Teaching Children the Structure of Science

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Stephen M. Uzzo, Bryan J. Hook

Workshop on "Using Maps of Science to teach Science"
ISSI 2009, Rio de Janeiro, Brazil.
July 14, 2009 (2-5pm)

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Abstract

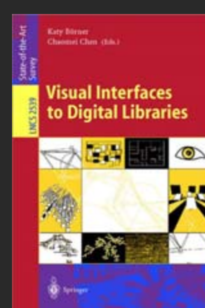
Maps of the world are common in classroom settings. They are used to teach the juxtaposition of natural and political functions, mineral resources, political, cultural and geographical boundaries; occurrences of processes such as tectonic drift; spreading of epidemics; and weather forecasts, among others. Recent work in scientometrics aims to create a map of science encompassing our collective scholarly knowledge. Maps of science can be used to see disciplinary boundaries; the origin of ideas, expertise, techniques, or tools; the birth, evolution, merging, splitting, and death of scientific disciplines; the spreading of ideas and technology; emerging research frontiers and bursts of activity; etc. Just like the first maps of our planet, the first maps of science are neither perfect nor correct. Today's science maps are predominantly generated based on English scholarly data: Techniques and procedures to achieve local and global accuracy of these maps are still being refined, and a visual language to communicate something as abstract and complex as science is still being developed. Yet, the maps are successfully used by institutions or individuals who can afford them to guide science policy decision making, economic decision making, or as visual interfaces to digital libraries. This paper presents the process and results of creating hands-on science maps for kids that teaches children ages 4-14 about the structure of scientific disciplines. The maps were tested in both formal and informal science education environments. The results show that children can easily transfer their (world) map and concept map reading skills to utilize maps of science in interesting ways.

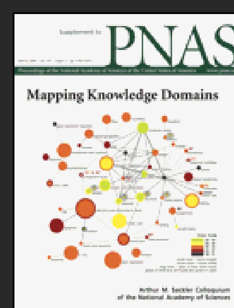
Börner, Katy, Palmer, Fileve, Davis, Julie M., Hardy, Elisha F., Uzzo, Stephen Miles & Hook, Bryan J.. (2009). Teaching Children the Structure of Science. In SPIE Conference on Visualization and Data Analysis (Vol. 7243, pp. 724307: 1-14), SPIE. http://ivl.slis.indiana.edu/km/pub/2009-borner-uzzo-kids-vda.pdf

Teaching Children the Structure of Science

- How can children start to understand the complex interplay of the different sciences?
- How can they get an intuitive understanding of the importance of math and how much it is needed to succeed in many if not all of the other sciences?
- What does it mean for teaching, learning, and job opportunities if the biomedical sciences account for 50% of all sciences?
- Can we make them see the central position of computer science and its evolving symbiosis with all other aptly named 'computational X' sciences?
- Can we offer them a means to see the emergence and evolution of new sciences, e.g., nano* or neuro*?
- How can we empower them to search for a certain expertise in the correct scientific discipline?
- How can we teach them to appreciate the very diverse cultures, research approaches, and languages that exist in the different sciences and enable them to 'speak' more than one science in order to collaborate across scientific boundaries?
- Last but not least, how can we engage children in the work of real scientists, have them share the excitement of discovery, and allow them to find their own 'place' in science?

Computational Scientometrics: Studying Science by Scientific Means





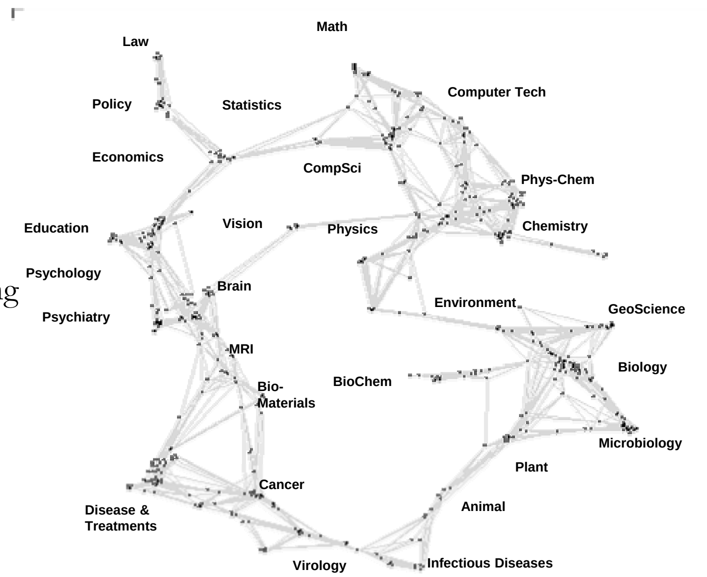
- *Börner, Katy, Chen, Chaomei, and Boyack, Kevin. (2003).* ***Visualizing Knowledge Domains.*** *In Blaise Cronin (Ed.), Annual Review of Information Science & Technology, Medford, NJ: Information Today, Inc./American Society for Information Science and Technology, Volume 37, Chapter 5, pp. 179-255.*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

Latest 'Base Map' of Science

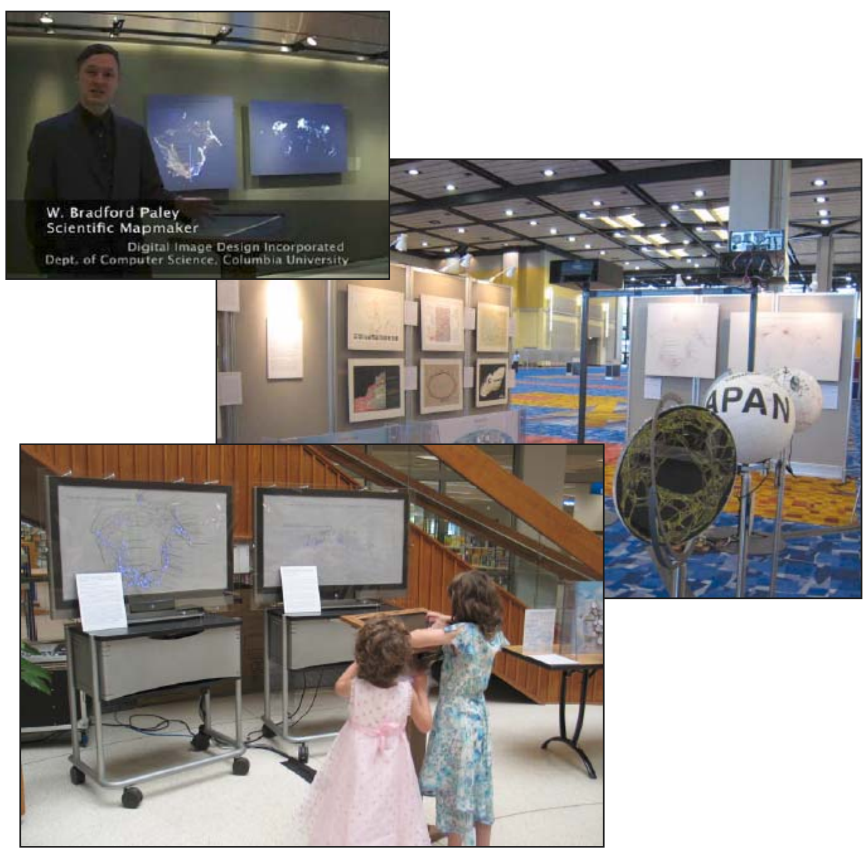
Kevin W. Boyack, Katy Börner, & Richard Klavans (2007). Mapping the Structure and Evolution of Chemistry Research. 11th International Conference on Scientometrics and Informetrics. pp. 112-123.

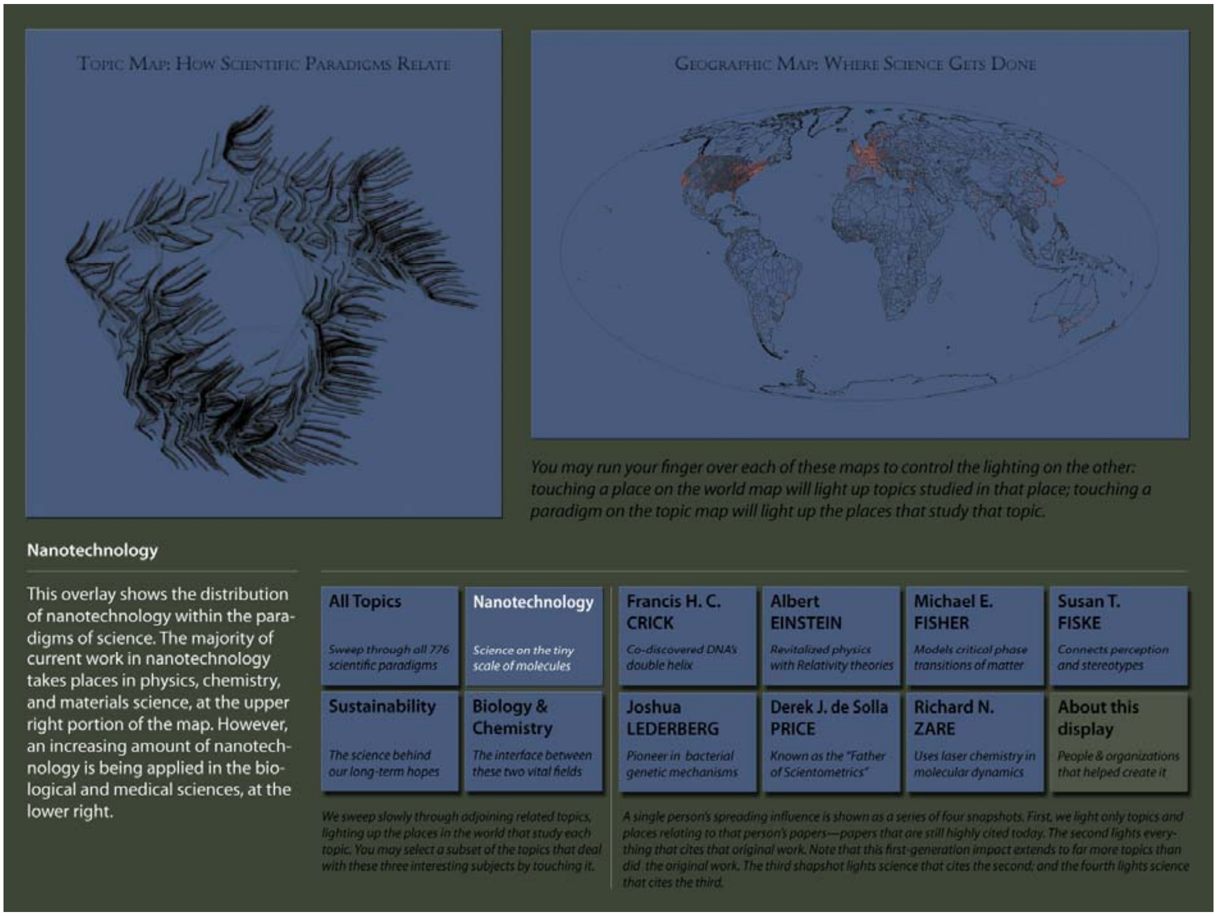
- Uses combined SCI/SSCI from 2002
  - 1.07M papers, 24.5M references, 7,300 journals
  - Bibliographic coupling of papers, aggregated to journals
- Initial ordination and clustering of journals gave 671 clusters
- Coupling counts were reaggregated at the journal cluster level to calculate the
  - (x,y)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

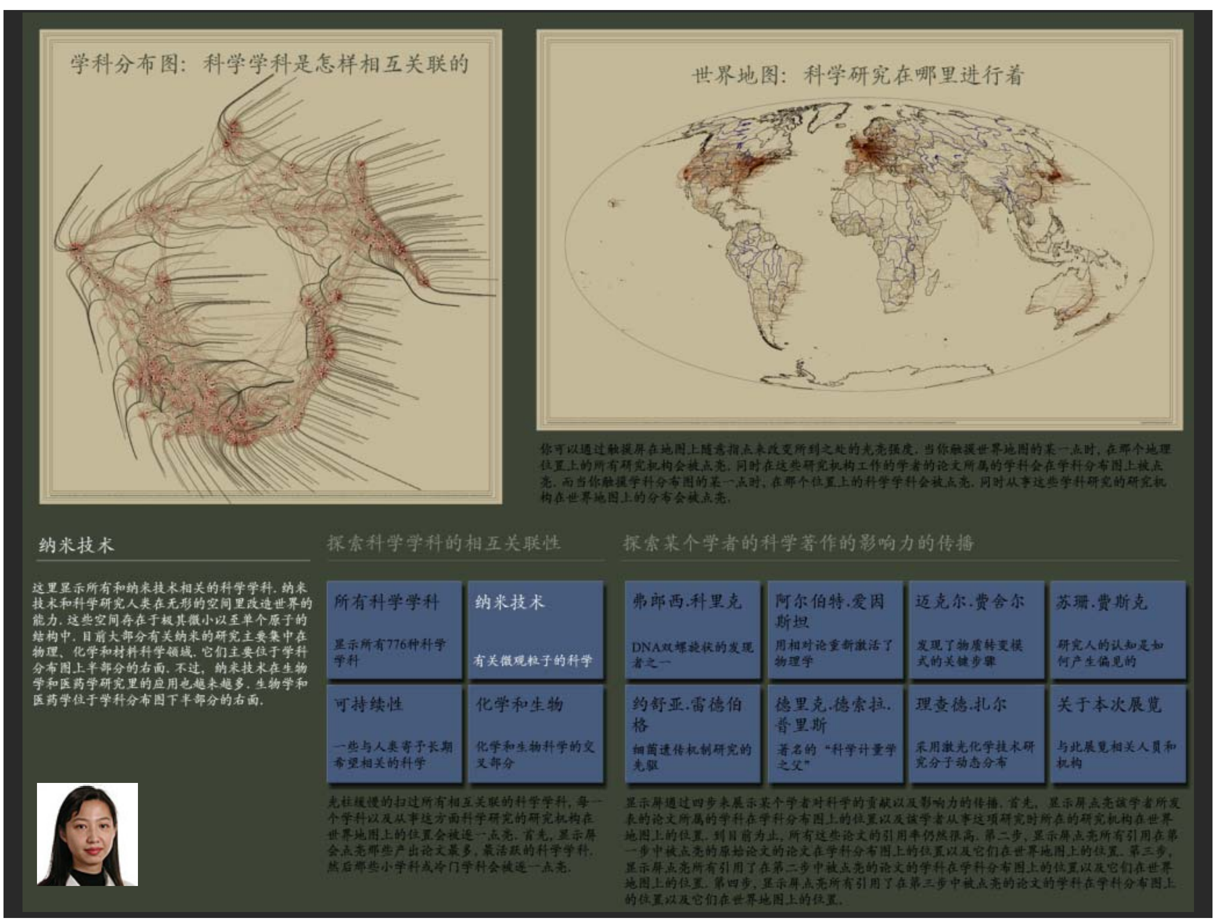


Illuminated Diagram Display

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

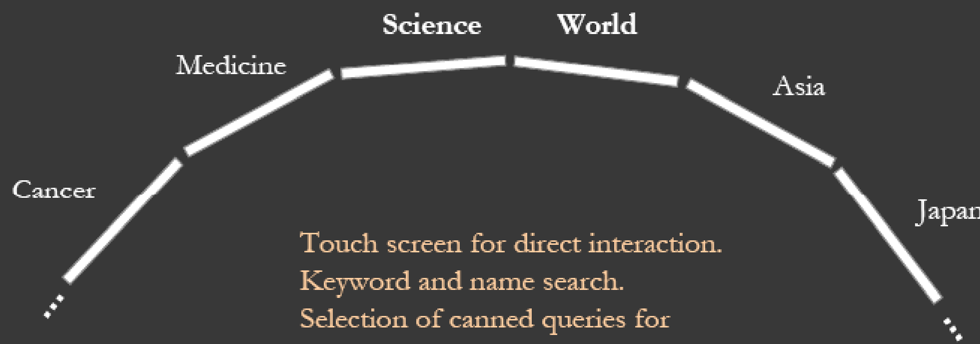



Topic Map: How Scientific Paradigms Relate
Geographic Map: Where Science Gets Done
You may run your finger over each of these maps to control the lighting on the other: touching a place on the world map will light up topics studied in that place; touching a paradigm on the topic map will light up the 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 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
Sustainability
The science behind our long-term hopes
Biology & Chemistry
The interface between these two vital fields
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.
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
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
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.

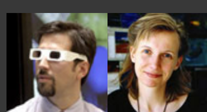

学科分布图：科学学科是怎样相互关联的
世界地图：科学研究在哪里进行着
你可以通过触摸屏在地图上随意指点来改变所到之处的光亮强度。当你触摸世界地图的某一点时，在那个地理位置上的所有研究机构会被点亮，同时在这些研究机构工作的学者的论文所属的学科会在学科分布图上被点亮。而当你触摸学科分布图的某一点时，在那个位置上的科学学科会被点亮，同时从事这些学科研究的研究机构在世界地图上的分布会被点亮。
纳米技术
这里显示所有和纳米技术相关的科学学科。纳米技术和科学研究人类在无形的空间里改造世界的能力。这些空间存在于极其微小以至单个原子的结构中。目前大部分有关纳米的研究主要集中在物理、化学和材料科学领域，它们主要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。
探索科学学科的相互关联性
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
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
先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
弗郎西.科里克
DNA双螺旋体的发现者之一
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
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
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。

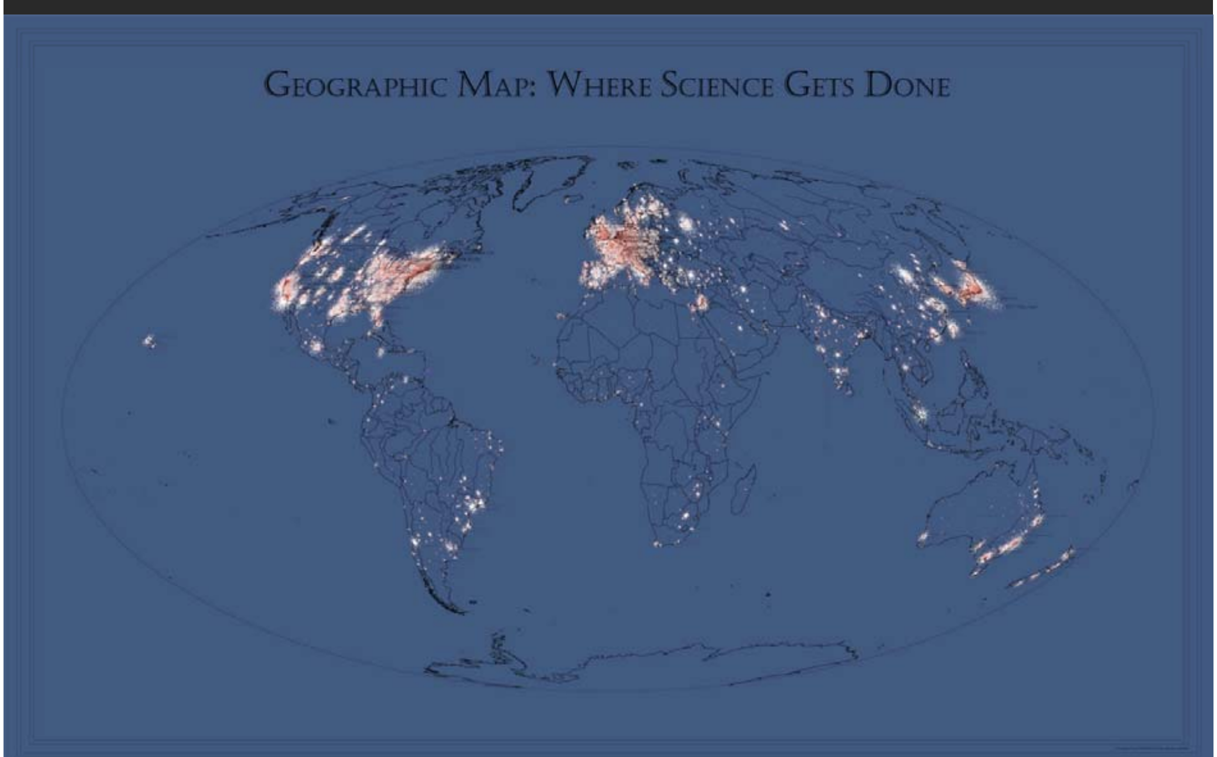
Re-implementation of Illuminated Diagram Software
by Advanced Visualization Lab, Indiana University

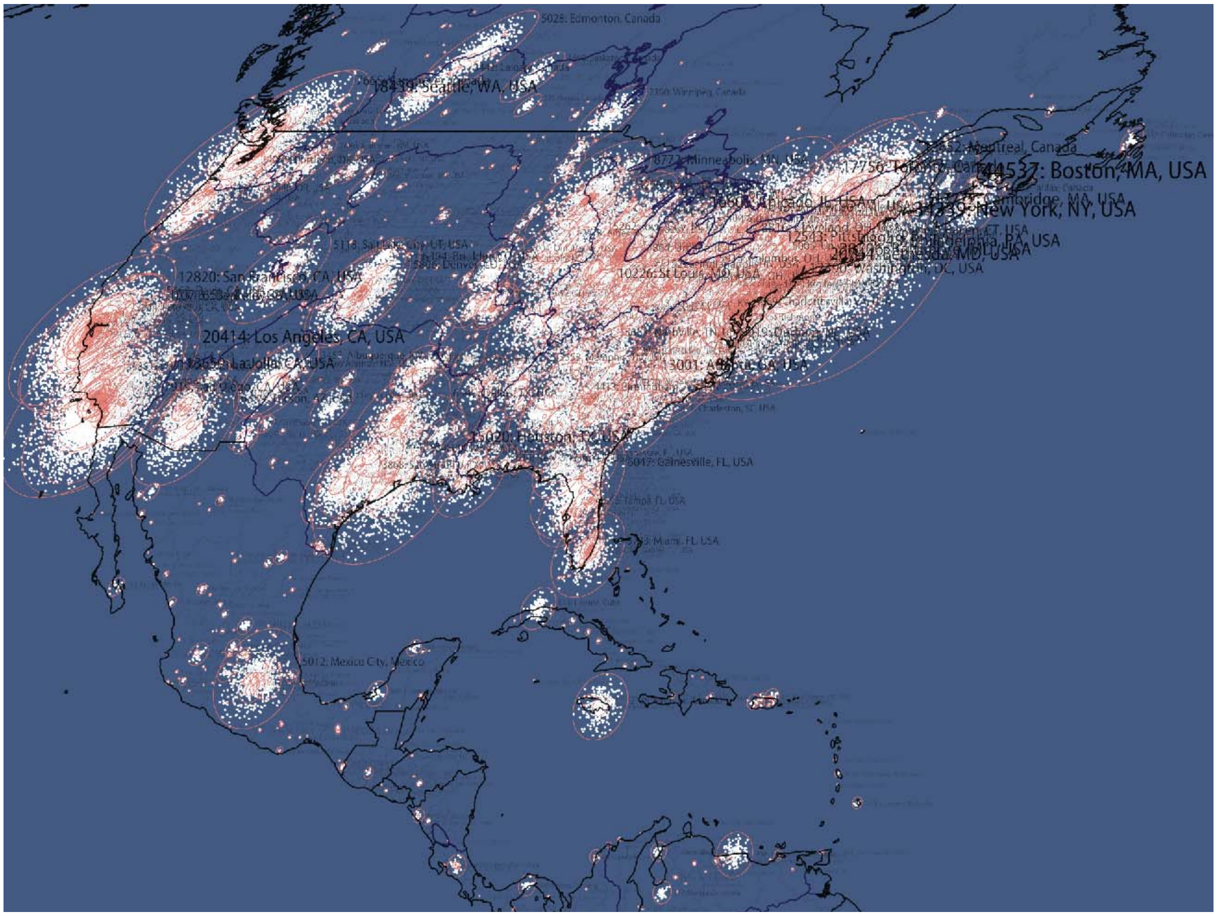
Drives unlimited number of ID screens.



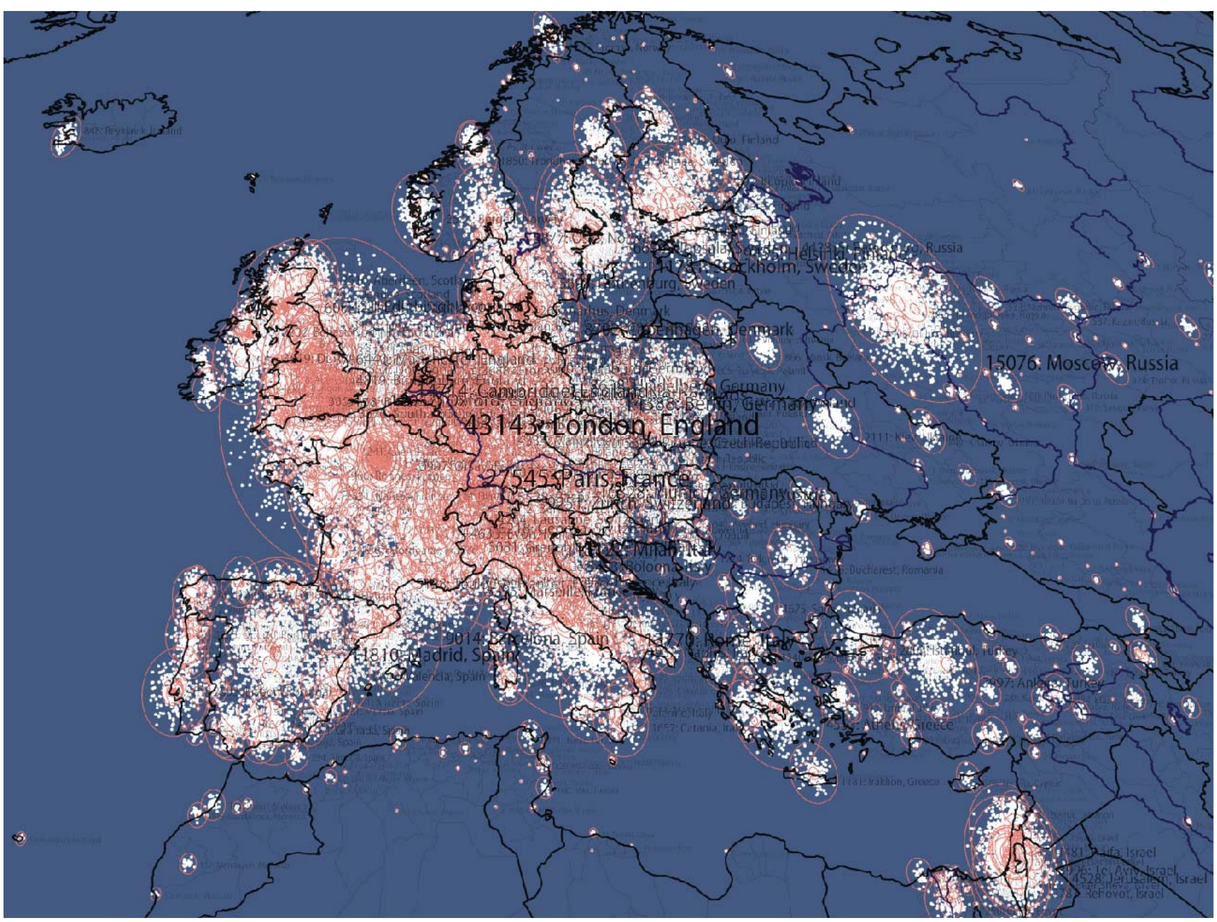
Touch screen for direct interaction.
Keyword and name search.
Selection of canned queries for
- interdisciplinary research areas
- famous people
- activity patterns, e.g., bursts, trends, etc.



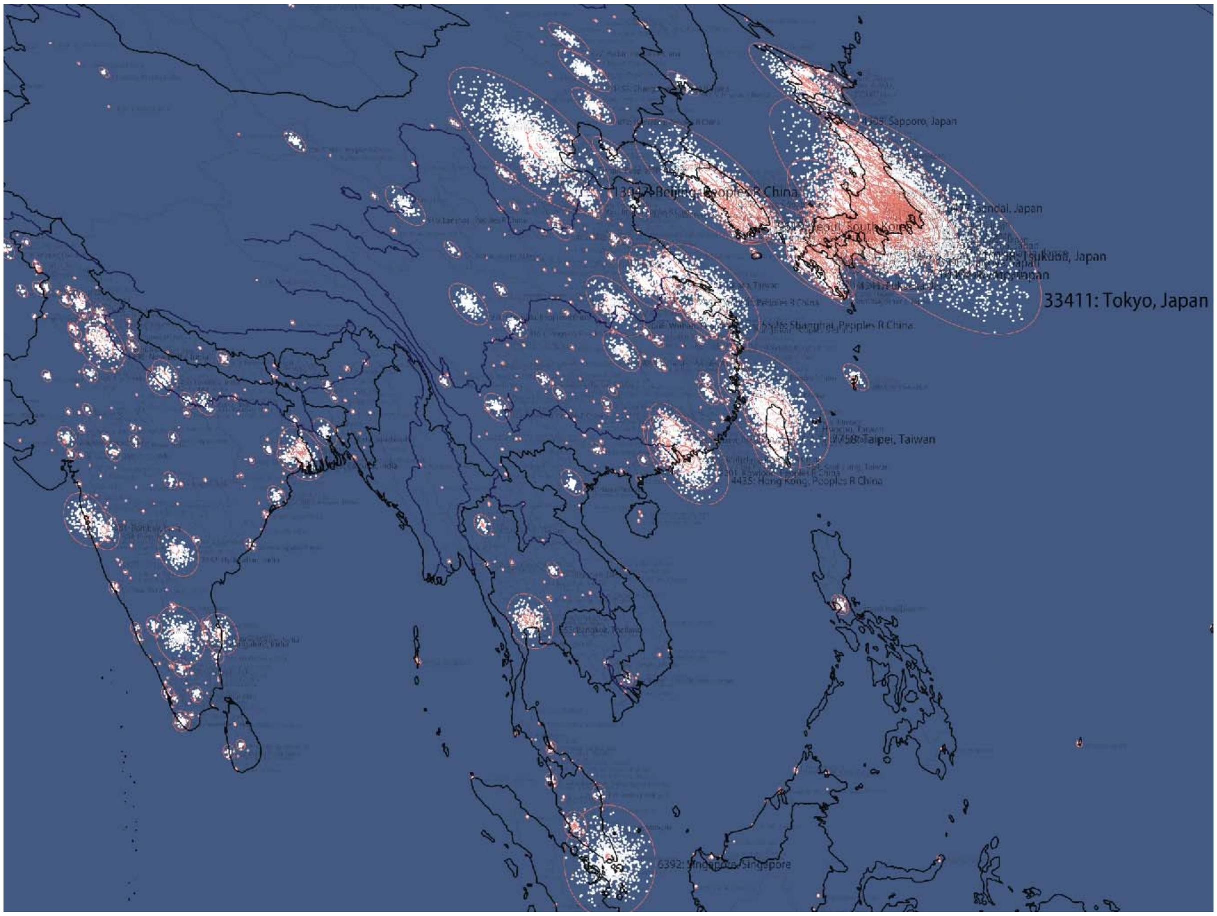


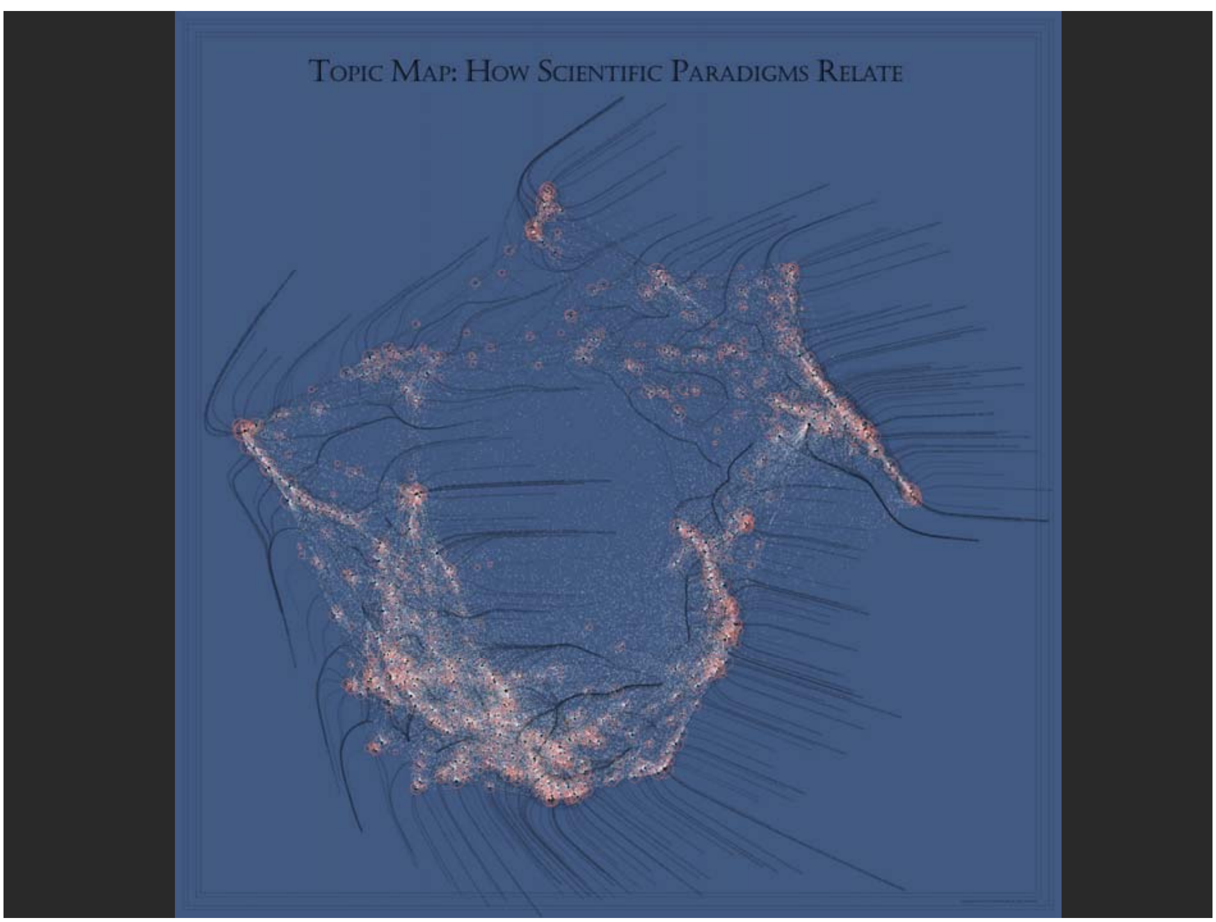


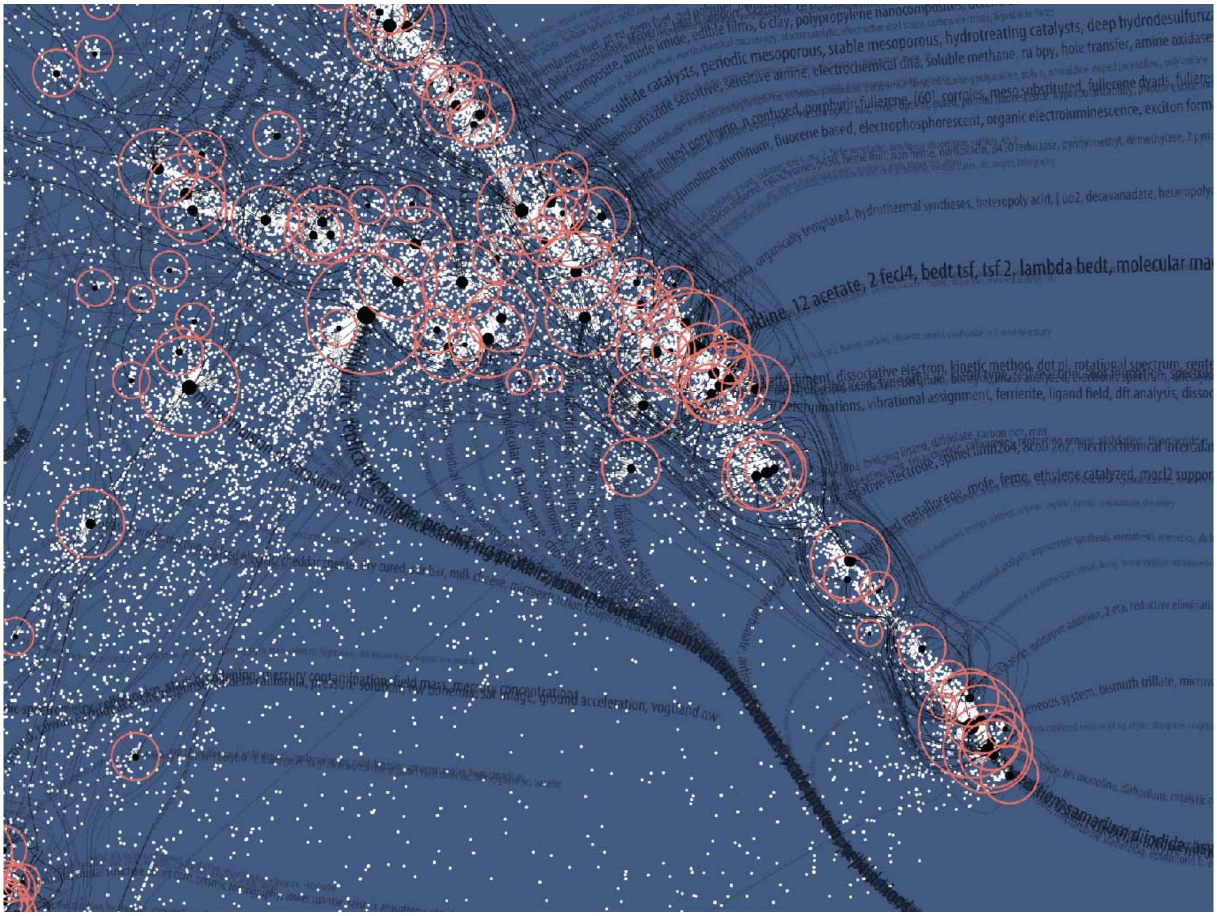
44537: Boston, MA, USA
20414: Los Angeles, CA, USA
5028: Edmonton, Canada
5012: Mexico City, Mexico



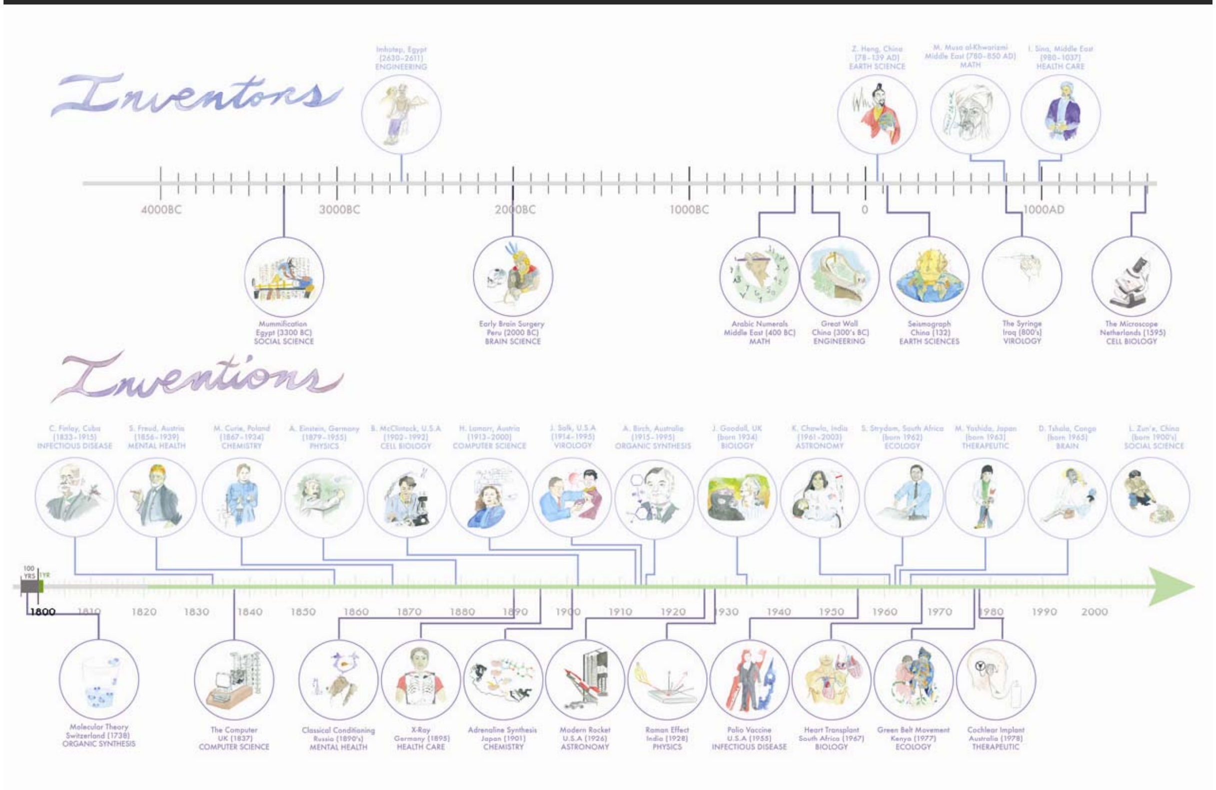
43143: London, England
15076: Moscow, Russia


4305: Sapporo, Japan
13047: Beijing, Peoples R China
Sendai, Japan
Seoul, South Korea
Tsukuba, Japan
33411: Tokyo, Japan
Shanghai, Peoples R China
Taipei, Taiwan
4435: Hong Kong, Peoples R China
6392: Singapore, Singapore


Topic Map: How Scientific Paradigms Relate

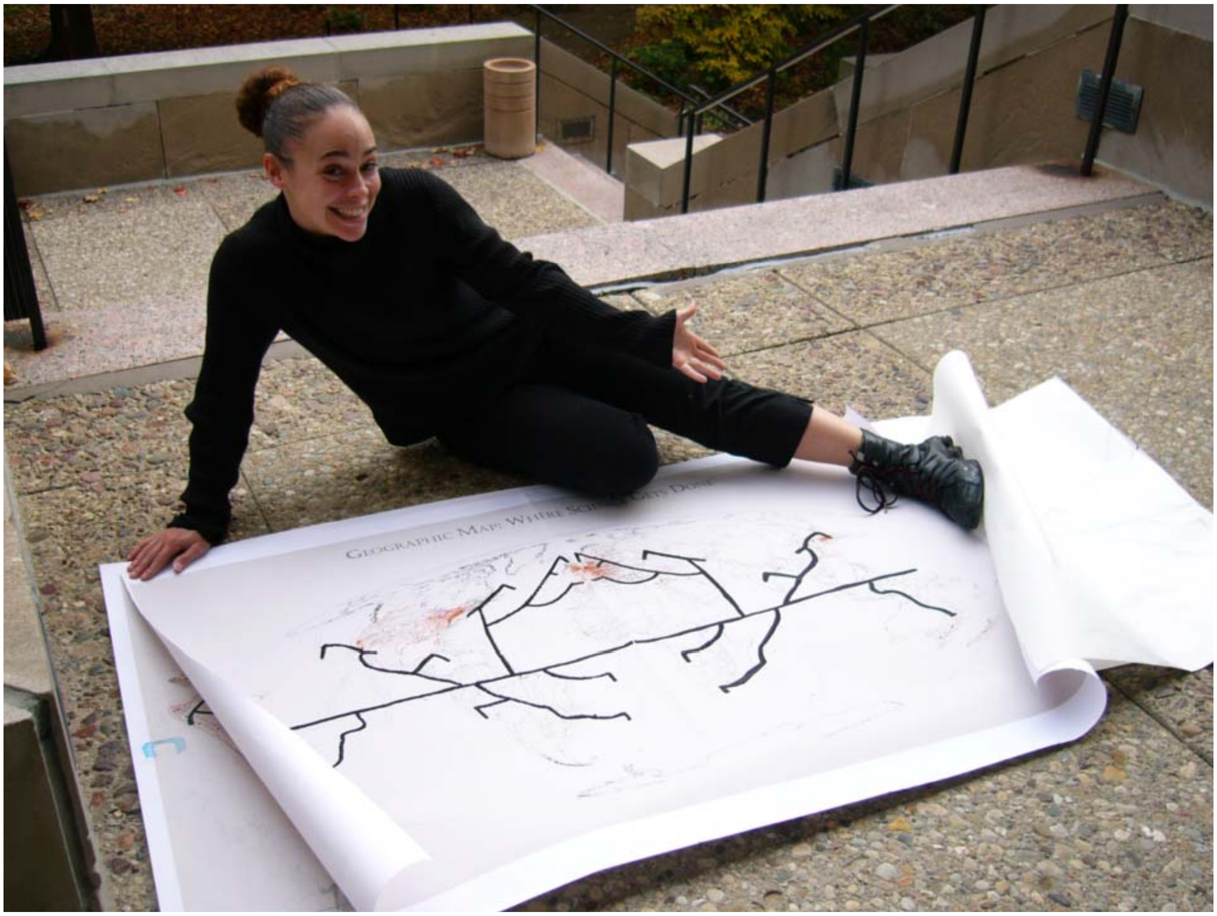


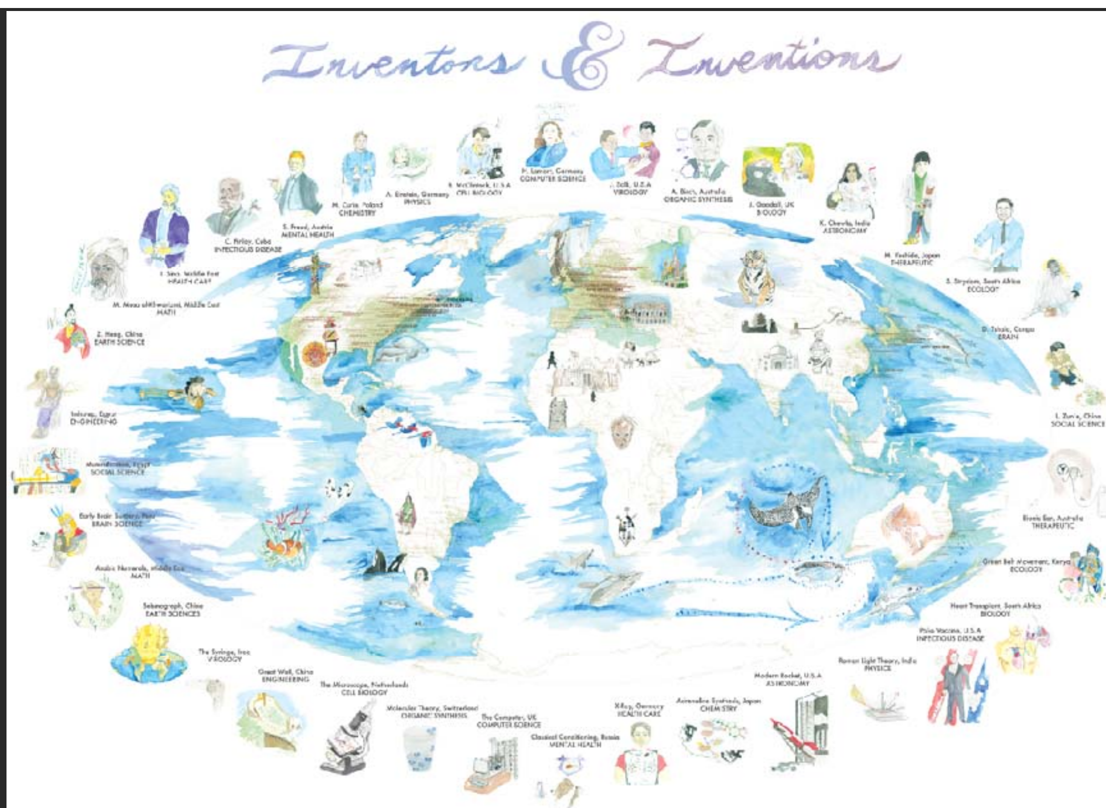
Inventors & Inventions
ASTRONOMY
PHYSICS
ENGINEERING
COMPUTER SCIENCE
MATH
SOCIAL SCIENCE
PHYSICAL CHEMISTRY
BRAIN
MENTAL HEALTH
EARTH SCIENCES
ORGANIC THEORY
ECOLOGY
HEALTH CARE
BIOLOGY
THERAPEUTIC RESEARCH
CELL BIOLOGY
VIRUSES
INFECTIOUS DISEASE



Inventors
Imhotep, Egypt (2630–2611) ENGINEERING
Z. Heng, China (78–139 AD) EARTH SCIENCE
M. Musa al-Khwarizmi Middle East (780–850 AD) MATH
I. Sina, Middle East (980–1037) HEALTH CARE
4000BC
3000BC
2000BC
1000BC
0
1000AD
Mummification Egypt (3300 BC) SOCIAL SCIENCE
Early Brain Surgery Peru (2000 BC) BRAIN SCIENCE
Arabic Numerals Middle East (400 BC) MATH
Great Wall China (300's BC) ENGINEERING
Seismograph China (132) EARTH SCIENCES
The Syringe Iraq (800's) VIROLOGY
The Microscope Netherlands (1595) CELL BIOLOGY
Inventions
C. Finlay, Cuba (1833–1915) INFECTIOUS DISEASE
S. Freud, Austria (1856–1939) MENTAL HEALTH
M. Curie, Poland (1867–1934) CHEMISTRY
A. Einstein, Germany (1879–1955) PHYSICS
B. McClintock, U.S.A (1902–1992) CELL BIOLOGY
H. Lamarr, Austria (1913–2000) COMPUTER SCIENCE
J. Salk, U.S.A (1914–1995) VIROLOGY
A. Birch, Australia (1915–1995) ORGANIC SYNTHESIS
J. Goodall, UK (born 1934) BIOLOGY
K. Chawla, India (1961–2003) ASTRONOMY
S. Strydom, South Africa (born 1962) ECOLOGY
M. Yoshida, Japan (born 1963) THERAPEUTIC
D. Tshala, Congo (born 1965) BRAIN
L. Zun'e, China (born 1900's) SOCIAL SCIENCE
100 YRS
1YR
1800
1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
Molecular Theory Switzerland (1738) ORGANIC SYNTHESIS
The Computer UK (1837) COMPUTER SCIENCE
Classical Conditioning Russia (1890's) MENTAL HEALTH
X-Ray Germany (1895) HEALTH CARE
Adrenaline Synthesis Japan (1901) CHEMISTRY
Modern Rocket U.S.A (1926) ASTRONOMY
Raman Effect India (1928) PHYSICS
Polio Vaccine U.S.A (1955) INFECTIOUS DISEASE
Heart Transplant South Africa (1967) BIOLOGY
Green Belt Movement Kenya (1977) ECOLOGY
Cochlear Implant Australia (1978) THERAPEUTIC

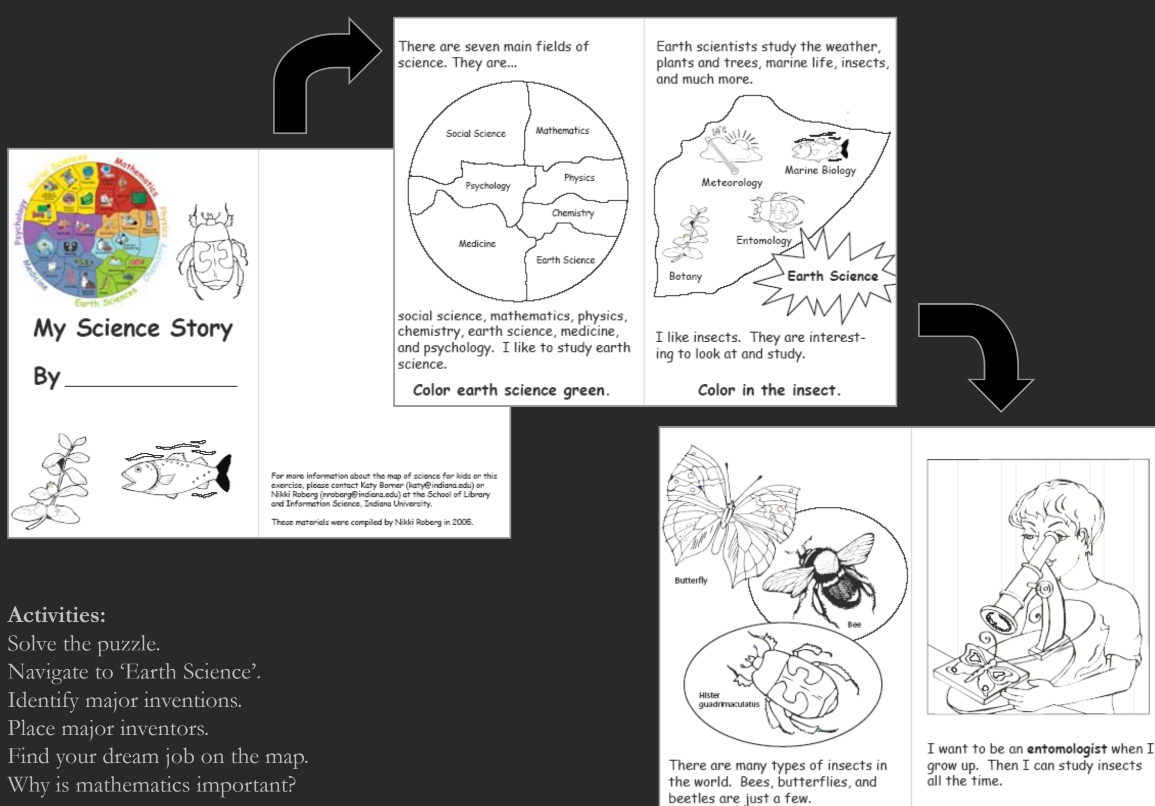
Inventors
ASTRONOMY
PHYSICS
ENGINEERING
COMPUTER SCIENCE
MATH
SOCIAL SCIENCE
PHYSICAL CHEMISTRY
BRAIN
MENTAL HEALTH
EARTH SCIENCES
ORGANIC THEORY
ECOLOGY
HEALTH CARE
BIOLOGY
THERAPEUTIC RESEARCH
CELL BIOLOGY
VIRUSES
INFECTIOUS DISEASE
Hands-On Science Maps for Kids, by Fileve Palmer (Painting), Julie Smith (Data Acquisition), Elisha Hardy and Katy Börner (Graphic Design), BLOOMINGTON, IN, 2006. Courtesy of Indiana University. Learn more at www.scimaps.org. This map plots the locations of where scientific papers were published: each light green dot represents 10 or fewer papers; they are scattered around the exact location for visibility, within a labelled green circle whose size is proportional to the number of papers published in that place. The base map is part of an "illuminated diagram" display which used a computer and two projectors, projecting spots of light on the prints to highlight different kinds of scientific research (on a sibling map of scientific paradigms) and the areas in the world where such



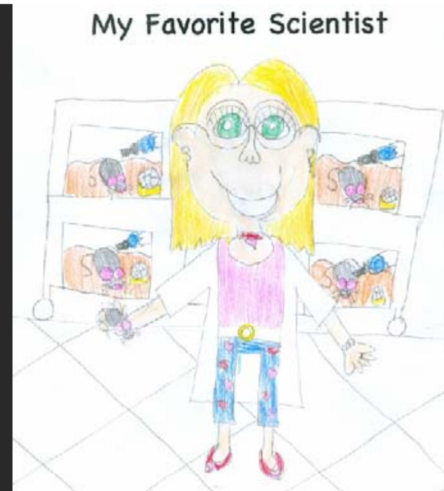


Science Puzzle Map for Kids by Fileve Palmer, Julie Smith, Elisha Hardy and Katy Börner, Indiana University, 2006.
(Base map taken from Illuminated Diagram display by Kevin Boyack, Richard Klavans, and W. Bradford Paley.)

Hands-On Science Maps for Kids, by Fileve Palmer (Painting), Julie Smith (Data Acquisition), Elisha Hardy and Katy Börner (Graphic Design), BLOOMINGTON, IN, 2006, Courtesy of Indiana University. Learn more at www.scimaps.org. This map plots the locations of where scientific papers were published: each light green dot represents 10 or fewer papers; they are scattered around the exact location for visibility, within a labelled green circle whose size is proportional to the number of papers published in that place. The base map is part of an "illuminated diagram" display which used a computer and two projectors, projecting spots of light on the points to highlight different kinds of scientific research (on a sibling map of scientific paradigms) and the areas in the world where such science was performed. Base map research by Kevin Boyack and Dick Klavans, cartography by John Burgoon, data from Thompson ISI, graphics and typography by W. Bradford Paley. Copyright © 2006 W. Bradford Paley, all rights reserved.



Activities:
Solve the puzzle.
Navigate to 'Earth Science'.
Identify major inventions.
Place major inventors.
Find your dream job on the map.
Why is mathematics important?



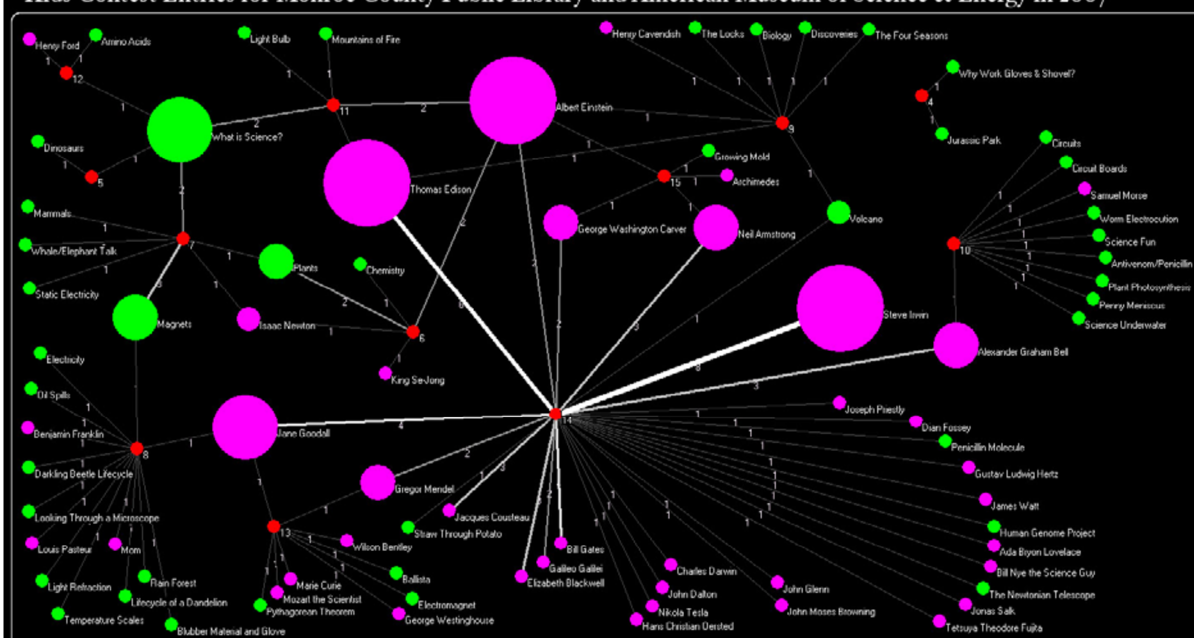
Winners @ AMSE

JoHanna Sanders, age 12, a picture of someone enjoying nature and a theme that science is all around us.

Sascha Richey, age 8, drew a picture of her mother and explained why her mother is her favorite scientist.

Places & Spaces: Mapping Science

Kids Contest Entries for Monroe County Public Library and American Museum of Science & Energy in 2007



Node Color: Experiment, Scientist, Child

Node Label: Name, Age

Node Size: Number of Times Entered

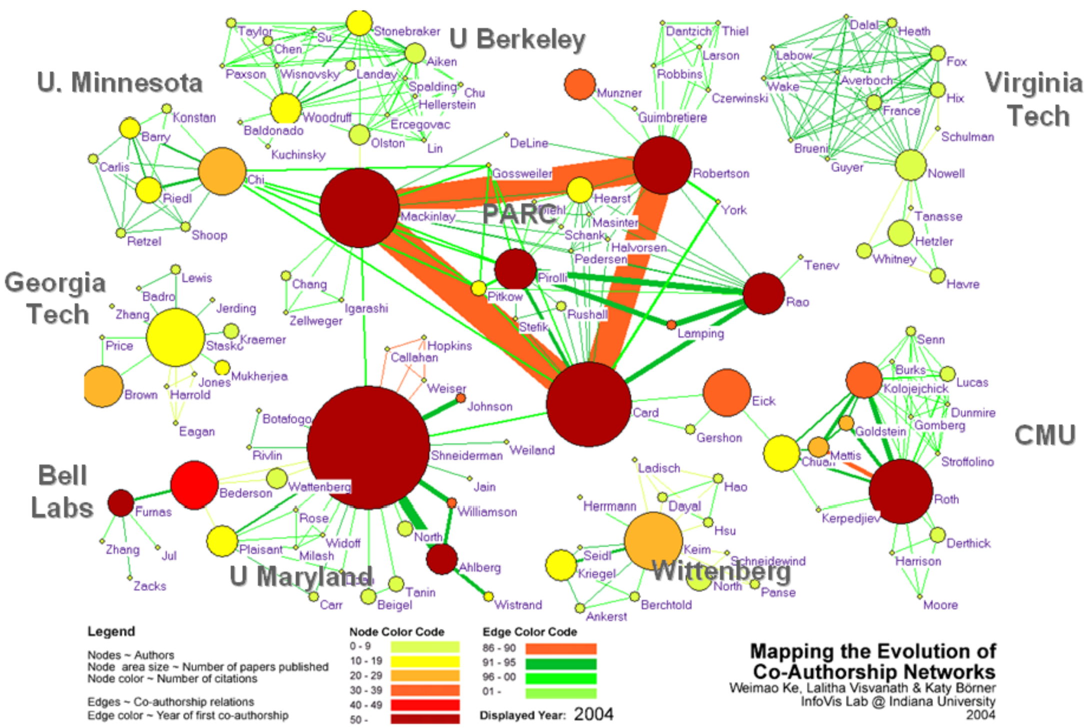
Edge Label & Size: Number of Times Entered

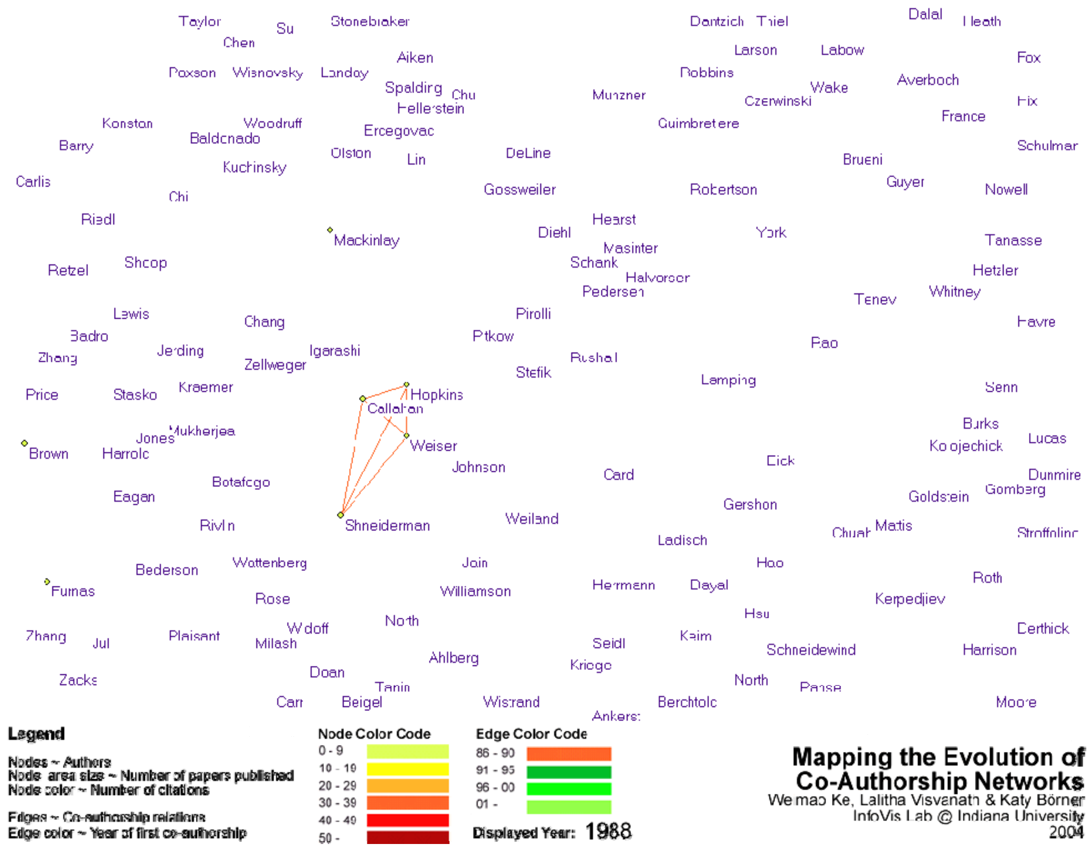
Science Map Usage at Graduate Student Level

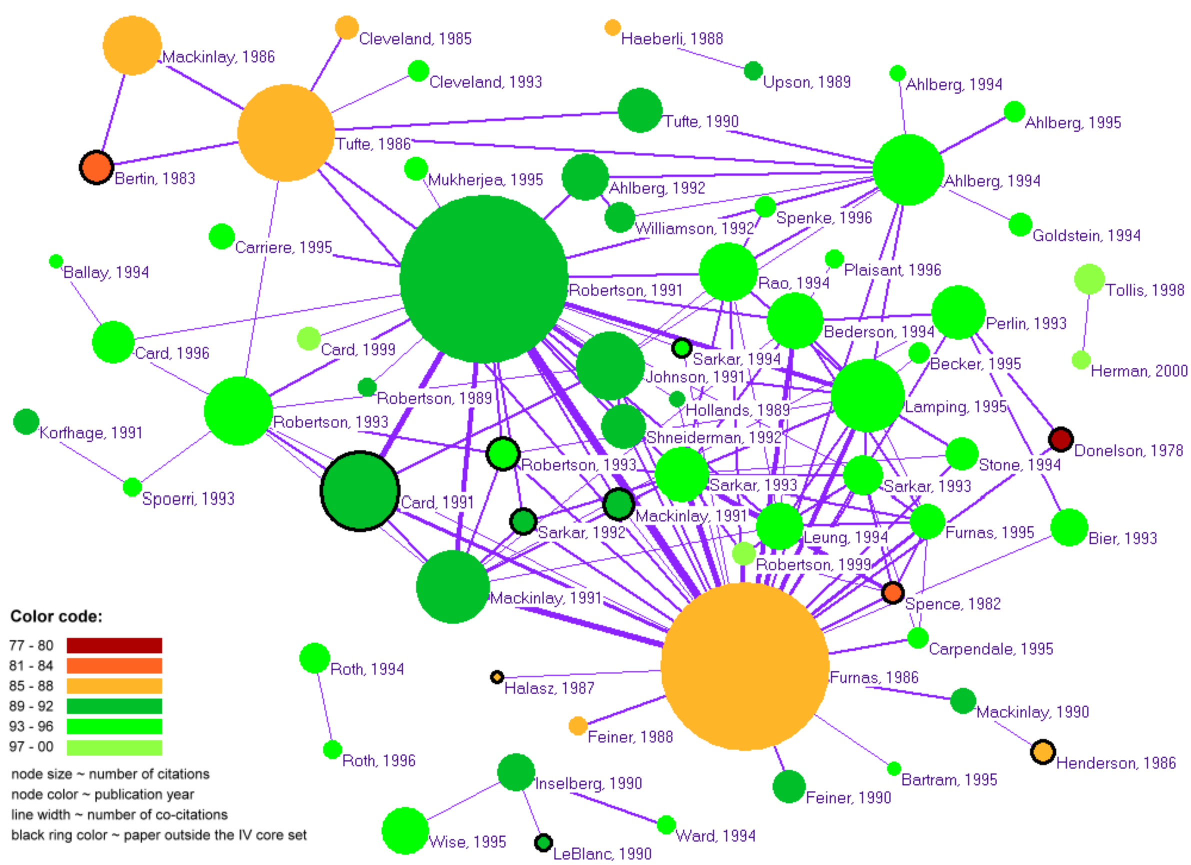


Mapping the Evolution of Co-Authorship Networks

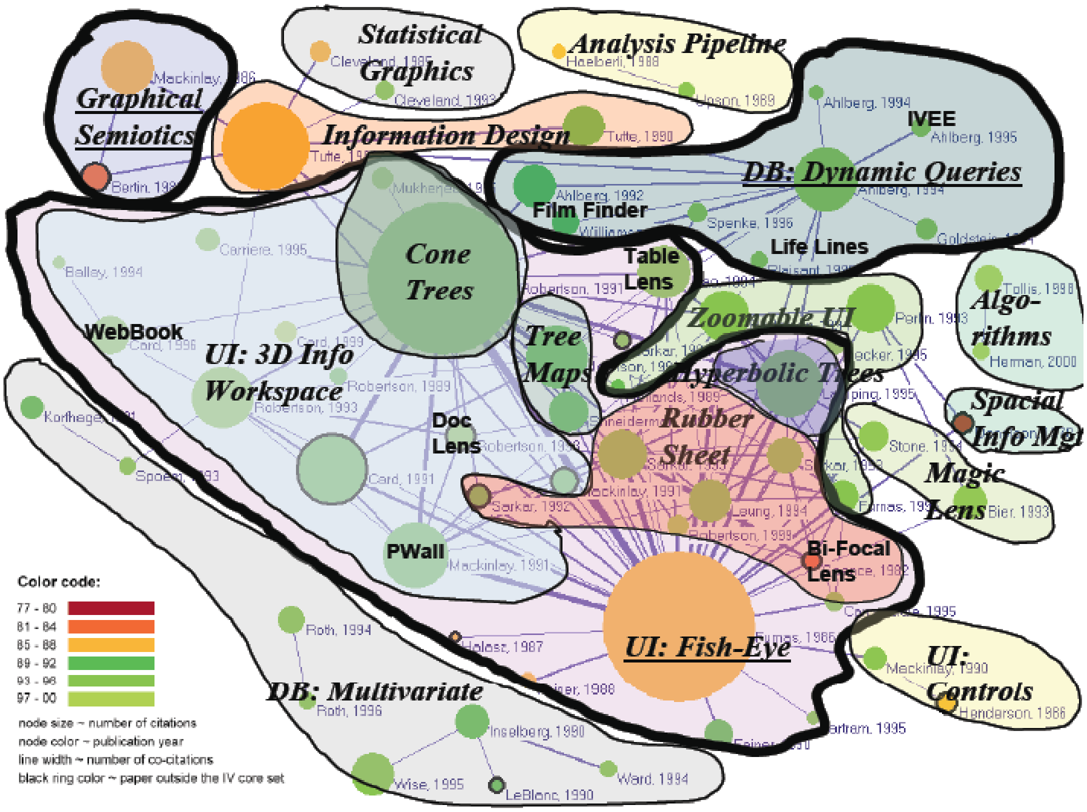
Ke, Visvanath & Börner, (2004) Won 1st price at the IEEE InfoVis Contest.

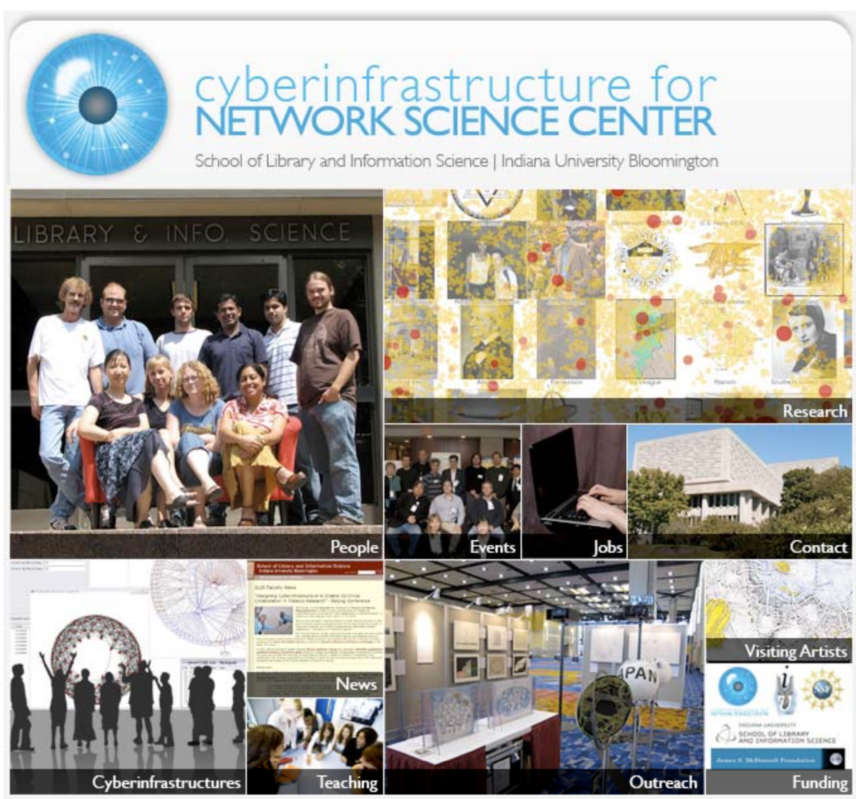



Taylor
Su
Stonebraker
Chen
Dantzich
Thiel
Dalal
Heath
Paxson
Wisnovsky
Landay
Aiken
Larson
Labow
Fox
Spalding
Chu
Hellerstein
Robbins
Averboch
Munzner
Czerwinski
Wake
Fix
Konstan
Woodruff
Baldonado
Ercegovac
Guimbretere
France
Barry
Olston
Lin
DeLine
Brueni
Schulman
Kuchinsky
Carlis
Gossweiler
Robertson
Guyer
Nowell
Chi
Riedl
Hearst
Diehl
York
Mackinlay
Masinter
Tanasse
Schank
Retzel
Shoop
Halvorson
Hetzler
Pedersen
Whitney
Tenev
Lewis
Pirolli
Chang
Badro
Favre
Pitkow
Rao
Zhang
Jerding
Igarashi
Rushall
Zellweger
Stefik
Lamping
Price
Stasko
Kraemer
Hopkins
Senn
Callahan
Burks
Mukherjea
Jones
Koojechick
Lucas
Brown
Harrold
Weiser
Johnson
Eick
Card
Dunmire
Botafogo
Goldstein
Gomberg
Eagan
Gershon
Rivlin
Shneiderman
Weiland
Chuah
Mattis
Ladisch
Stroffolino
Bederson
Wattenberg
Join
Hao
Furnas
Roth
Williamson
Hermann
Dayal
Rose
Kerpedjiev
Hsu
Zhang
Jul
Plaisant
Wdoff
North
Derthick
Milash
Seidl
Keim
Schneidewind
Harrison
Ahlberg
Kriegel
Zacks
Doan
North
Pause
Tanin
Carr
Beigel
Wistrand
Berchtold
Moore
Ankerst
Legend
Nodes ~ Authors
Node area size ~ Number of papers published
Node color ~ Number of citations
Edges ~ Co-authorship relations
Edge color ~ Year of first co-authorship
Node Color Code
0 - 9
10 - 19
20 - 29
30 - 39
40 - 49
50 -
Edge Color Code
86 - 90
91 - 95
96 - 00
01 -
Displayed Year: 1988
Mapping the Evolution of
Co-Authorship Networks
Weimao Ke, Lalitha Visvanath & Katy Börner
InfoVis Lab @ Indiana University
2004


Mackinlay, 1986
Cleveland, 1985
Haeberli, 1988
Cleveland, 1993
Upson, 1989
Ahlberg, 1994
Tufte, 1990
Ahlberg, 1995
Tufte, 1986
Bertin, 1983
Mukherjea, 1995
Ahlberg, 1992
Ahlberg, 1994
Spenke, 1996
Williamson, 1992
Goldstein, 1994
Carriere, 1995
Plaisant, 1996
Ballay, 1994
Rao, 1994
Tollis, 1998
Robertson, 1991
Perlin, 1993
Bederson, 1994
Card, 1996
Card, 1999
Sarkar, 1994
Becker, 1995
Herman, 2000
Johnson, 1991
Robertson, 1989
Hollands, 1989
Lamping, 1995
Robertson, 1993
Korfhage, 1991
Shneiderman, 1992
Donelson, 1978
Robertson, 1993
Stone, 1994
Sarkar, 1993
Sarkar, 1993
Card, 1991
Spoerri, 1993
Mackinlay, 1991
Furnas, 1995
Sarkar, 1992
Leung, 1994
Bier, 1993
Robertson, 1999
Mackinlay, 1991
Spence, 1982
Color code:
77 - 80
81 - 84
85 - 88
89 - 92
93 - 96
97 - 00
Carpendale, 1995
Roth, 1994
Furnas, 1986
Halasz, 1987
Mackinlay, 1990
Feiner, 1988
Henderson, 1986
Roth, 1996
Bartram, 1995
Inselberg, 1990
Feiner, 1990
Ward, 1994
Wise, 1995
LeBlanc, 1990
node size ~ number of citations
node color ~ publication year
line width ~ number of co-citations
black ring color ~ paper outside the IV core set

Stuart Card, IEEE InfoVis Keynote, 2004.





http://cns.slis.indiana.edu