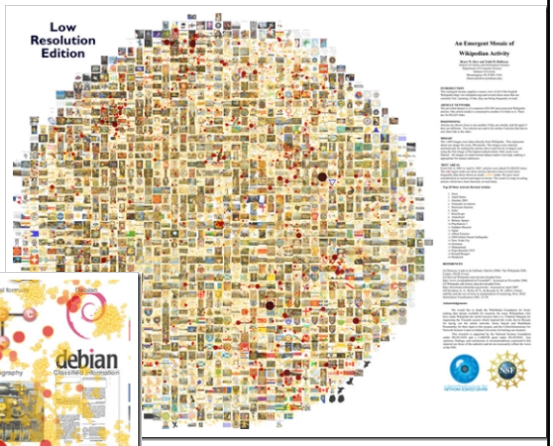
Herr, Holloway & Börner (2007)

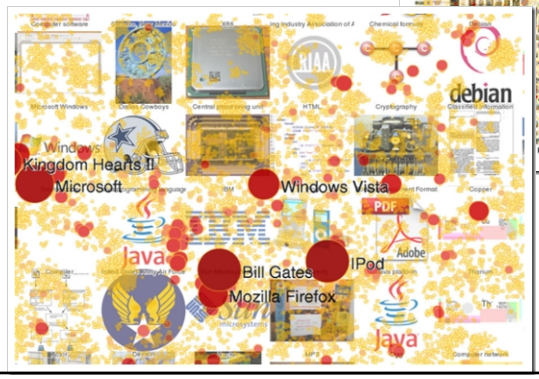
Research questions:

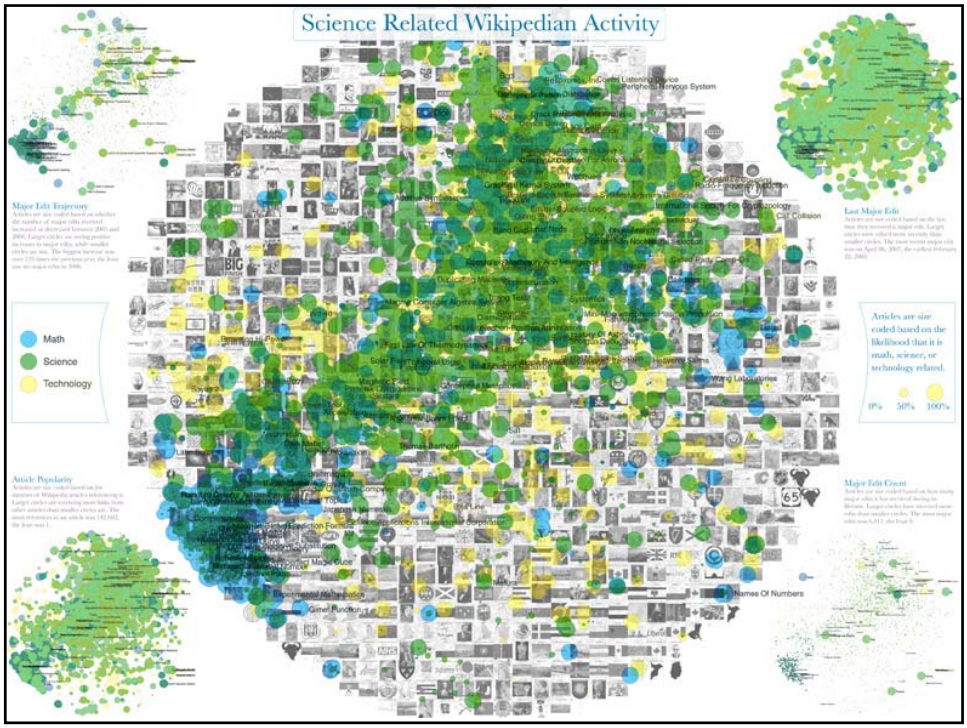
What topics does Wikipedia cover?

What article is edited most?

Does Wikipedia cover math, science and technology?

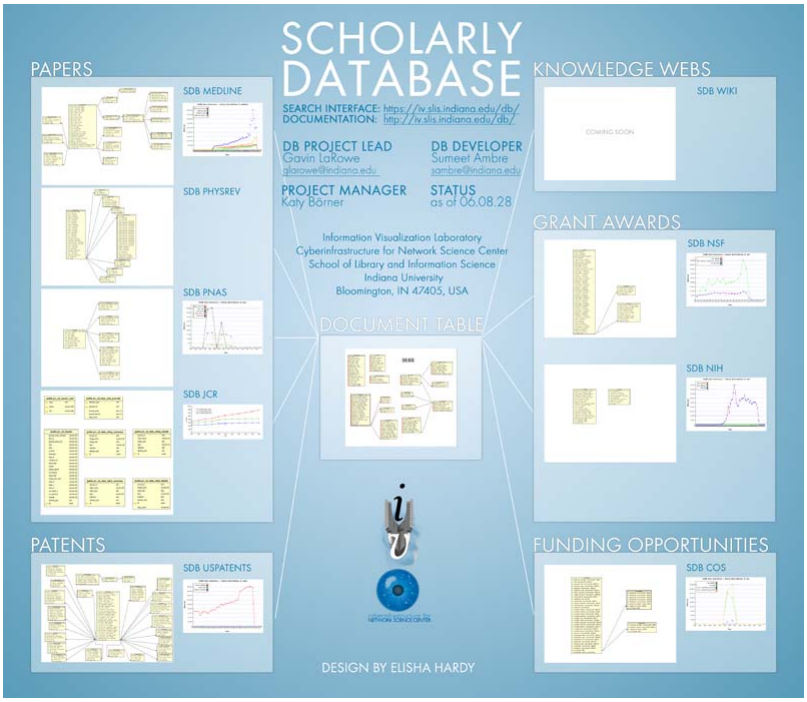






Overview

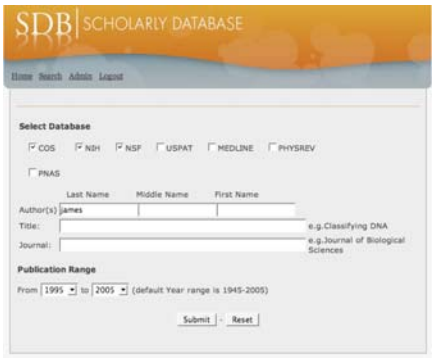
- Mapping Science Exhibit
  - 1st Iteration in 2005: **The Power of Maps**
  - 2nd Iteration in 2006: **The Power of Reference Systems**
  - 3rd Iteration in 2007: **The Power of Forecasts**
- Science Map Making
  - General Process
  - Recent Insights
- Scholarly Marketplaces
  - Scholarly Database
  - Cyberinsfrastructure Shell
  - Network Workbench / EpiC Cyberinfrastructure



Scholarly Database: Web Interface

Search across publications, patents, grants.

Download records and/or (evolving) co-author, paper-citation networks.



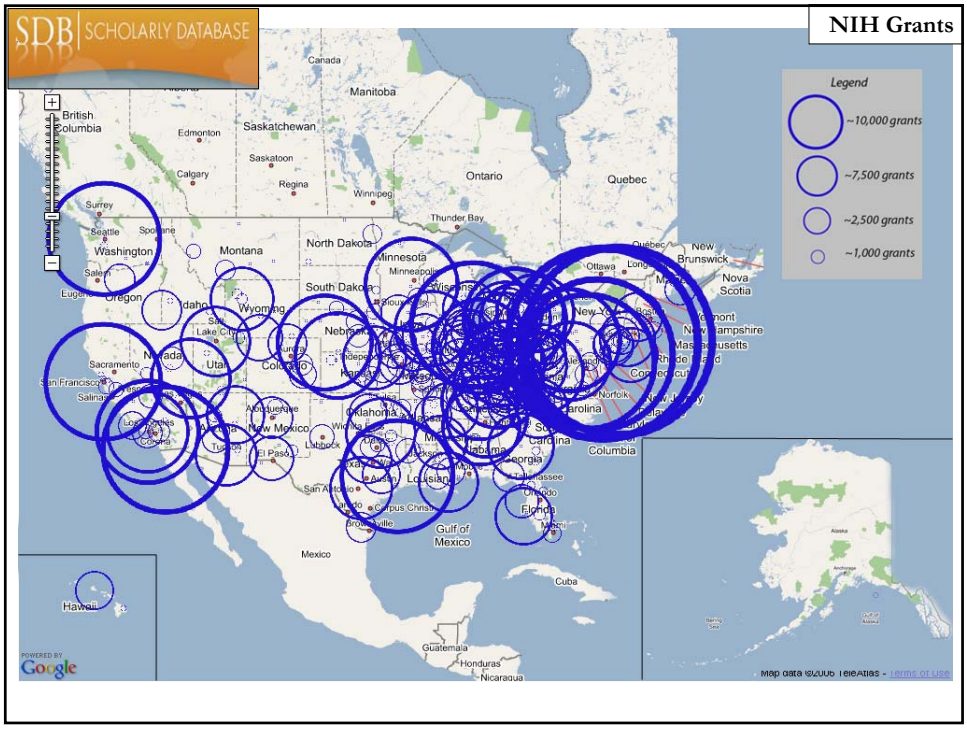
Register for free access at https://sdb.slis.indiana.edu.

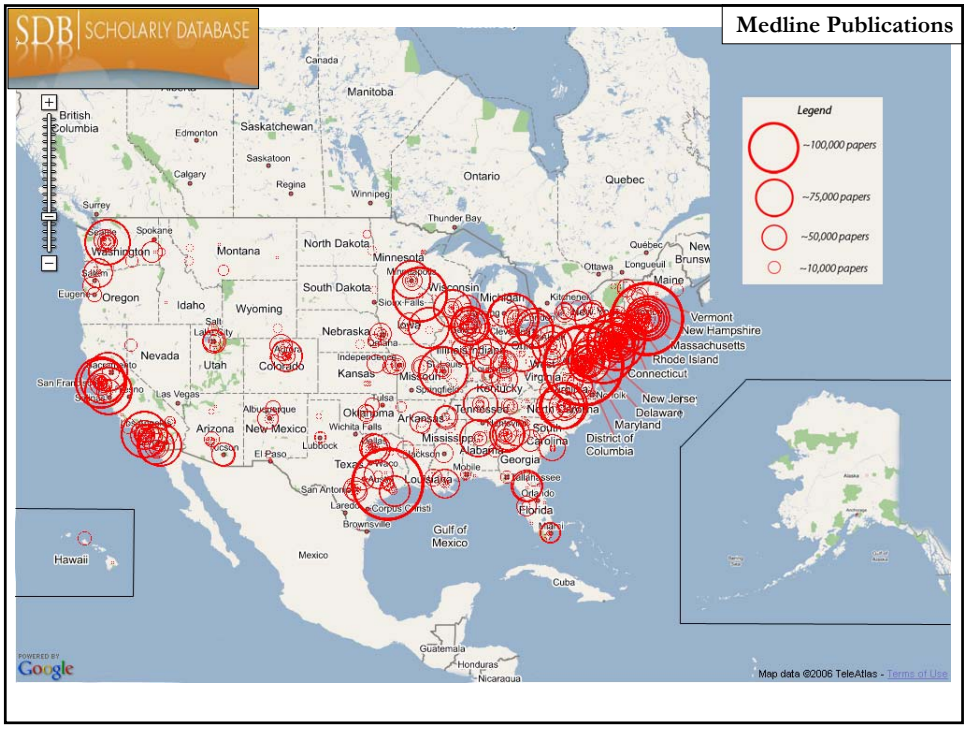
Scholarly Database: # Records & Years Covered

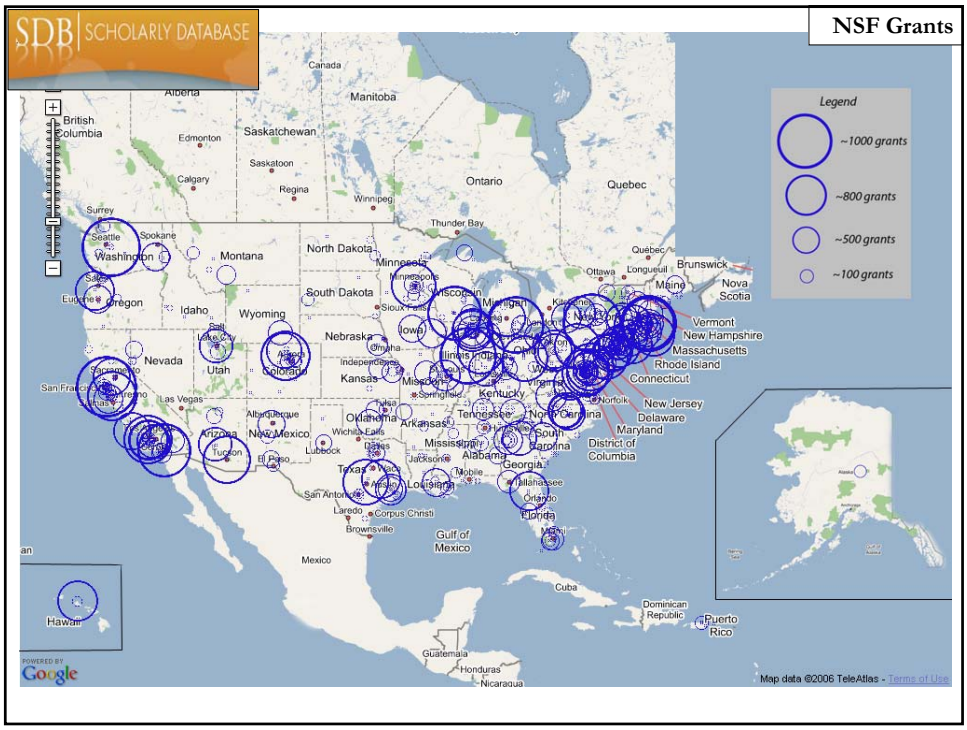
Datasets available via the Scholarly Database (* future feature)

Dataset	# Records	Years Covered	Updated	Restricted Access
Medline	13,149,741	1965-2005	Yes	
PhysRev	398,005	1893-2006		Yes
PNAS	16,167	1997-2002		Yes
JCR	59,078	1974, 1979, 1984, 1989 1994-2004		Yes
USPTO	3,179,930	1976-2004	Yes*	
NSF	174,835	1985-2003	Yes*	
NIH	1,043,804	1972-2002	Yes*	
Total	**18,021,560**	**1893-2006**	**4**	**3**

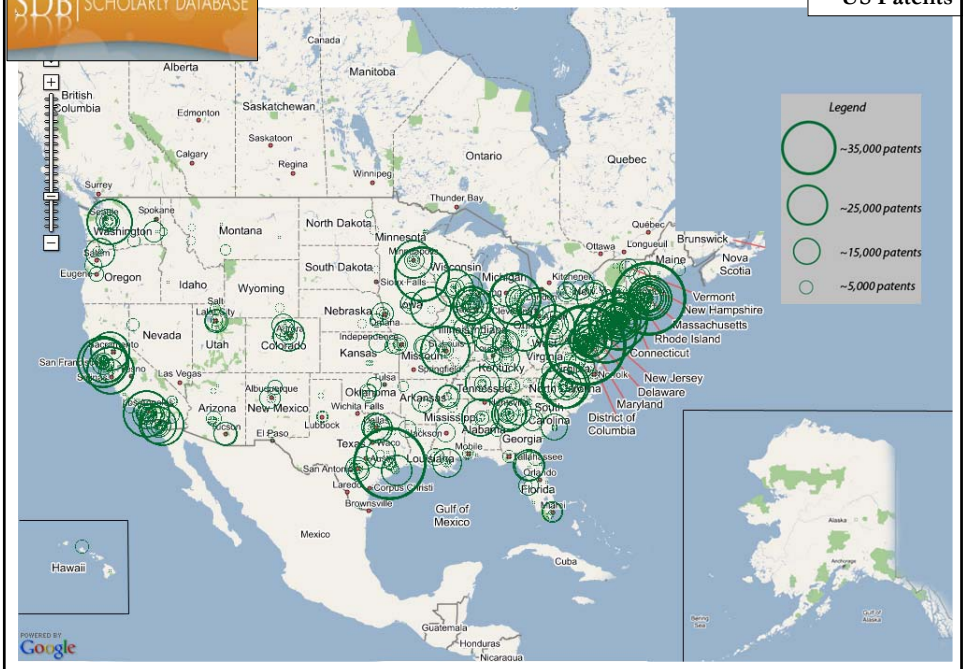
Aim for comprehensive time, geospatial, and topic coverage.




SDB | SCHOLARLY DATABASE
Medline Publications
Legend
~100,000 papers
~75,000 papers
~50,000 papers
~10,000 papers
Canada
Manitoba
Saskatchewan
Ontario
Quebec
British Columbia
Edmonton
Saskatoon
Calgary
Regina
Winnipeg
Thunder Bay
North Dakota
Minnesota
South Dakota
Montana
Wyoming
Idaho
Oregon
Nevada
Utah
Colorado
Nebraska
Kansas
Missouri
Wisconsin
Michigan
Vermont
New Hampshire
Massachusetts
Rhode Island
Connecticut
New Jersey
Delaware
Maryland
District of Columbia
Arizona
New Mexico
Oklahoma
Arkansas
Tennessee
Mississippi
Alabama
Georgia
Louisiana
Florida
Texas
Hawaii
Gulf of Mexico
Mexico
Cuba
Guatemala
Honduras
Nicaragua
Google
Map data ©2006 TeleAtlas - Terms of Use


SDB | SCHOLARLY DATABASE
NSF Grants
Legend
~1000 grants
~800 grants
~500 grants
~100 grants
Canada
Manitoba
Saskatchewan
Ontario
Quebec
British Columbia
Edmonton
Saskatoon
Calgary
Regina
Winnipeg
Thunder Bay
North Dakota
Minnesota
South Dakota
Montana
Wyoming
Idaho
Oregon
Nevada
Utah
Colorado
Nebraska
Kansas
Missouri
Wisconsin
Michigan
Brunswick
Nova Scotia
Vermont
New Hampshire
Massachusetts
Rhode Island
Connecticut
New Jersey
Delaware
Maryland
District of Columbia
Arizona
New Mexico
Oklahoma
Arkansas
Tennessee
Mississippi
Alabama
Georgia
Louisiana
Florida
Texas
Hawaii
Gulf of Mexico
Mexico
Cuba
Dominican Republic
Puerto Rico
Guatemala
Honduras
Nicaragua
Google
Map data ©2006 TeleAtlas - Terms of Use

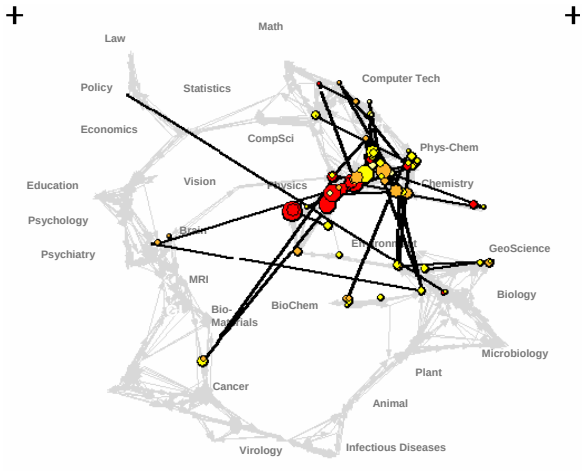
US Patents



Science map applications: Identifying core competency

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

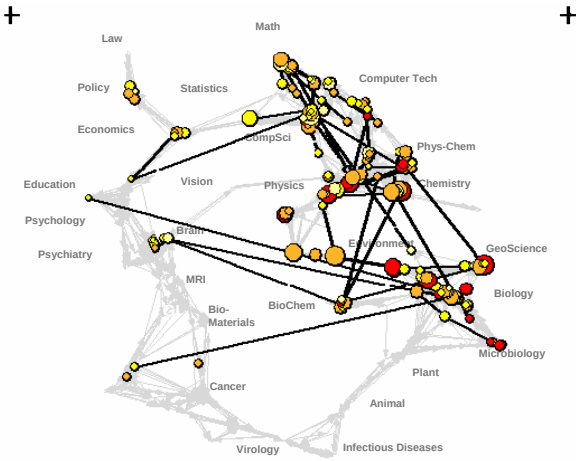
Funding patterns of the US Department of Energy (DOE)



Science map applications: Identifying core competency

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

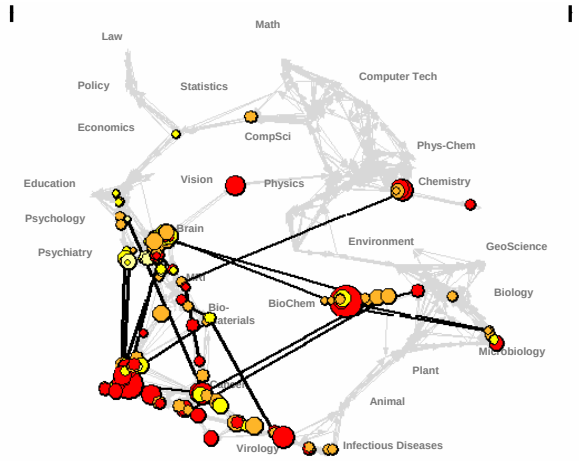
Funding Patterns of the National Science Foundation (NSF)



Science map applications: Identifying core competency

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

Funding Patterns of the National Institutes of Health (NIH)



Building Marketplaces not Cathedrals

- Design & implementation of 'software glue' that can interlink datasets and algorithms written in different languages using different data formats.
- The smaller the glue or 'CI Shell', the more likely it can be maintained.
- Dataset and algorithm 'plugins' are provided by application holders/ community.
- Applications resemble custom 'fillings'.

Cyberinfrastructure Shell (CIShell)

http://cishell.org

CIShell is an 'empty shell' that supports

- Easy integration of new datasets and algorithms by algorithm developers and
- Easy usage of algorithms by algorithm users.

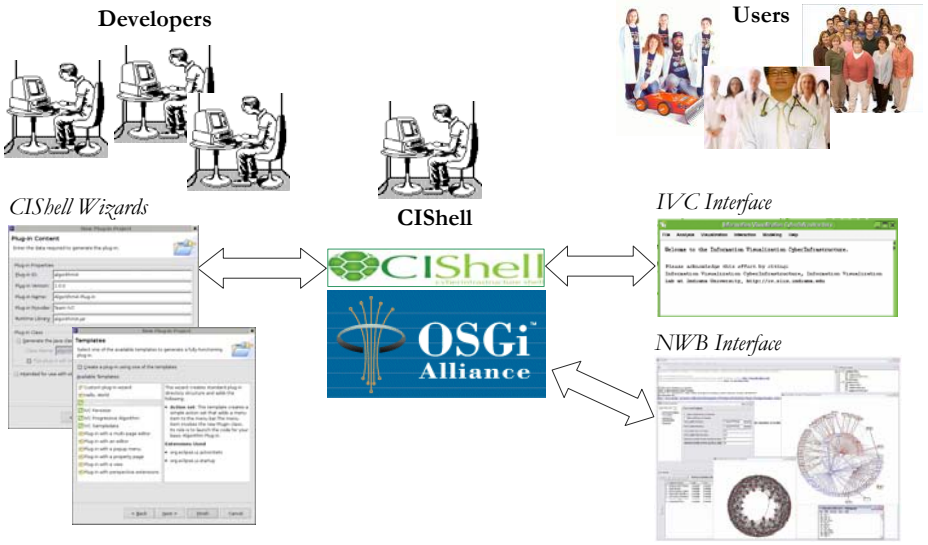
Its plug-and-play architecture supports the integration and utilization of diverse

- Datasets, e.g., stored in files, databases, steaming data.
- Algorithms, e.g., data processing, analysis, modeling, visualization.
- Interfaces, e.g., remote services, scripting engines, peer-to-peer clients.
- Services, e.g., workflow support, scheduler.

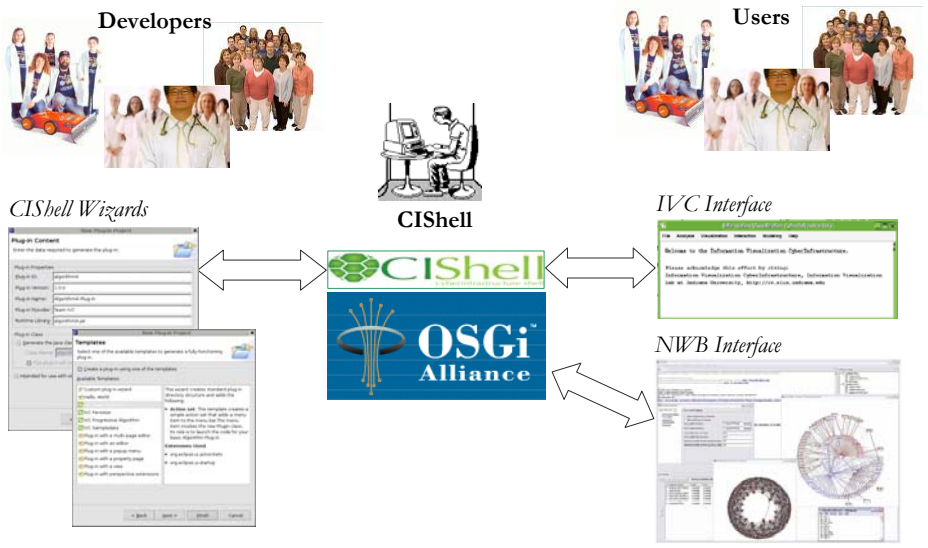
Hence, it can be used for custom UI/Toolkit development.

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-Laszlo Barabasi, Santiago Schnell, Alessandro Vespignani & Stanley Wasserman, Eric Wernert (Senior Personnel), $1,120,926) Sept. 05 - Aug. 08.
http://nwb.slis.indiana.edu

CIShell – Needs of Algorithm Developers & Users



CIShell – Needs of Algorithm Developers & Users



CIShell – Technical Details

CIShell is built upon the Open Services Gateway Initiative (OSGi) Framework.

OSGi (http://www.osgi.org) is

- A standardized, component oriented, computing environment for networked services.
- Successfully used in the industry from high-end servers to embedded mobile devices since 7 years.
- Alliance members include IBM (Eclipse), Sun, Intel, Oracle, Motorola, NEC and many others.
- Widely adopted in open source realm, especially since Eclipse 3.0 that uses OSGi R4 for its plugin model.

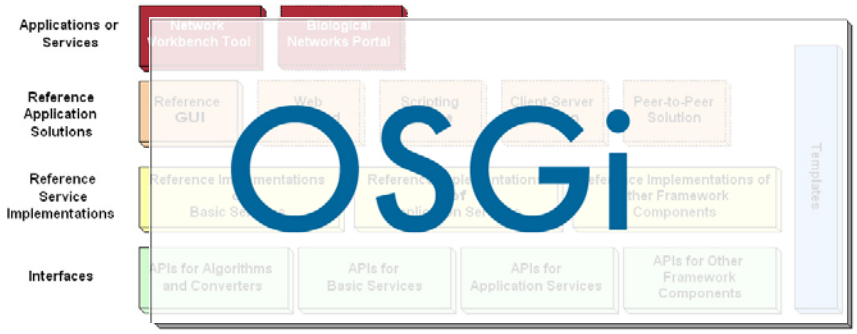
Advantages of Using OSGi

- Any CIShell algorithm is a service that can be used in any OSGi-framework based system.
- Using OSGi, running CIShells/tools can connected via RPC/RMI supporting peer-to-peer sharing of data, algorithms, and computing power.

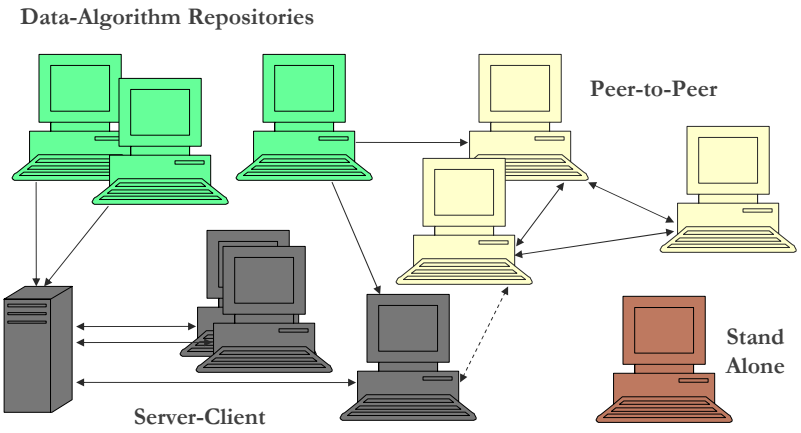
Ideally, CIShell becomes a standard for creating OSGi Services for algorithms. Developed Tools/CI, e.g., IVC & NWB, provide a reference GUI for underlying services.

CIShell – Technical Details

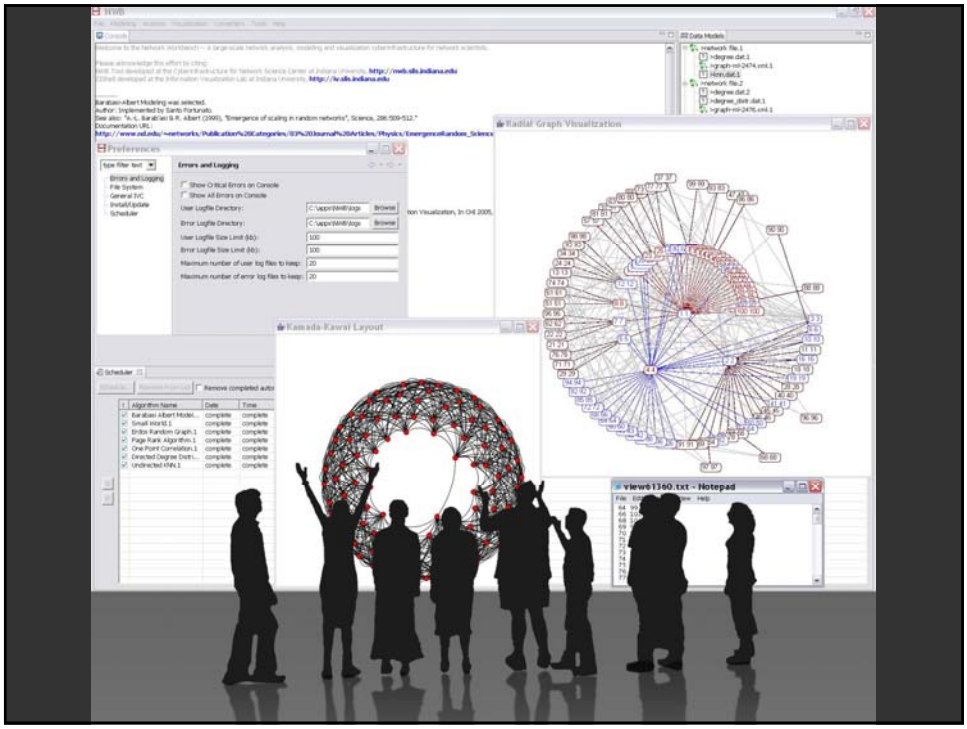
CIShell layer cake.



CIShell – Deployment



CIShell applications can be deployed as distributed data and algorithm repositories, stand alone applications, peer-to-peer architectures, and server-client architectures.



Network Workbench (NWB)

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

Software Team: Lead: Weixia (Bonnie) Huang

Developers: Bruce Herr, Ben Markines, Santo Fortunato, Cesar Hidalgo, Ramya Sabbineni, Vivek S. Thakre, & Russell Duhon

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

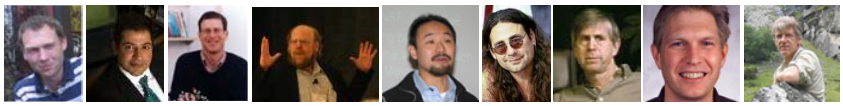
Amount: $1,120,926 NSF IIS-0513650 award.

Duration: Sept. 2005 - Aug. 2008

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

NWB Advisory Board

- Ulrik Brandes, University of Konstanz, Germany (Graph Theory)
- Noshier Contractor, Northwestern University (Communication Theory)
- Mark Gerstein, Yale University (Bioinformatics)
- James Hendler, Rensselaer Polytechnic Institute (Semantic Web)
- Jason Leigh, Electronic Visualization Laboratory, University of Illinois at Chicago (Visualization & CI)
- Neo Martinez, Pacific Ecoinformatics and Computational Ecology Lab (Biology)
- Michael Macy, Cornell University (Sociology)
- Stephen North, AT&T (Graph Visualization)
- Tom Snijders, University of Groningen (Social Network Analysis)



NWB CI Deliverables

Glue:

- CIShell — Core programmer team lead by Bonnie Huang

Tools, Services & Portals:

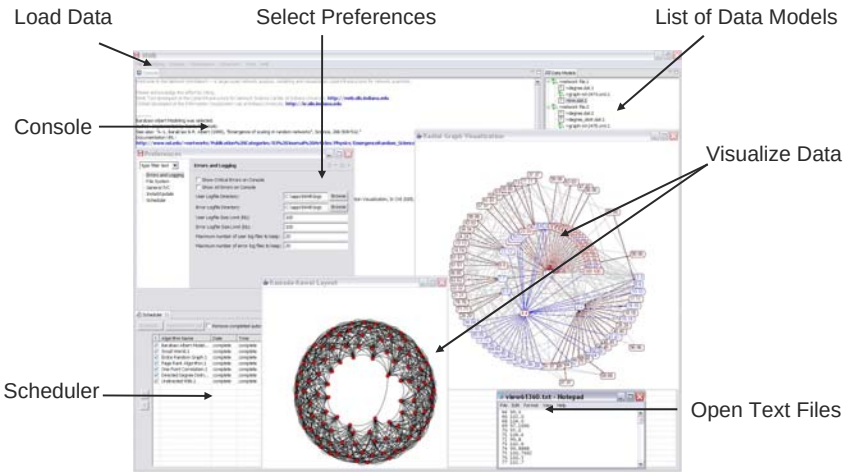
- NWB Tool — Lead by Alex Vespignani with input from other PIs
- SciMaps Service Online — Lead by Katy Borner
- Bio Tool — Lead by Laszlo Barabasi & Santiago Schnell

All three are prototypical instantiations of CIShell serving as reference implementations.

Documentation/Registry/Market Place:

- NWB Community Wiki — Lead by Katy Borner

NWB Tool: Interface Elements

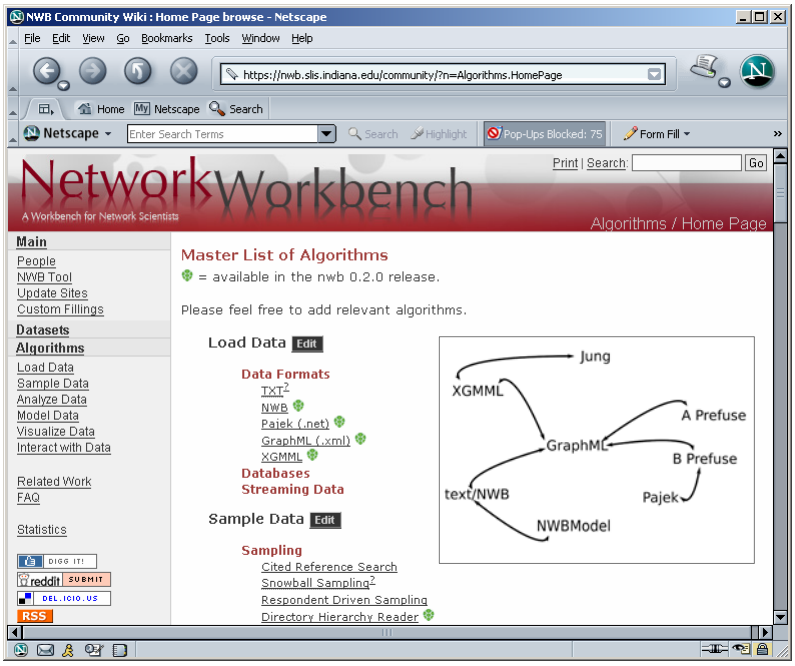


http://nwb.slis.indiana.edu/software.html

NWB Tool 0.2.0: List of Algorithms

Category	*Algorithm*	*Language*
Preprocessing	Directory Hierarchy Reader	JAVA
Modeling	Erdös-Rényi Random	FORTRAN
	Barabási-Albert Scale-Free	FORTRAN
	Watts-Strogatz Small World	FORTRAN
	Chord	JAVA
	CAN	JAVA
	Hypergrid	JAVA
	PRU	JAVA
Visualization	Tree Map	JAVA
	Tree Viz	JAVA
	Radial Tree / Graph	JAVA
	Kamada-Kawai	JAVA
	Force Directed	JAVA
	Spring	JAVA
	Fruchterman-Reingold	JAVA
	Circular	JAVA
	Parallel Coordinates (demo)	JAVA
Tool	XMGrace	

Analysis Algorithm	*Language*
Attack Tolerance	JAVA
Error Tolerance	JAVA
Betweenness Centrality	JAVA
Site Betweenness	FORTRAN
Average Shortest Path	FORTRAN
Connected Components	FORTRAN
Diameter	FORTRAN
Page Rank	FORTRAN
Shortest Path Distribution	FORTRAN
Watts-Strogatz Clustering Coefficient	FORTRAN
Watts-Strogatz Clustering Coefficient Versus Degree	FORTRAN
Directed k-Nearest Neighbor	FORTRAN
Undirected k-Nearest Neighbor	FORTRAN
Indegree Distribution	FORTRAN
Outdegree Distribution	FORTRAN
Node Indegree	FORTRAN
Node Outdegree	FORTRAN
One-point Degree Correlations	FORTRAN
Undirected Degree Distribution	FORTRAN
Node Degree	FORTRAN
k Random-Walk Search	JAVA
Random Breadth First Search	JAVA
CAN Search	JAVA



https://nwb.slis.indiana.edu/community

References

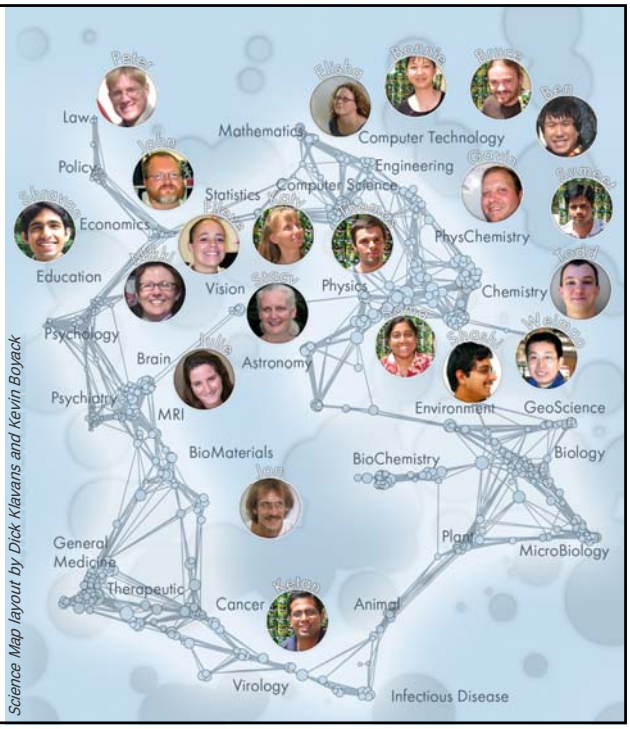
- Bruce Herr, Weixia Huang, Shashikant Penumarthy, Katy Börner. Designing Highly Flexible and Usable Cyberinfrastructures for Convergence. Submitted to William S. Bainbridge (Ed.) Progress in Convergence. Annals of the New York Academy of Sciences.
- Börner, Katy. Mapping All of Science: How to Collect, Organize and Make Sense of Mankind's Scholarly Knowledge and Expertise. Accepted for *Environment and Planning B*, Special Issue on *Mapping Humanity's Knowledge and Expertise in the Digital Domain*.
- 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.
- Holloway, Todd, Božicevic, Miran and Börner, Katy. Analyzing and Visualizing the Semantic Coverage of Wikipedia and Its Authors. Accepted for *Complexity*. Also available as cs.IR/0512085.
- Katy Börner. (2006) Semantic Association Networks: Using Semantic Web Technology to Improve Scholarly Knowledge and Expertise Management. In Vladimir Geroimenko & Chaomei Chen (eds.) *Visualizing the Semantic Web*, Springer Verlag, 2nd Edition, chapter 11, pp. 183-198.
- Boyack, Kevin W., Klavans, R. and Börner, Katy. (2005). Mapping the Backbone of Science. *Scientometrics,* 64(3), 351-374.
- Hook, Peter A. and Börner, Katy. (2005) Educational Knowledge Domain Visualizations: Tools to Navigate, Understand, and Internalize the Structure of Scholarly Knowledge and Expertise. In Amanda Spink and Charles Cole (eds.) *New Directions in Cognitive Information Retrieval*. Springer-Verlag, Netherlands, chapter 5, pp. 187-208.
- Börner, Katy, Dall'Asta, Luca, Ke, Weimao and Vespignani, Alessandro. (April 2005) Studying the Emerging Global Brain: Analyzing and Visualizing the Impact of Co-Authorship Teams. *Complexity*, special issue on *Understanding Complex Systems*, 10(4): pp. 58 - 67. Also available as cond-mat/0502147.
- Ord, Terry J., Martins, Emília P., Thakur, Sidharth, Mane, Ketan K., and Börner, Katy. (2005) Trends in animal behaviour research (1968-2002): Ethoinformatics and mining library databases. *Animal Behaviour*, 69, 1399-1413. Supplementary Material.
- Mane, Ketan K. and Börner, Katy. (2004). Mapping Topics and Topic Bursts in PNAS. *Proceedings of the National Academy of Sciences of the United States of America*, 101(Suppl. 1):5287-5290. Also available as cond-mat/0402380.
- Börner, Katy, Maru, Jeegar and Goldstone, Robert. (2004). The Simultaneous Evolution of Author and Paper Networks. *Proceedings of the National Academy of Sciences of the United States of America*, 101(Suppl_1):5266-5273. Also available as cond-mat/0311459.

Our Sponsors

- I-IKM: "Visualizing Network Dynamics" Competition at the International Conference on Network Science 2007. NSF IIS-0724282 award (Katy Börner) April 07 - March. 08.
- Creative Metaphors to Stimulate New Approaches to Visualizing, Understanding, and Rethinking Large Repositories of Scholarly Data. NSF award (Katy Börner) June 07 - May 09.
- Mapping Science Exhibit at the 233rd National Meeting & Exposition of the American Chemical Society in Chicago, IL. NSF award (Katy Börner, March 15, 07- March 14, 08)
- Collaborative Research: Social Networking Tools to Enable Collaboration in the Tobacco Surveillance, Epidemiology, and Evaluation Network (TSEEN). Collaborative Systems NSF IIS-0534909 award (Katy Börner, March 15, 06 - Feb 28, 09). Collaborative proposal with Noshir S. Contractor, NCSA, Tom Finholt, University of Michigan, and Gary Giovino, University at Buffalo.
- Modeling the Structure and Evolution of Scholarly Knowledge. James S. McDonnell Foundation grant in area Studying Complex Systems (Katy Börner & Robert L. Goldstone) Jan. 06 - Dec. 08.
- SEI: NetWorkBench: A Large-Scale Network Analysis, Modeling and Visualization Toolkit for Biomedical, Social Science and Physics Research. NSF IIS-0513650 award (Katy Börner, Albert-Laszlo Barabasi, Santiago Schnell, Alessandro Vespignani & Stanley Wasserman, Eric Wernert (Senior Personnel)) Sept. 05 - Aug. 08.
- Center of Excellence for Computational Diagnostics. 21st Century Grant (Susanne Ragg, David Clemmer, Sven Rahmann, and Ilka Ott, Terry Vik, R Clement McDonald, Nunroe Pecock, Zina Ben Miled & Katy Börner) Sept. 04 - Aug. 07.
- Quest Atlantis: Advancing a Socially-Responsive Meta-Game for Learning. NSF Role-0411846 award (Sasha Barab & Susan Herring, Daniel Hickey, William Blanton, Katy Börner (Senior Personnel)) Sept. 04 - Aug. 07.
- CAREER: Visualizing Knowledge Domains. NSF IIS-0238261 award (Katy Börner) Sept. 03-Aug. 08.

I would like to thank all my colleagues and collaborators.

If not otherwise indicated, this work was conducted at the Information Visualization Laboratory and the Cyberinfrastructure for Network Science Center at Indiana University.



The End.