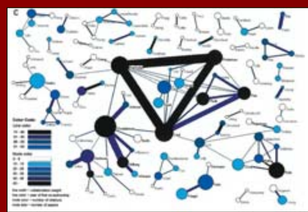
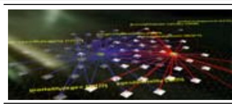
Mapping Knowledge Domains



Katy Börner
School of Library and Information Science
INDIANA UNIVERSITY
BLOOMINGTON
katy@indiana.edu

School and Workshop on "Structure and Function of Complex Networks",
Abdus Salam International Centre for Theoretical Physics (ICTP),
Trieste, Italy, May 24th, 2005.



Overview

1. Motivation for Mapping Knowledge Domains / Computational Scientometrics

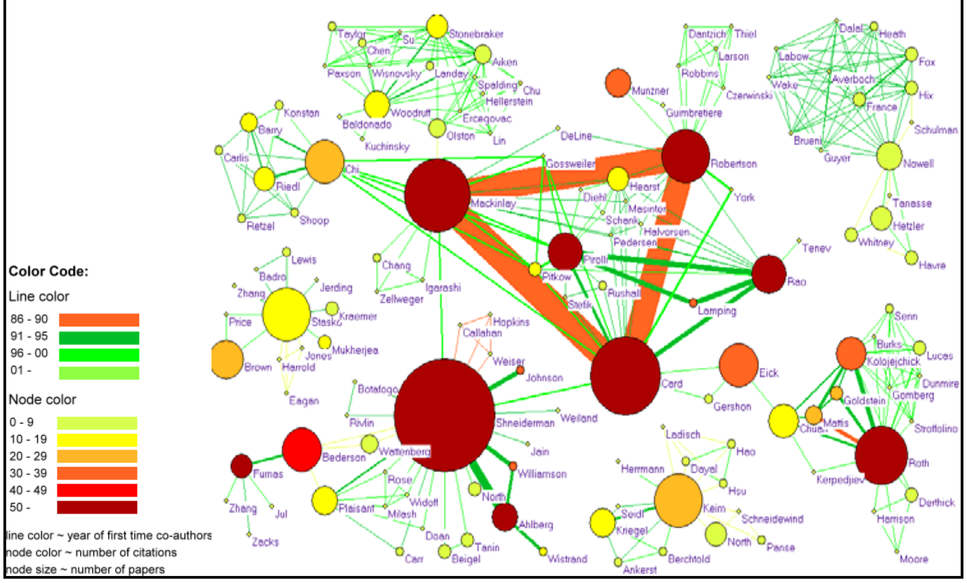
2. Mapping the Structure and Evolution of
   - Scientific Disciplines
   - All of Sciences

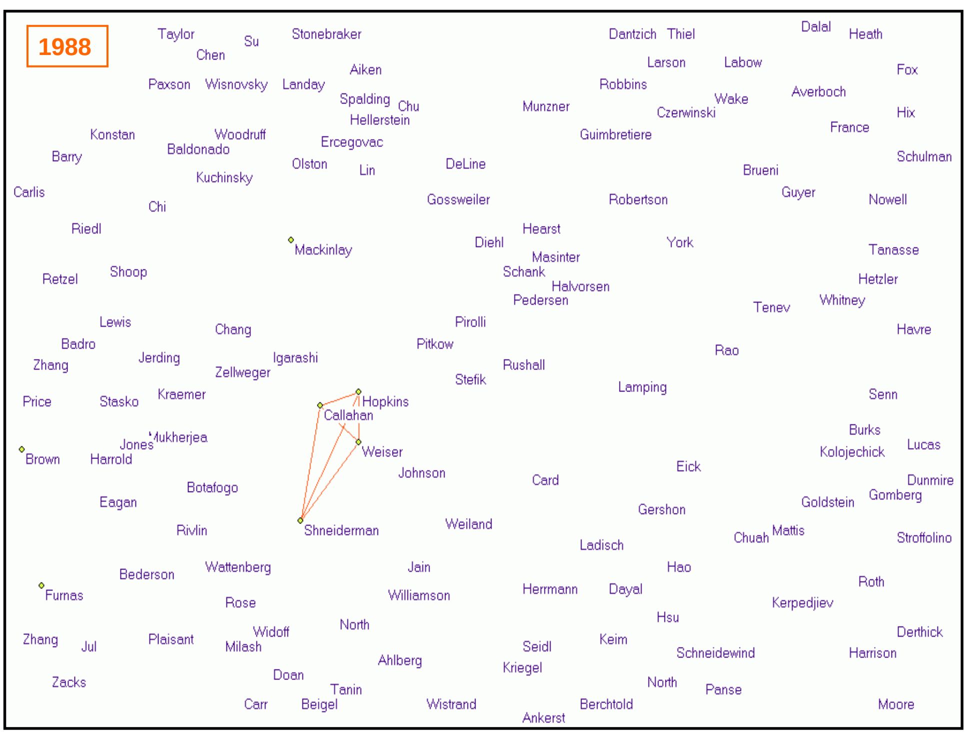
3. Challenges and Opportunities

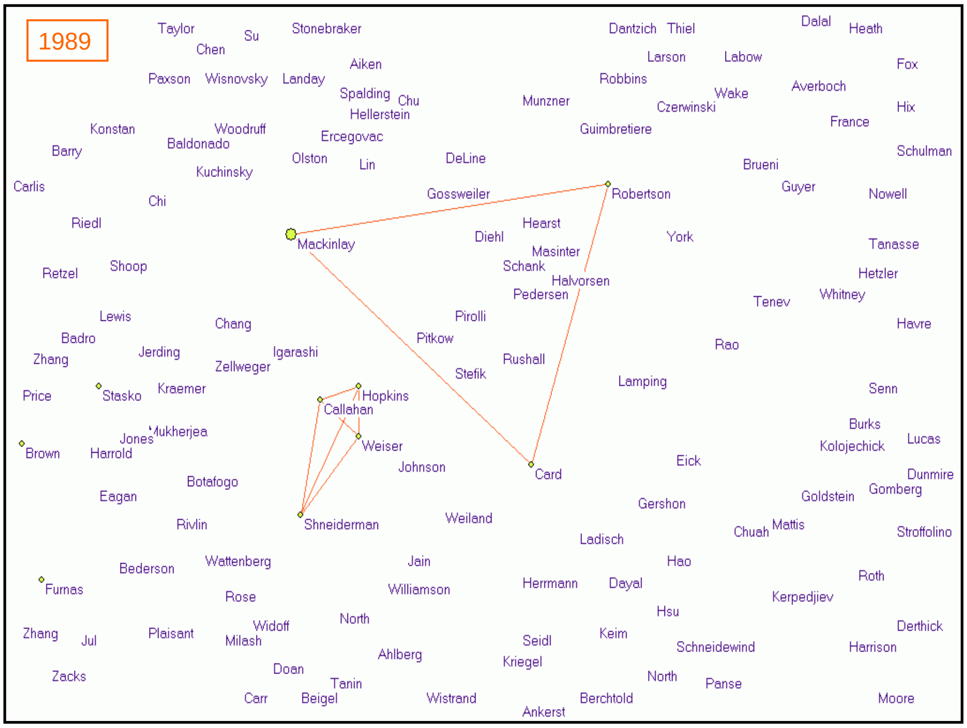
Mapping Knowledge Domains, Katy Börner, Indiana University 2

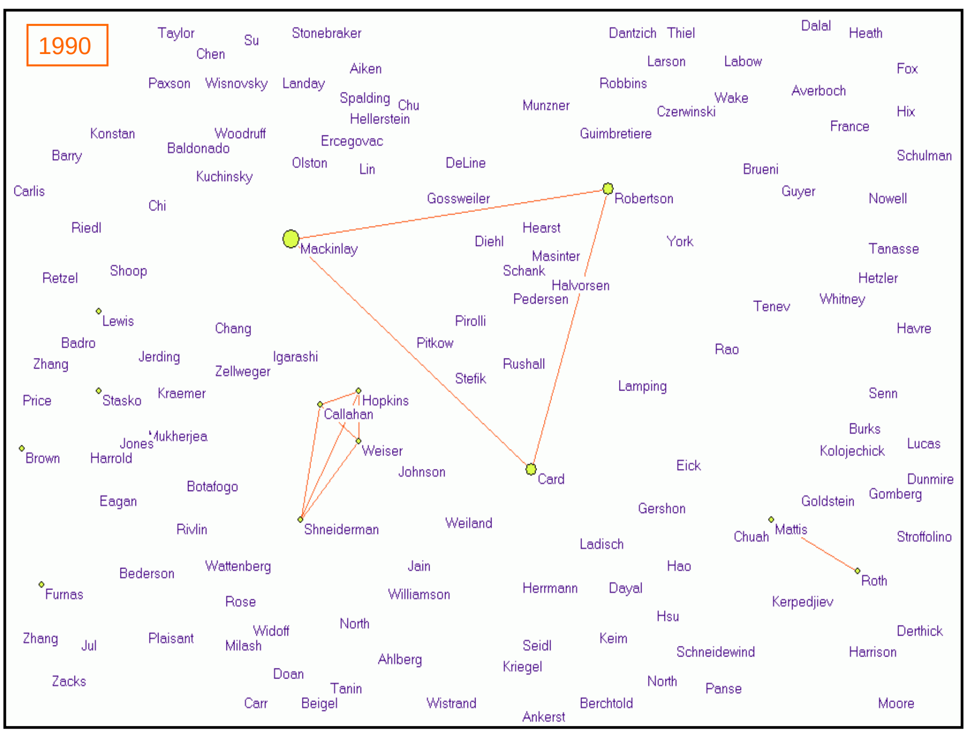
Mapping the Evolution of Co-Authorship Networks

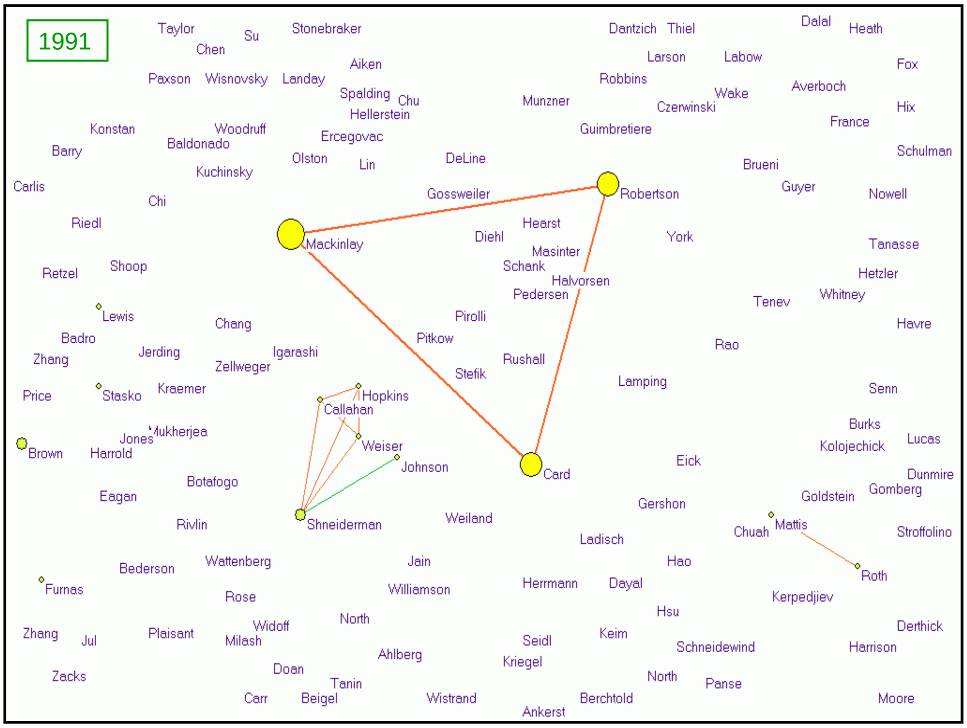
Ke, Visvanath & Börner, (2004) Won 1st price at the IEEE InfoVis Contest.

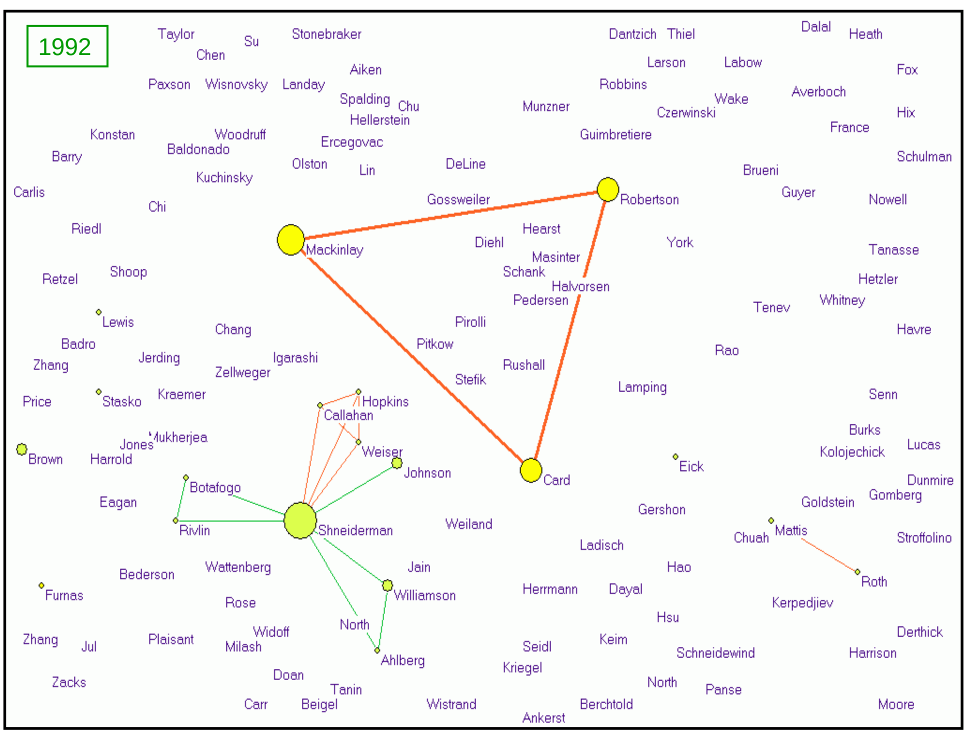


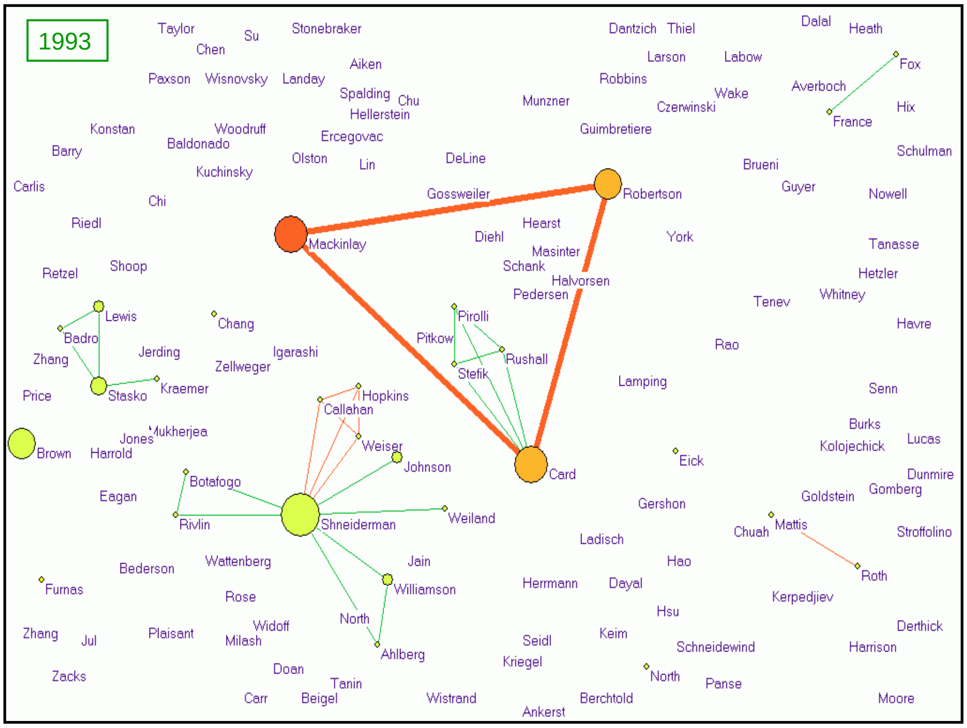


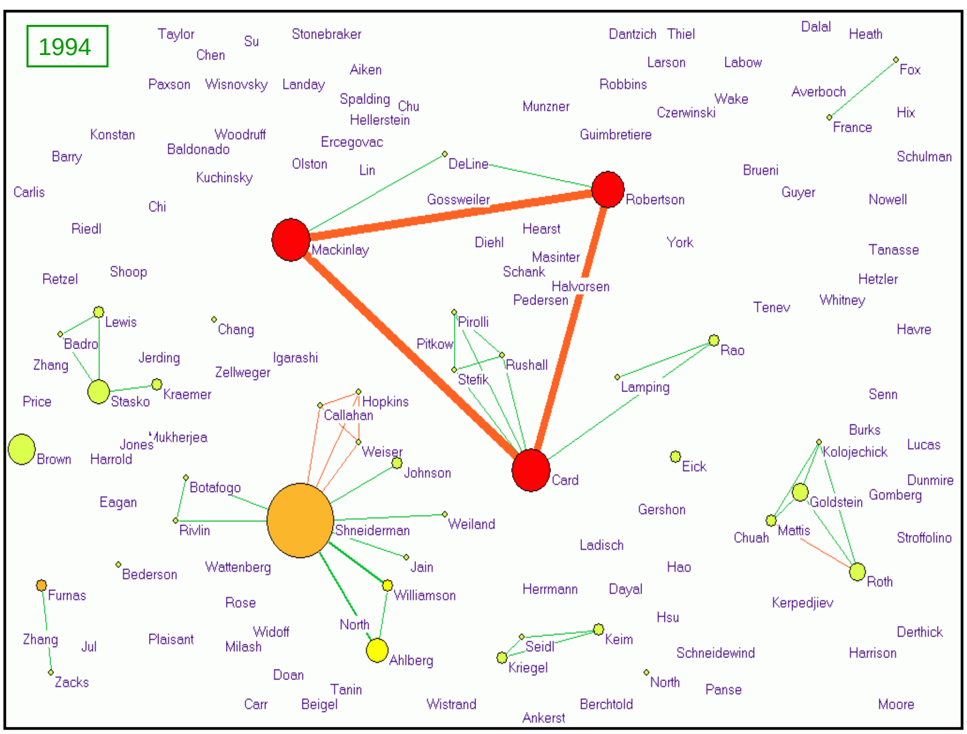

1989
Taylor Su Stonebraker Dantzich Thiel Dalal Heath
Chen Larson Labow Fox
Paxson Wisnovsky Landay Aiken Robbins
Spalding Chu Munzner Wake Averboch
Hellerstein Czerwinski Hix
Konstan Woodruff Guimbretiere France
Baldonado Ercegovac
Barry Schulman
Olston Lin DeLine Brueni
Kuchinsky
Carlis Guyer
Gossweiler Robertson Nowell
Chi
Riedl Hearst
Mackinlay Diehl York Tanasse
Masinter
Retzel Shoop Schank Hetzler
Halvorsen
Pedersen Whitney Tenev
Lewis Chang Pirolli Havre
Badro Pitkow Rao
Jerding Igarashi
Zhang Zellweger Rushall
Stefik Lamping
Price Stasko Kraemer Hopkins Senn
Callahan
Burks
Mukherjea Lucas
Jones Weiser Kolojechick
Brown Harrold Johnson Eick
Card Dunmire
Botafogo Gomberg
Eagan Goldstein
Gershon
Rivlin Shneiderman Weiland Mattis
Chuah Stroffolino
Ladisch
Wattenberg Jain Hao
Bederson Roth
Furnas Williamson Herrmann Dayal
Rose Kerpedjiev
North Hsu
Widoff Derthick
Zhang Plaisant Keim
Jul Milash Seidl
Ahlberg Schneidewind Harrison
Kriegel
Doan
Zacks North
Tanin Panse
Carr Beigel Wistrand Berchtold Moore
Ankerst

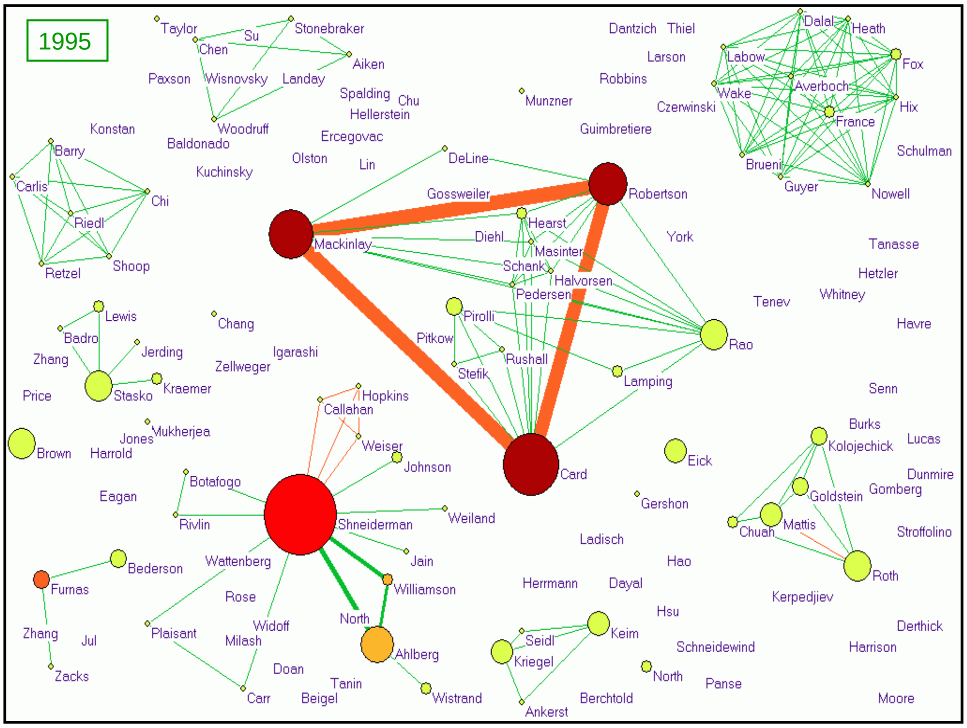

1990
Taylor Su Stonebraker Dantzich Thiel Dalal Heath
Chen Larson Labow Fox
Paxson Wisnovsky Landay Aiken Robbins
Spalding Chu Munzner Wake Averboch
Hellerstein Czerwinski Hix
Konstan Woodruff Guimbretiere France
Baldonado Ercegovac
Barry Schulman
Olston Lin DeLine Brueni
Kuchinsky
Carlis Guyer
Gossweiler Robertson Nowell
Chi
Riedl Hearst
Mackinlay Diehl York Tanasse
Masinter
Retzel Shoop Schank Hetzler
Halvorsen
Pedersen Whitney Tenev
Lewis Chang Pirolli Havre
Badro Pitkow Rao
Jerding Igarashi
Zhang Zellweger Rushall
Stefik Lamping
Price Stasko Kraemer Hopkins Senn
Callahan
Burks
Mukherjea Lucas
Jones Weiser Kolojechick
Brown Harrold Johnson Eick
Card Dunmire
Botafogo Gomberg
Eagan Goldstein
Gershon
Rivlin Shneiderman Weiland Mattis
Chuah Stroffolino
Ladisch
Wattenberg Jain Hao
Bederson Roth
Furnas Williamson Herrmann Dayal
Rose Kerpedjiev
North Hsu
Widoff Derthick
Zhang Plaisant Keim
Jul Milash Seidl
Ahlberg Schneidewind Harrison
Kriegel
Doan
Zacks North
Tanin Panse
Carr Beigel Wistrand Berchtold Moore
Ankerst

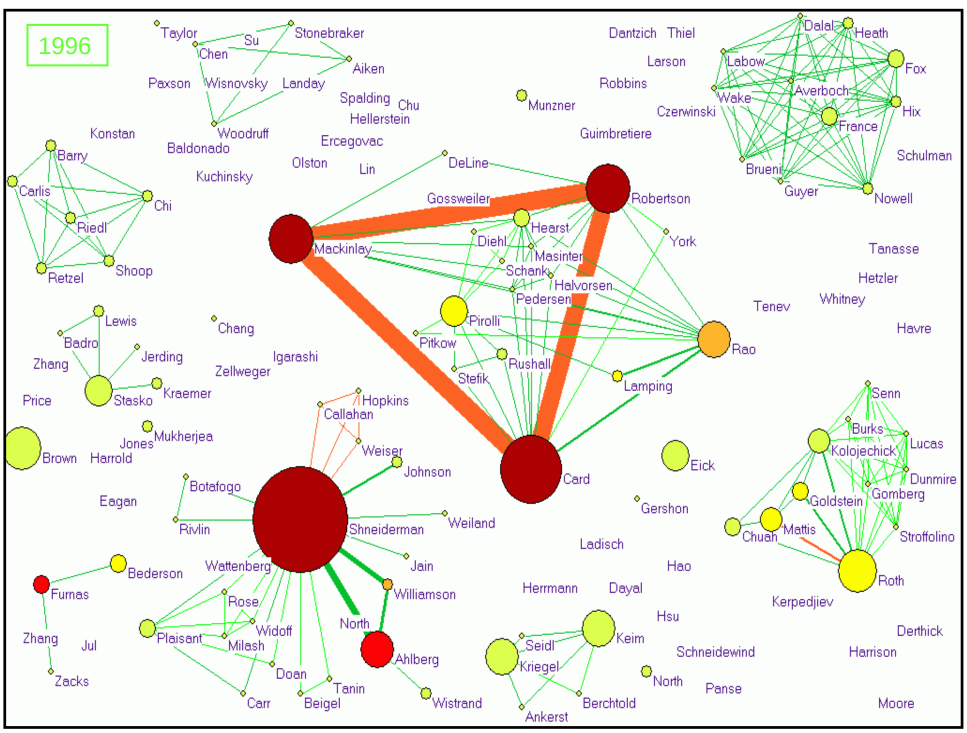

1991
Taylor
Su
Stonebraker
Dantzich
Thiel
Dalal
Heath
Chen
Larson
Labow
Paxson
Wisnovsky
Landay
Aiken
Fox
Robbins
Spalding
Chu
Munzner
Wake
Averboch
Hellerstein
Czerwinski
Hix
Konstan
Woodruff
Guimbretiere
France
Barry
Baldonado
Ercegovac
Olston
Lin
DeLine
Schulman
Kuchinsky
Brueni
Carlis
Gossweiler
Robertson
Guyer
Nowell
Chi
Riedl
Hearst
Mackinlay
Diehl
York
Tanasse
Masinter
Schank
Retzel
Shoop
Halvorsen
Hetzler
Pedersen
Whitney
Tenev
Lewis
Chang
Pirolli
Havre
Badro
Pitkow
Rao
Zhang
Jerding
Igarashi
Zellweger
Rushall
Stefik
Lamping
Kraemer
Hopkins
Senn
Price
Stasko
Callahan
Mukherjea
Burks
Jones
Weiser
Kolojechick
Lucas
Brown
Harrold
Johnson
Eick
Card
Dunmire
Botafogo
Gomberg
Eagan
Goldstein
Gershon
Weiland
Mattis
Rivlin
Shneiderman
Chuah
Stroffolino
Ladisch
Wattenberg
Jain
Hao
Bederson
Roth
Furnas
Herrmann
Dayal
Williamson
Rose
Kerpedjiev
Hsu
North
Widoff
Derthick
Zhang
Jul
Plaisant
Milash
Seidl
Keim
Ahlberg
Schneidewind
Harrison
Kriegel
Doan
North
Panse
Zacks
Tanin
Carr
Beigel
Wistrand
Berchtold
Moore
Ankerst

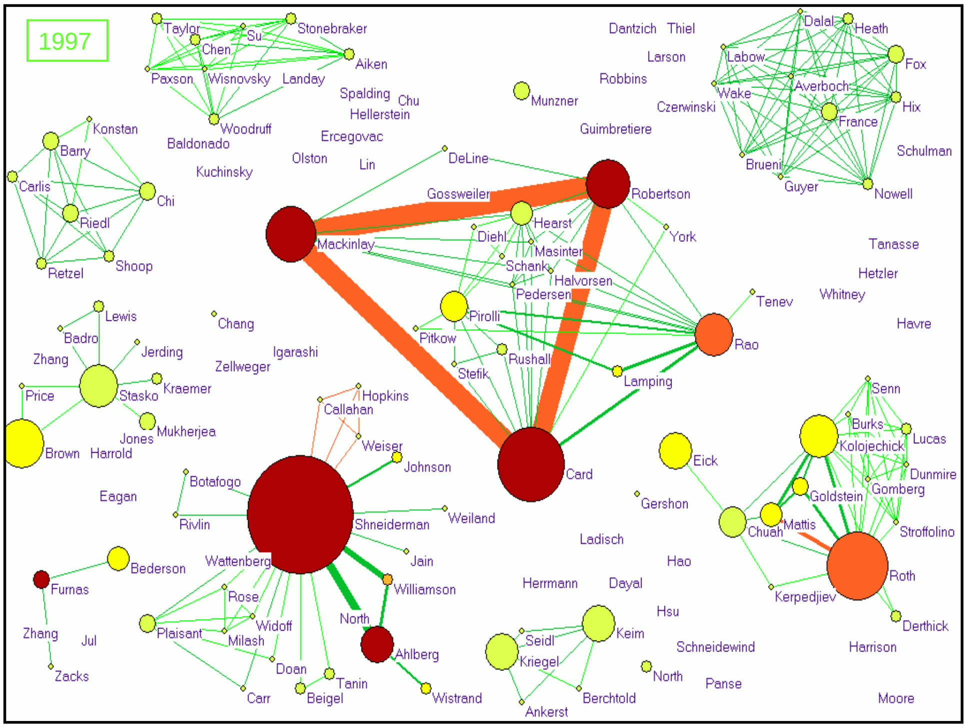

1992
Taylor
Su
Stonebraker
Dantzich
Thiel
Dalal
Heath
Chen
Larson
Labow
Paxson
Wisnovsky
Landay
Aiken
Fox
Robbins
Spalding
Chu
Munzner
Wake
Averboch
Hellerstein
Czerwinski
Hix
Konstan
Woodruff
Guimbretiere
France
Barry
Baldonado
Ercegovac
Olston
Lin
DeLine
Schulman
Kuchinsky
Brueni
Carlis
Gossweiler
Robertson
Guyer
Nowell
Chi
Riedl
Hearst
Mackinlay
Diehl
York
Tanasse
Masinter
Schank
Retzel
Shoop
Halvorsen
Hetzler
Pedersen
Whitney
Tenev
Lewis
Chang
Pirolli
Havre
Badro
Pitkow
Rao
Zhang
Jerding
Igarashi
Zellweger
Rushall
Stefik
Lamping
Kraemer
Hopkins
Senn
Price
Stasko
Callahan
Mukherjea
Burks
Jones
Weiser
Kolojechick
Lucas
Brown
Harrold
Johnson
Eick
Card
Dunmire
Botafogo
Gomberg
Eagan
Goldstein
Gershon
Weiland
Mattis
Rivlin
Shneiderman
Chuah
Stroffolino
Ladisch
Wattenberg
Jain
Hao
Bederson
Roth
Furnas
Herrmann
Dayal
Williamson
Rose
Kerpedjiev
Hsu
North
Widoff
Derthick
Zhang
Jul
Plaisant
Milash
Seidl
Keim
Ahlberg
Schneidewind
Harrison
Kriegel
Doan
North
Panse
Zacks
Tanin
Carr
Beigel
Wistrand
Berchtold
Moore
Ankerst

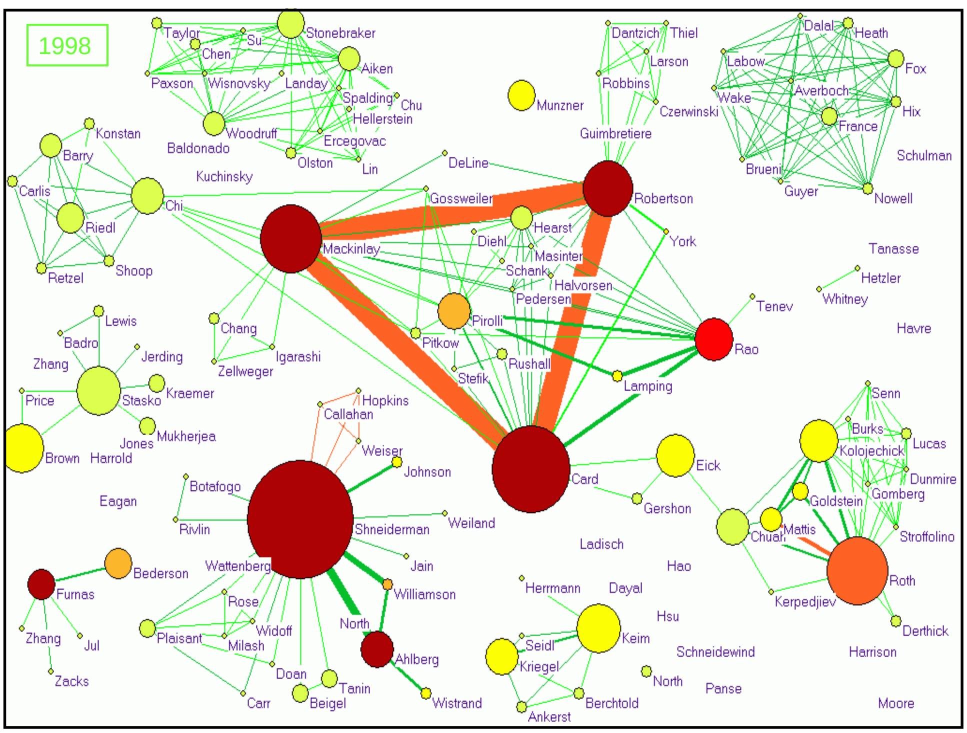

1993
Taylor
Su
Stonebraker
Dantzich
Thiel
Dalal
Heath
Chen
Larson
Labow
Aiken
Fox
Paxson
Wisnovsky
Landay
Robbins
Spalding
Chu
Munzner
Wake
Averboch
Hellerstein
Czerwinski
Hix
Konstan
Woodruff
Guimbretiere
France
Barry
Baldonado
Ercegovac
Schulman
Olston
DeLine
Lin
Brueni
Kuchinsky
Carlis
Guyer
Gossweiler
Robertson
Nowell
Chi
Riedl
Hearst
Diehl
York
Mackinlay
Masinter
Tanasse
Retzel
Shoop
Schank
Hetzler
Halvorsen
Pedersen
Whitney
Tenev
Lewis
Chang
Pirolli
Havre
Badro
Pitkow
Jerding
Igarashi
Rao
Zhang
Rushall
Zellweger
Stefik
Lamping
Kraemer
Price
Stasko
Hopkins
Senn
Callahan
Burks
Mukherjea
Lucas
Jones
Kolojechick
Weiser
Eick
Brown
Harrold
Johnson
Card
Dunmire
Botafogo
Goldstein
Gomberg
Eagan
Gershon
Weiland
Mattis
Rivlin
Shneiderman
Chuah
Stroffolino
Ladisch
Wattenberg
Jain
Hao
Bederson
Roth
Furnas
Williamson
Herrmann
Dayal
Rose
Kerpedjiev
Hsu
Widoff
North
Derthick
Zhang
Plaisant
Keim
Jul
Milash
Seidl
Schneidewind
Harrison
Ahlberg
Kriegel
Zacks
Doan
North
Panse
Tanin
Carr
Beigel
Wistrand
Berchtold
Moore
Ankerst

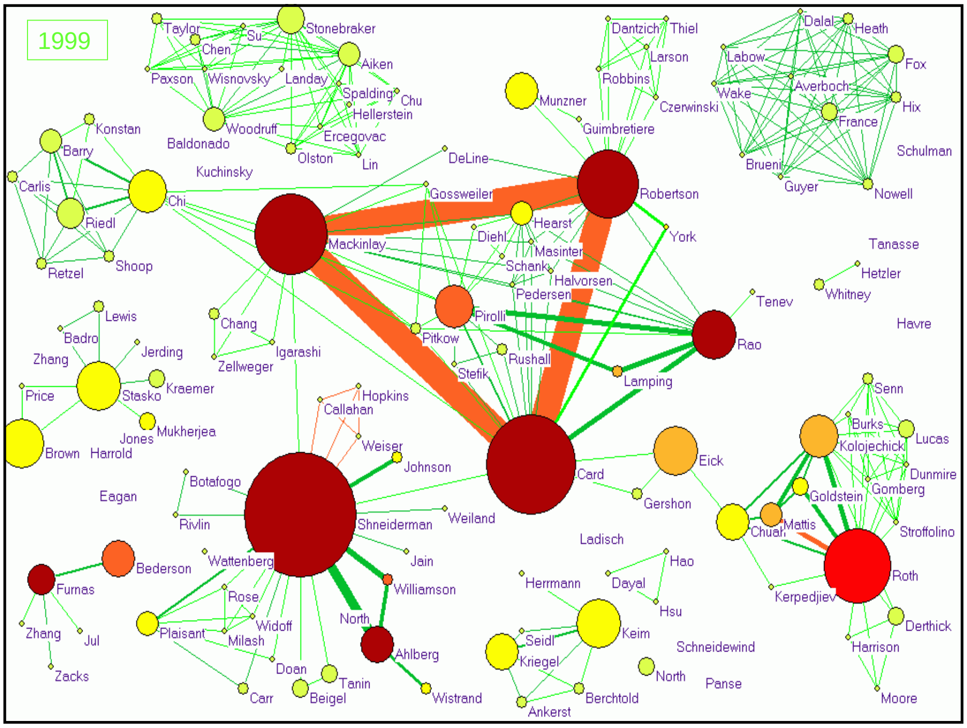

1994
Taylor
Su
Stonebraker
Dantzich
Thiel
Dalal
Heath
Chen
Larson
Labow
Aiken
Fox
Paxson
Wisnovsky
Landay
Robbins
Spalding
Chu
Munzner
Wake
Averboch
Hellerstein
Czerwinski
Hix
Konstan
Woodruff
Guimbretiere
France
Barry
Baldonado
Ercegovac
Schulman
Olston
DeLine
Lin
Brueni
Kuchinsky
Carlis
Guyer
Gossweiler
Robertson
Nowell
Chi
Riedl
Hearst
Diehl
York
Mackinlay
Masinter
Tanasse
Retzel
Shoop
Schank
Hetzler
Halvorsen
Pedersen
Whitney
Tenev
Lewis
Chang
Pirolli
Havre
Badro
Pitkow
Rao
Jerding
Igarashi
Zhang
Rushall
Zellweger
Stefik
Lamping
Kraemer
Price
Stasko
Hopkins
Senn
Callahan
Burks
Mukherjea
Lucas
Jones
Kolojechick
Weiser
Eick
Brown
Harrold
Johnson
Card
Dunmire
Botafogo
Goldstein
Gomberg
Eagan
Gershon
Weiland
Mattis
Rivlin
Shneiderman
Chuah
Stroffolino
Ladisch
Wattenberg
Jain
Hao
Bederson
Roth
Furnas
Williamson
Herrmann
Dayal
Rose
Kerpedjiev
Hsu
Widoff
North
Derthick
Zhang
Plaisant
Seidl
Keim
Jul
Milash
Schneidewind
Harrison
Ahlberg
Kriegel
Zacks
Doan
North
Panse
Tanin
Carr
Beigel
Wistrand
Berchtold
Moore
Ankerst

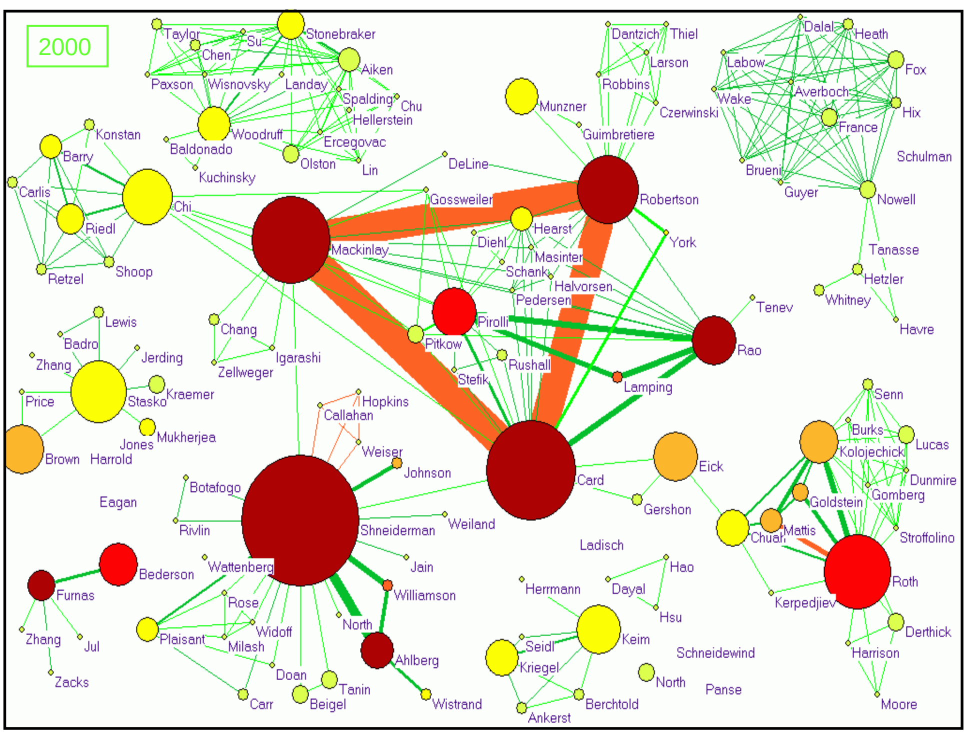

1995
Taylor
Su
Stonebraker
Chen
Aiken
Paxson
Wisnovsky
Landay
Spalding
Chu
Hellerstein
Woodruff
Ercegovac
Konstan
Baldonado
Barry
Olston
Lin
DeLine
Kuchinsky
Carlis
Chi
Riedl
Retzel
Shoop
Lewis
Badro
Zhang
Jerding
Chang
Zellweger
Igarashi
Price
Stasko
Kraemer
Mukherjea
Jones
Brown
Harrold
Hopkins
Callahan
Weiser
Johnson
Botafogo
Eagan
Rivlin
Shneiderman
Weiland
Jain
Bederson
Wattenberg
Williamson
Furnas
Rose
North
Widoff
Milash
Zhang
Jul
Plaisant
Ahlberg
Doan
Tanin
Zacks
Carr
Beigel
Wistrand
Dantzich
Thiel
Larson
Robbins
Munzner
Czerwinski
Guimbretiere
Gossweiler
Robertson
Hearst
Diehl
Mackinlay
Masinter
Schank
Halvorsen
Pedersen
Pirolli
Pitkow
Rushall
Stefik
Lamping
York
Rao
Tenev
Card
Eick
Gershon
Ladisch
Hao
Herrmann
Dayal
Hsu
Seidl
Keim
Kriegel
Schneidewind
North
Panse
Ankerst
Berchtold
Dalal
Heath
Labow
Fox
Wake
Averboch
Hix
France
Schulman
Brueni
Guyer
Nowell
Tanasse
Hetzler
Whitney
Havre
Senn
Burks
Lucas
Kolojechick
Dunmire
Goldstein
Gomberg
Chuah
Mattis
Stroffolino
Roth
Kerpedjiev
Derthick
Harrison
Moore

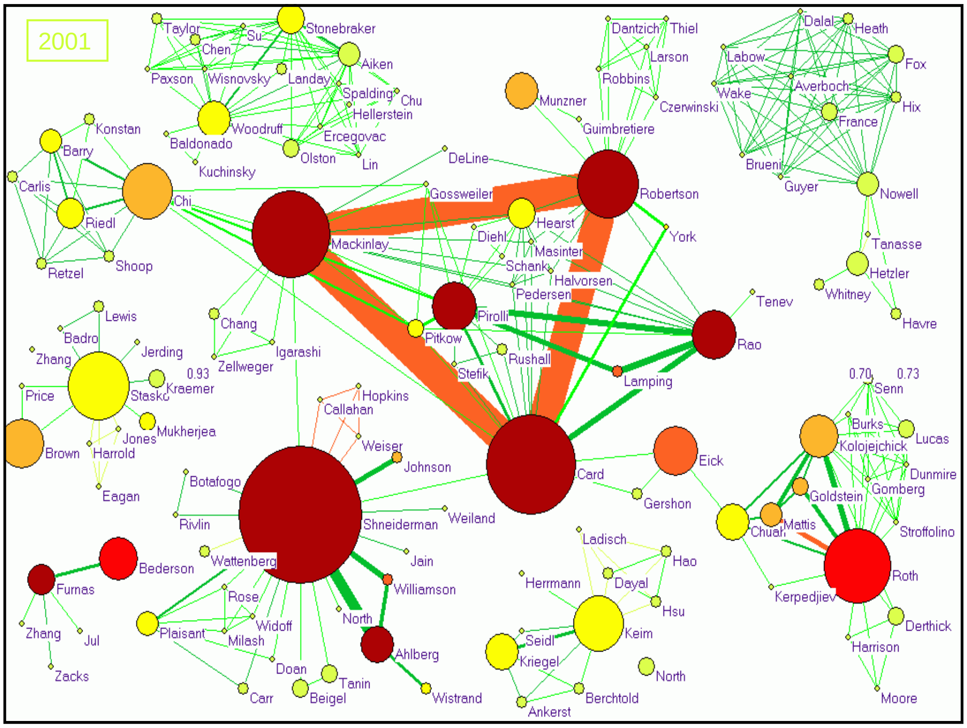

1996
Taylor
Su
Stonebraker
Chen
Aiken
Paxson
Wisnovsky
Landay
Spalding
Chu
Hellerstein
Woodruff
Ercegovac
Konstan
Baldonado
Barry
Olston
Lin
DeLine
Kuchinsky
Carlis
Chi
Riedl
Retzel
Shoop
Lewis
Badro
Zhang
Jerding
Chang
Zellweger
Igarashi
Price
Stasko
Kraemer
Mukherjea
Jones
Brown
Harrold
Hopkins
Callahan
Weiser
Johnson
Botafogo
Eagan
Rivlin
Shneiderman
Weiland
Jain
Bederson
Wattenberg
Williamson
Furnas
Rose
North
Widoff
Milash
Zhang
Jul
Plaisant
Ahlberg
Doan
Tanin
Zacks
Carr
Beigel
Wistrand
Dantzich
Thiel
Larson
Robbins
Munzner
Czerwinski
Guimbretiere
Gossweiler
Robertson
Hearst
Diehl
Mackinlay
Masinter
Schank
Halvorsen
Pedersen
Pirolli
Pitkow
Rushall
Stefik
Lamping
York
Rao
Tenev
Card
Eick
Gershon
Ladisch
Hao
Herrmann
Dayal
Hsu
Seidl
Keim
Kriegel
Schneidewind
North
Panse
Ankerst
Berchtold
Dalal
Heath
Labow
Fox
Wake
Averboch
Hix
France
Schulman
Brueni
Guyer
Nowell
Tanasse
Hetzler
Whitney
Havre
Senn
Burks
Lucas
Kolojechick
Dunmire
Goldstein
Gomberg
Chuah
Mattis
Stroffolino
Roth
Kerpedjiev
Derthick
Harrison
Moore

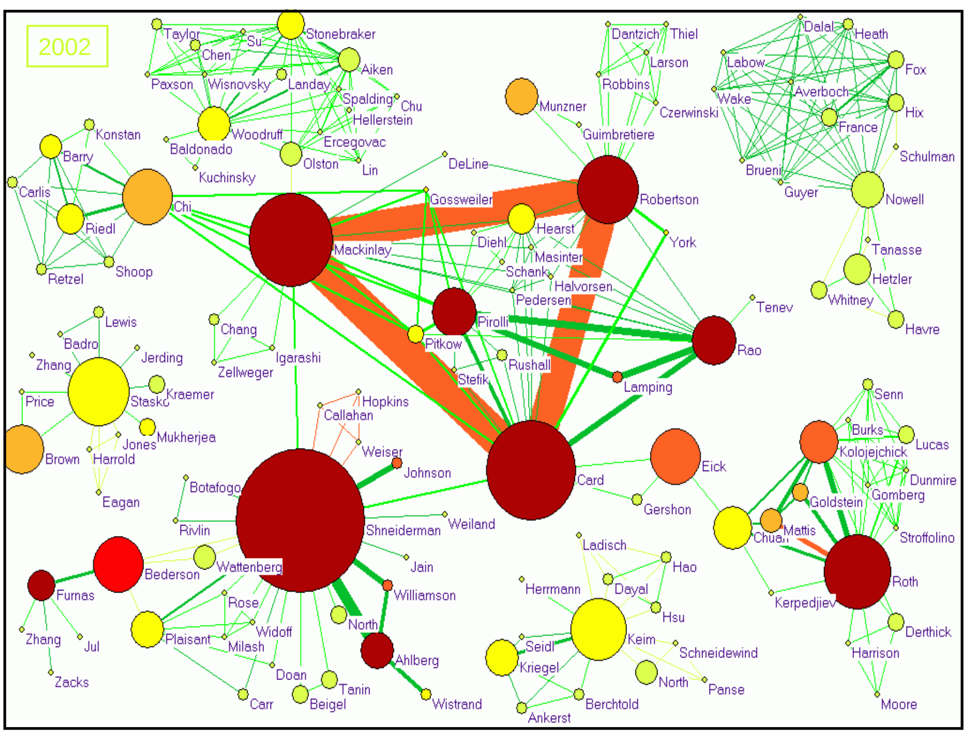

1997
Taylor
Su
Stonebraker
Chen
Aiken
Paxson
Wisnovsky
Landay
Spalding
Chu
Hellerstein
Woodruff
Ercegovac
Baldonado
Olston
Lin
Kuchinsky
Konstan
Barry
Carlis
Chi
Riedl
Shoop
Retzel
Dantzich
Thiel
Larson
Robbins
Czerwinski
Munzner
Guimbretiere
DeLine
Gossweiler
Robertson
Hearst
Mackinlay
Diehl
Masinter
Schank
Halvorsen
Pedersen
York
Dalal
Heath
Labow
Fox
Wake
Averboch
France
Hix
Schulman
Brueni
Guyer
Nowell
Tanasse
Hetzler
Tenev
Whitney
Havre
Rao
Pirolli
Pitkow
Rushall
Stefik
Lamping
Lewis
Badro
Chang
Jerding
Zhang
Zellweger
Igarashi
Price
Kraemer
Stasko
Hopkins
Callahan
Jones
Mukherjea
Brown
Harrold
Weiser
Johnson
Card
Eick
Senn
Burks
Lucas
Kolojechick
Dunmire
Goldstein
Gomberg
Botafogo
Eagan
Gershon
Rivlin
Shneiderman
Weiland
Chuah
Mattis
Stroffolino
Ladisch
Jain
Hao
Wattenberg
Bederson
Furnas
Williamson
Roth
Herrmann
Dayal
Kerpedjiev
Rose
Hsu
Zhang
Jul
Plaisant
Widoff
North
Milash
Keim
Seidl
Derthick
Schneidewind
Harrison
Kriegel
Ahlberg
Doan
North
Zacks
Tanin
Panse
Carr
Beigel
Wistrand
Berchtold
Moore
Ankerst

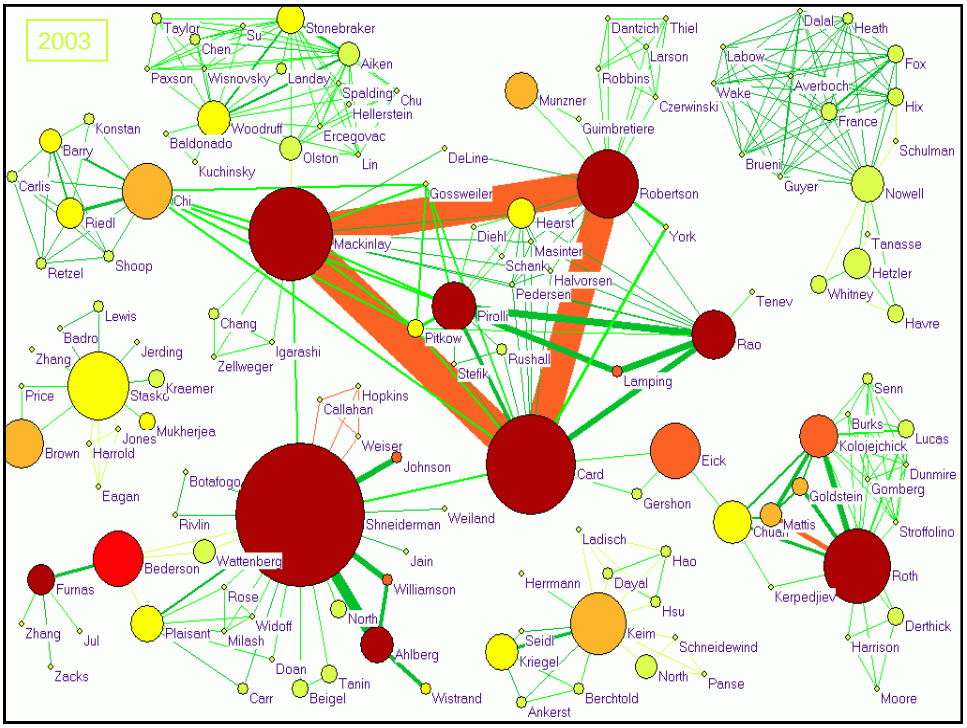

1998
Taylor
Su
Stonebraker
Chen
Aiken
Paxson
Wisnovsky
Landay
Spalding
Chu
Hellerstein
Woodruff
Ercegovac
Baldonado
Olston
Lin
Kuchinsky
Konstan
Barry
Carlis
Chi
Riedl
Shoop
Retzel
Dantzich
Thiel
Larson
Robbins
Czerwinski
Munzner
Guimbretiere
DeLine
Gossweiler
Robertson
Hearst
Mackinlay
Diehl
Masinter
Schank
Halvorsen
Pedersen
York
Dalal
Heath
Labow
Fox
Wake
Averboch
France
Hix
Schulman
Brueni
Guyer
Nowell
Tanasse
Hetzler
Tenev
Whitney
Havre
Rao
Pirolli
Pitkow
Rushall
Stefik
Lamping
Lewis
Badro
Chang
Jerding
Zhang
Zellweger
Igarashi
Price
Kraemer
Stasko
Hopkins
Callahan
Jones
Mukherjea
Brown
Harrold
Weiser
Johnson
Card
Eick
Senn
Burks
Lucas
Kolojechick
Dunmire
Goldstein
Gomberg
Botafogo
Eagan
Gershon
Rivlin
Shneiderman
Weiland
Chuah
Mattis
Stroffolino
Ladisch
Jain
Hao
Wattenberg
Bederson
Furnas
Williamson
Roth
Herrmann
Dayal
Kerpedjiev
Rose
Hsu
Zhang
Jul
Plaisant
Widoff
North
Milash
Keim
Seidl
Derthick
Schneidewind
Harrison
Kriegel
Ahlberg
Doan
North
Zacks
Tanin
Panse
Carr
Beigel
Wistrand
Berchtold
Moore
Ankerst

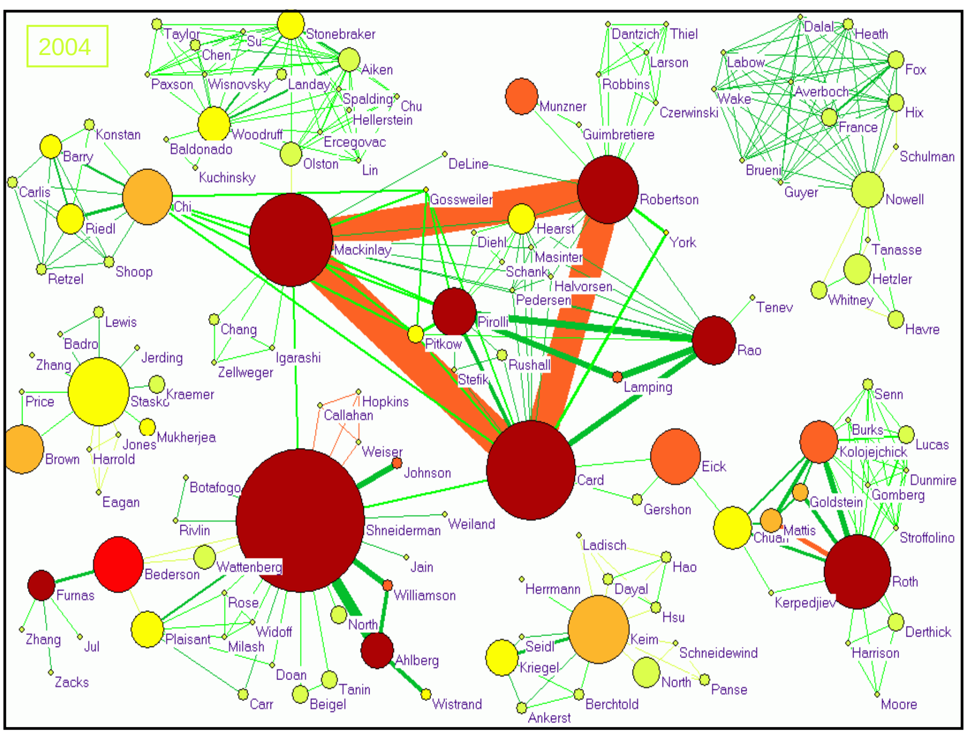

1999
Taylor
Su
Stonebraker
Chen
Aiken
Paxson
Wisnovsky
Landay
Spalding
Chu
Hellerstein
Woodruff
Ercegovac
Baldonado
Olston
Lin
Konstan
Barry
Kuchinsky
DeLine
Carlis
Chi
Gossweiler
Riedl
Mackinlay
Hearst
Diehl
Masinter
Schank
Halvorsen
Pedersen
Retzel
Shoop
Lewis
Chang
Pirolli
Badro
Jerding
Pitkow
Zhang
Zellweger
Igarashi
Rushall
Stefik
Price
Stasko
Kraemer
Lamping
Jones
Mukherjea
Hopkins
Callahan
Brown
Harrold
Weiser
Johnson
Eagan
Botafogo
Rivlin
Shneiderman
Weiland
Card
Gershon
Ladisch
Eick
Bederson
Wattenberg
Jain
Furnas
Rose
Williamson
Widoff
North
Zhang
Jul
Plaisant
Milash
Ahlberg
Doan
Tanin
Zacks
Carr
Beigel
Wistrand
Munzner
Dantzich
Thiel
Larson
Robbins
Czerwinski
Guimbretiere
Robertson
York
Rao
Tenev
Herrmann
Dayal
Hao
Hsu
Seidl
Kriegel
Keim
Schneidewind
North
Panse
Berchtold
Ankerst
Dalal
Heath
Labow
Fox
Wake
Averboch
Hix
France
Schulman
Brueni
Guyer
Nowell
Tanasse
Hetzler
Whitney
Havre
Senn
Burks
Lucas
Kolojechick
Dunmire
Goldstein
Gomberg
Chuah
Mattis
Stroffolino
Roth
Kerpedjiev
Derthick
Harrison
Moore

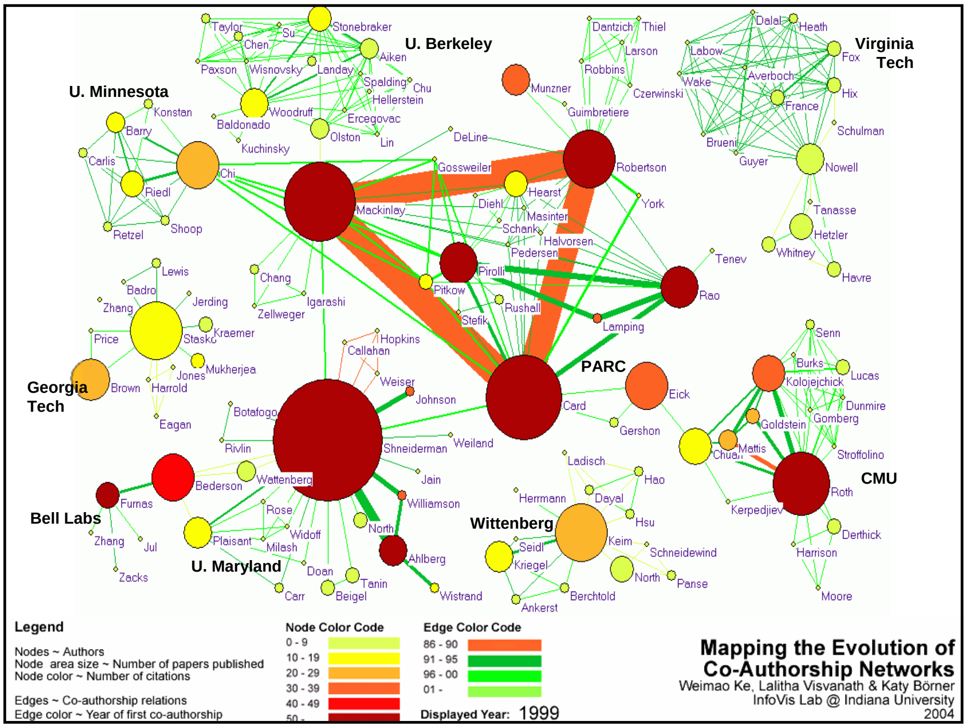

2000
Taylor
Su
Stonebraker
Chen
Aiken
Paxson
Wisnovsky
Landay
Spalding
Chu
Hellerstein
Woodruff
Ercegovac
Baldonado
Olston
Lin
Konstan
Barry
Kuchinsky
DeLine
Carlis
Chi
Gossweiler
Riedl
Mackinlay
Hearst
Diehl
Masinter
Schank
Halvorsen
Pedersen
Retzel
Shoop
Lewis
Chang
Pirolli
Badro
Jerding
Pitkow
Zhang
Zellweger
Igarashi
Rushall
Stefik
Price
Stasko
Kraemer
Lamping
Jones
Mukherjea
Hopkins
Callahan
Brown
Harrold
Weiser
Johnson
Eagan
Botafogo
Rivlin
Shneiderman
Weiland
Card
Gershon
Ladisch
Eick
Bederson
Wattenberg
Jain
Furnas
Rose
Williamson
Widoff
North
Zhang
Jul
Plaisant
Milash
Ahlberg
Doan
Tanin
Zacks
Carr
Beigel
Wistrand
Munzner
Dantzich
Thiel
Larson
Robbins
Czerwinski
Guimbretiere
Robertson
York
Rao
Tenev
Herrmann
Dayal
Hao
Hsu
Seidl
Kriegel
Keim
Schneidewind
North
Panse
Berchtold
Ankerst
Dalal
Heath
Labow
Fox
Wake
Averboch
Hix
France
Schulman
Brueni
Guyer
Nowell
Tanasse
Hetzler
Whitney
Havre
Senn
Burks
Lucas
Kolojechick
Dunmire
Goldstein
Gomberg
Chuah
Mattis
Stroffolino
Roth
Kerpedjiev
Derthick
Harrison
Moore

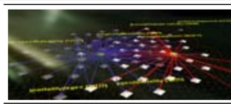

2001
Taylor
Su
Stonebraker
Chen
Aiken
Paxson
Wisnovsky
Landay
Spalding
Chu
Hellerstein
Woodruff
Baldonado
Ercegovac
Olston
Lin
Kuchinsky
Konstan
Barry
Carlis
Chi
Riedl
Shoop
Retzel
Dantzich
Thiel
Larson
Robbins
Czerwinski
Munzner
Guimbretiere
Dalal
Heath
Labow
Fox
Wake
Averboch
Hix
France
Brueni
Guyer
Nowell
DeLine
Gossweiler
Robertson
Hearst
Diehl
Masinter
Mackinlay
York
Schank
Halvorsen
Pedersen
Tanasse
Hetzler
Whitney
Tenev
Havre
Pirolli
Pitkow
Rao
Rushall
Stefik
Lamping
Lewis
Badro
Chang
Jerding
Zhang
Zellweger
Igarashi
0.93
Kraemer
Price
Stasko
Hopkins
Callahan
Mukherjea
Jones
Brown
Harrold
Weiser
Johnson
Eagan
Botafogo
Rivlin
Shneiderman
Weiland
Card
Eick
Gershon
0.70
0.73
Senn
Burks
Lucas
Kolojejchick
Dunmire
Gomberg
Goldstein
Mattis
Chuah
Stroffolino
Bederson
Wattenberg
Jain
Williamson
Furnas
Rose
Zhang
Jul
Plaisant
Widoff
Milash
North
Doan
Tanin
Ahlberg
Carr
Beigel
Wistrand
Zacks
Ladisch
Hao
Herrmann
Dayal
Hsu
Seidl
Keim
Kriegel
North
Berchtold
Ankerst
Roth
Kerpedjiev
Derthick
Harrison
Moore


2002
Taylor
Su
Stonebraker
Chen
Aiken
Paxson
Wisnovsky
Landay
Spalding
Chu
Hellerstein
Woodruff
Baldonado
Ercegovac
Olston
Lin
Kuchinsky
Konstan
Barry
Carlis
Chi
Riedl
Shoop
Retzel
Dantzich
Thiel
Larson
Robbins
Czerwinski
Munzner
Guimbretiere
Dalal
Heath
Labow
Fox
Wake
Averboch
Hix
France
Schulman
Brueni
Guyer
Nowell
DeLine
Gossweiler
Robertson
Hearst
Diehl
Masinter
Mackinlay
York
Schank
Halvorsen
Pedersen
Tanasse
Hetzler
Whitney
Tenev
Havre
Pirolli
Pitkow
Rao
Rushall
Stefik
Lamping
Lewis
Badro
Chang
Jerding
Zhang
Zellweger
Igarashi
Kraemer
Price
Stasko
Hopkins
Callahan
Mukherjea
Jones
Brown
Harrold
Weiser
Johnson
Eagan
Botafogo
Rivlin
Shneiderman
Weiland
Card
Eick
Gershon
Senn
Burks
Lucas
Kolojejchick
Dunmire
Gomberg
Goldstein
Mattis
Chuah
Stroffolino
Bederson
Wattenberg
Jain
Williamson
Furnas
Rose
Zhang
Jul
Plaisant
Widoff
Milash
North
Doan
Tanin
Ahlberg
Carr
Beigel
Wistrand
Zacks
Ladisch
Hao
Herrmann
Dayal
Hsu
Seidl
Keim
Schneidewind
Kriegel
North
Panse
Berchtold
Ankerst
Roth
Kerpedjiev
Derthick
Harrison
Moore


2003
Taylor
Su
Chen
Stonebraker
Aiken
Paxson
Wisnovsky
Landay
Spalding
Chu
Hellerstein
Woodruff
Baldonado
Ercegovac
Olston
Lin
Kuchinsky
Konstan
Barry
Carlis
Chi
Riedl
Retzel
Shoop
DeLine
Gossweiler
Mackinlay
Hearst
Diehl
Masinter
Schank
Halvorsen
Pedersen
Pirolli
Pitkow
Rushall
Stefik
Lamping
Rao
Tenev
Dantzich
Thiel
Larson
Robbins
Czerwinski
Munzner
Guimbretiere
Robertson
York
Labow
Dalal
Heath
Fox
Wake
Averboch
Hix
France
Schulman
Brueni
Guyer
Nowell
Tanasse
Hetzler
Whitney
Havre
Lewis
Badro
Jerding
Zhang
Chang
Zellweger
Igarashi
Price
Stasko
Kraemer
Jones
Mukherjea
Brown
Harrold
Eagan
Hopkins
Callahan
Weiser
Johnson
Botafogo
Rivlin
Shneiderman
Weiland
Card
Eick
Gershon
Senn
Burks
Kolojejchick
Lucas
Dunmire
Goldstein
Gomberg
Chuah
Mattis
Stroffolino
Roth
Kerpedjiev
Derthick
Harrison
Moore
Ladisch
Hao
Dayal
Herrmann
Hsu
Keim
Schneidewind
Seidl
Kriegel
North
Panse
Berchtold
Ankerst
Bederson
Wattenberg
Furnas
Jain
Williamson
Rose
Widoff
Plaisant
Milash
North
Ahlberg
Zhang
Jul
Zacks
Doan
Tanin
Carr
Beigel
Wistrand


2004
Taylor
Su
Chen
Stonebraker
Aiken
Paxson
Wisnovsky
Landay
Spalding
Chu
Hellerstein
Woodruff
Baldonado
Ercegovac
Olston
Lin
Kuchinsky
Konstan
Barry
Carlis
Chi
Riedl
Retzel
Shoop
DeLine
Gossweiler
Mackinlay
Hearst
Diehl
Masinter
Schank
Halvorsen
Pedersen
Pirolli
Pitkow
Rushall
Stefik
Lamping
Rao
Tenev
Dantzich
Thiel
Larson
Robbins
Czerwinski
Munzner
Guimbretiere
Robertson
York
Labow
Dalal
Heath
Fox
Wake
Averboch
Hix
France
Schulman
Brueni
Guyer
Nowell
Tanasse
Hetzler
Whitney
Havre
Lewis
Badro
Jerding
Zhang
Chang
Zellweger
Igarashi
Price
Stasko
Kraemer
Jones
Mukherjea
Brown
Harrold
Eagan
Hopkins
Callahan
Weiser
Johnson
Botafogo
Rivlin
Shneiderman
Weiland
Card
Eick
Gershon
Senn
Burks
Kolojejchick
Lucas
Dunmire
Goldstein
Gomberg
Chuah
Mattis
Stroffolino
Roth
Kerpedjiev
Derthick
Harrison
Moore
Ladisch
Hao
Dayal
Herrmann
Hsu
Keim
Schneidewind
Seidl
Kriegel
North
Panse
Berchtold
Ankerst
Bederson
Wattenberg
Furnas
Jain
Williamson
Rose
Widoff
Plaisant
Milash
North
Ahlberg
Zhang
Jul
Zacks
Doan
Tanin
Carr
Beigel
Wistrand

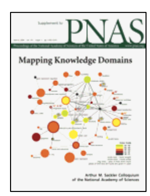




1. Motivation for Mapping Knowledge Domains / Computational Scientometrics

Knowledge domain visualizations help answer questions such as:

- What are the major research areas, experts, institutions, regions, nations, grants, publications, journals in xx research?
- Which areas are most insular?
- What are the main connections for each area?
- What is the relative speed of areas?
- Which areas are the most dynamic/static?
- What new research areas are evolving?
- Impact of xx research on other fields?
- How does funding influence the number and quality of publications?



Answers are needed by funding agencies, companies, and researchers.

Shiffrin & Börner (Eds). (2004) Mapping Knowledge Domains. PNAS, 101(Suppl_1):5266-5273.

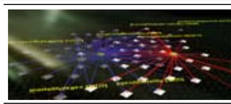
Mapping Knowledge Domains, Katy Börner, Indiana University 22

User Groups

- **Students** can gain an overview of a particular knowledge domain, identify major research areas, experts, institutions, grants, publications, patents, citations, and journals as well as their interconnections, or see the influence of certain theories.
- **Researchers** can monitor and access research results, relevant funding opportunities, potential collaborators inside and outside the fields of inquiry, the dynamics (speed of growth, diversification) of scientific fields, and complementary capabilities.
- **Grant agencies/R&D managers** could use the maps to select reviewers or expert panels, to augment peer-review, to monitor (long-term) money flow and research developments, evaluate funding strategies for different programs, decisions on project durations, and funding patterns, but also to identify the impact of strategic and applied research funding programs.
- **Industry** can use the maps to access scientific results and knowledge carriers, to detect research frontiers, etc. Information on needed technologies could be incorporated into the maps, facilitating industry pulls for specific directions of research.
- **Data providers** benefit as the maps provide unique visual interfaces to digital libraries.

- Last but not least, the availability of dynamically evolving maps of science (as ubiquitous as daily weather forecast maps) would dramatically improve the communication of scientific results to the **general public**.

Mapping Knowledge Domains, Katy Börner, Indiana University 23



2. Mapping the Structure and Evolution of Knowledge Domains

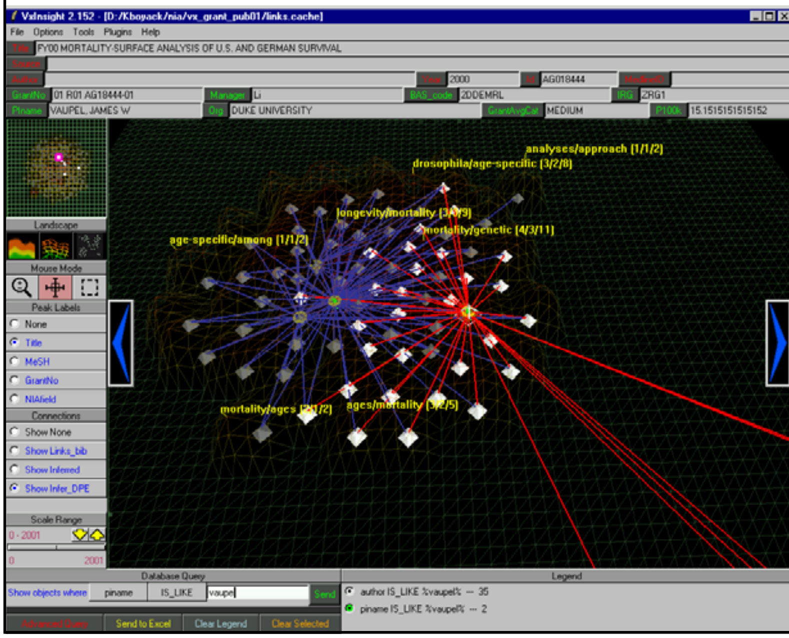
DATA EXTRACTION	UNIT OF ANALYSIS	MEASURES	LAYOUT (often one code does both similarity and ordination steps)		DISPLAY
			SIMILARITY	ORDINATION	
SEARCHES	COMMON	COUNTS/FREQUENCIES	SCALAR (unit by unit matrix)	DIMENSIONALITY REDUCTION	INTERACTION
ISI	CHOICES	Attributes (e.g. terms)	Direct citation	Eigenvector/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

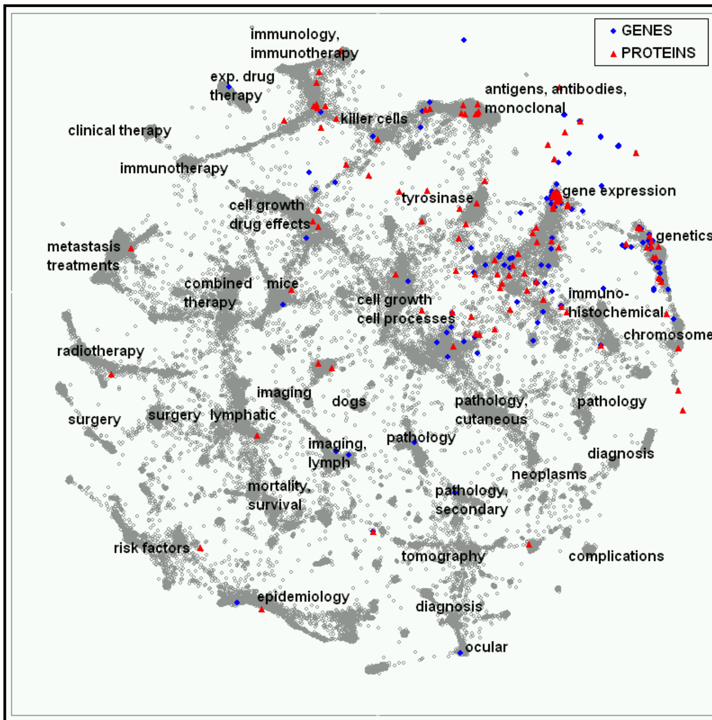
Börner, Chen & Boyack.. (2003) Visualizing Knowledge Domains. In Blaise Cronin (Ed.), Annual Review of Information Science & Technology, Volume 37, Medford, NJ: Information Today, Inc./American Society for Information Science and Technology, chapter 5, pp. 179-255.

Mapping Knowledge Domains, Katy Börner, Indiana University 24

Indicator-Assisted Evaluation and Funding of Research

Boyack & Börner. (2003) JASIST, 54(5):447-461.





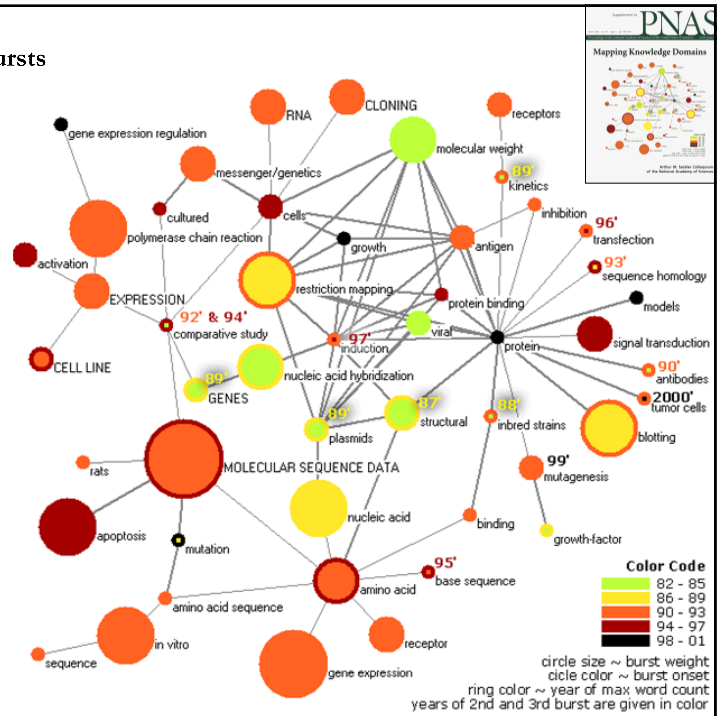
Mapping Medline Papers, Genes, and Proteins Related to Melanoma Research

Boyack, Mane & Börner. (2004) IV Conference, pp. 965-971.

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.

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

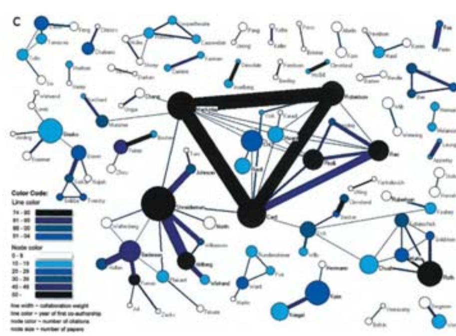
Börner, Dall'Asta, Ke & Vespignani (2005) Complexity, 10(4):58-67.

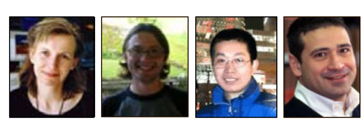
Research question:

- 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.





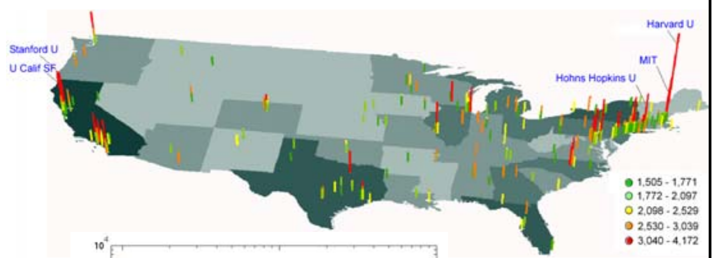
Spatio-Temporal Information Production and Consumption of Major U.S. Research Institutions

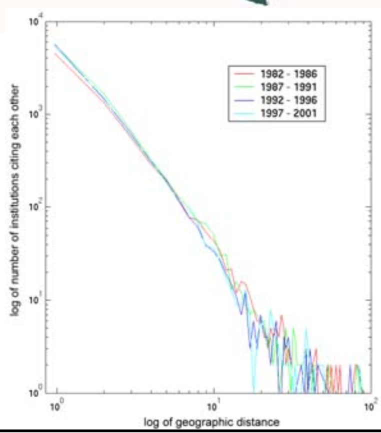
Börner & Penumarthy. (2005) Scientometrics Conference.

Does Internet lead to more global citation patterns, i.e., more citation links between papers produced at geographically distant research instructions?

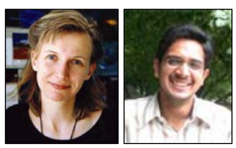
Analysis of top 500 most highly cited U.S. institutions.

Each institution is assumed to produce and consume information.





$\gamma_{82-86} = 1.94$ (R^2=91.5%)
$\gamma_{87-91} = 2.11$ (R^2=93.5%)
$\gamma_{92-96} = 2.01$ (R^2=90.8%)
$\gamma_{97-01} = 2.01$ (R^2=90.7%)



Mapping all of Sciences

(in English speaking domain, based on available data)

Subsequent slides are based on

- *Boyack, K.W., Klavans, R., & Börner, K. (2005, in press). Mapping the backbone of science. Scientometrics.*

Comparing different similarity measures

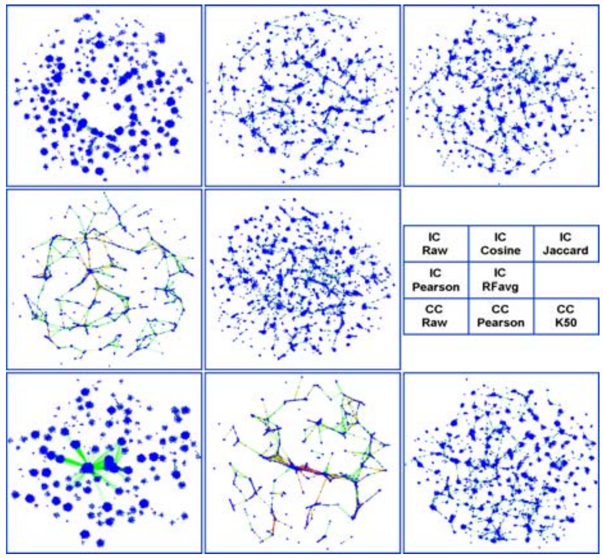
ISI file year 2000, SCI and SSCI: 7,121 journals.

Ten different similarity metrics

- 6 Inter-citation (raw counts, cosine, modified cosine, Jaccard, RF, Pearson)
- 4 Co-citation (raw counts, cosine, modified cosine, Pearson)

Maps were compared based on

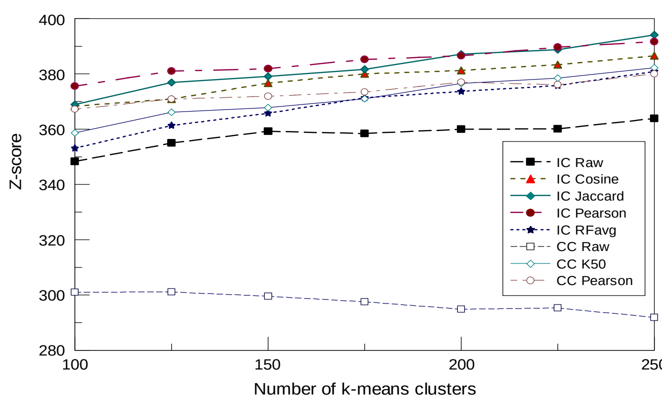
- regional accuracy,
- the scalability of the similarity algorithm, and
- the readability of the layouts.



Boyack, K.W., Klavans, R., & Börner, K. (2005, in press). Mapping the backbone of science. Scientometrics.

Selecting the similarity measure with the best regional accuracy

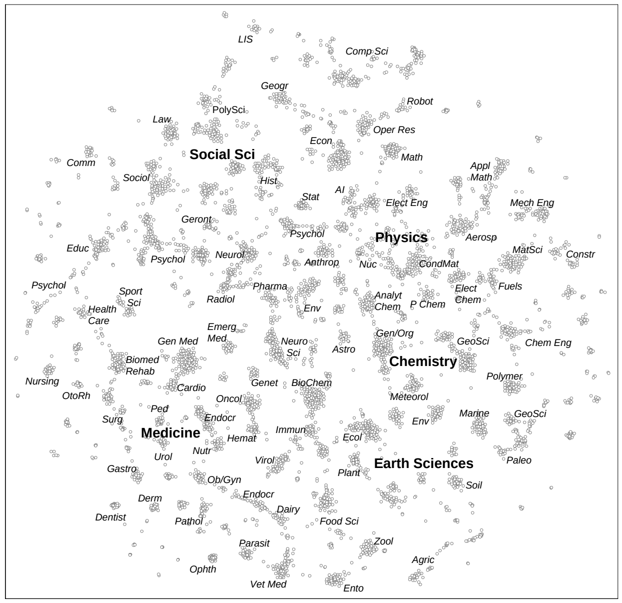
- For each similarity measure, the VxOrd layout was subjected to k-means clustering using different numbers of clusters.
- Resulting cluster/category memberships were compared to actual category memberships using entropy/mutual information method by Gibbons & Roth, 2002.
- Increasing Z-score indicates increasing distance from a random solution.
- Most similarity measures are within several percent of each other.



Boyack, K.W., Klavans, R., & Börner, K. (2005, in press). Mapping the backbone of science. Scientometrics.

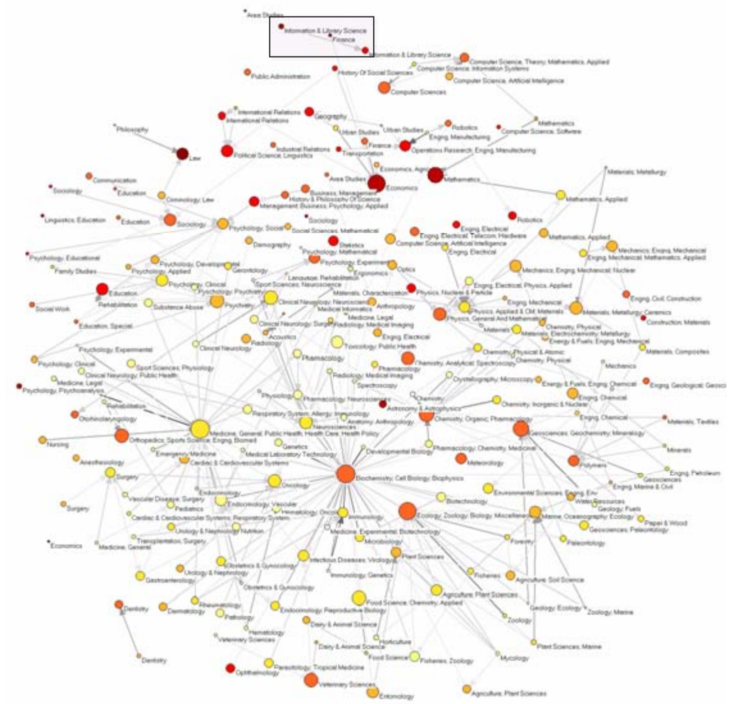
A map of all science & social science

- The map is comprised of 7,121 journals from year 2000.
- Each dot is one journal
- An *IC-Jaccard* similarity measure was used.
- Journals group by discipline
- Groups are labeled by hand
- Large font size labels identify major areas of science.
- Small labels denote the disciplinary topics of nearby large clusters of journals.

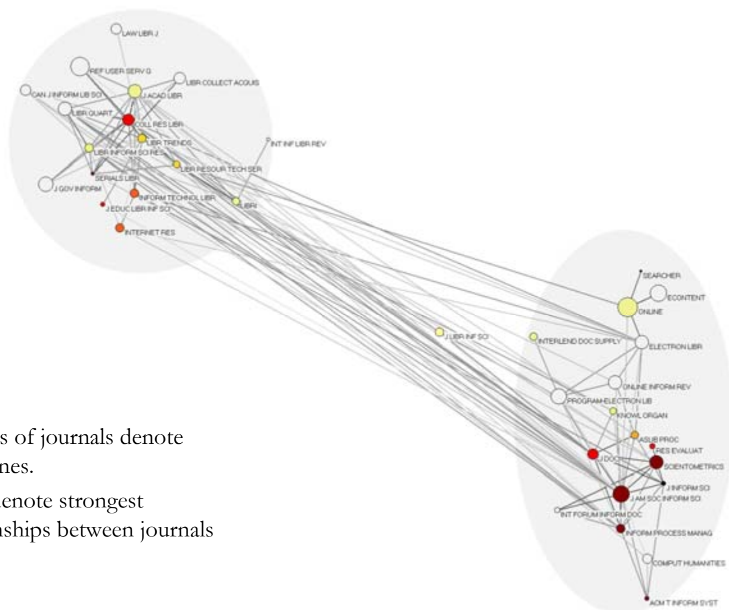


Structural map: Studying disciplinary diffusion

- The 212 nodes represent clusters of journals for different disciplines.
- Nodes are labeled with their dominant ISI category name.
- Circle sizes (area) denote the number of journals in each cluster.
- Circle color depicts the independence of each cluster, with darker colors depicting greater independence.
- Lines denote strongest relationships between disciplines (citing cluster gives more than 7.5% of its total citations to the cited cluster).

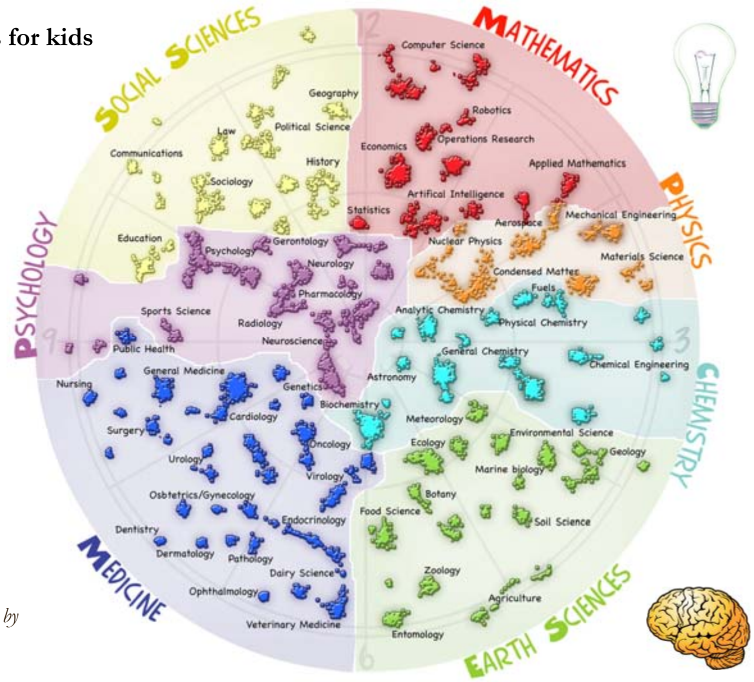


Zoom into structural map



- Clusters of journals denote disciplines.
- Lines denote strongest relationships between journals

Science maps for kids

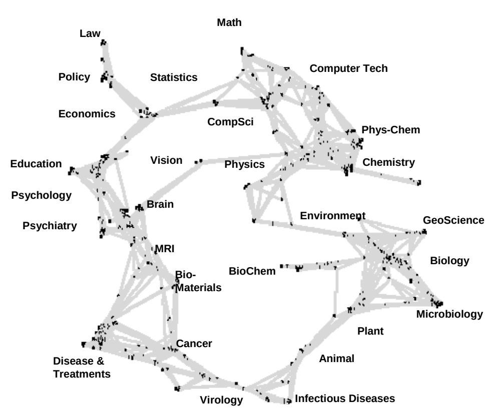


Base map modified by
Ian Aliman, IU.

Latest 'Base Map' of sciences

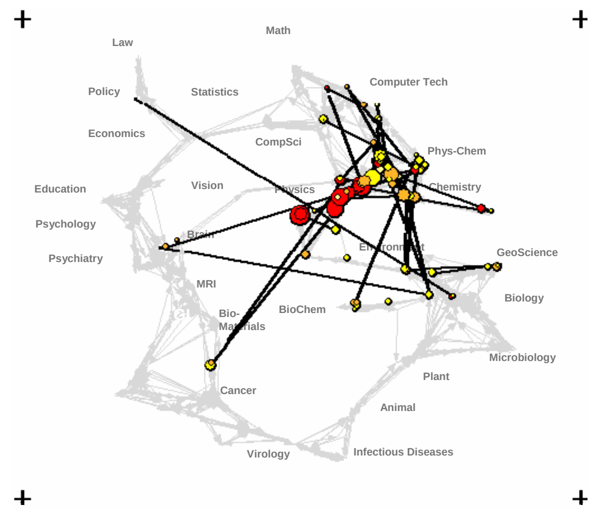
Presented by Kevin Boyack at AAG, 2005.

- Uses combined SCIE/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



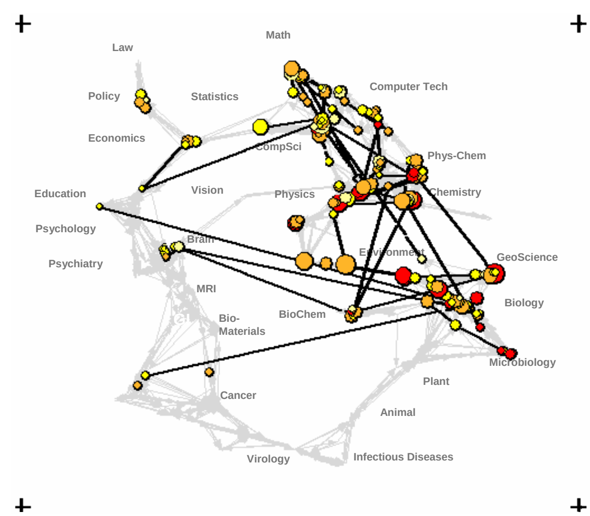
Science Map Applications: Identifying Core Competency

Funding patterns of the US Department of Energy (DOE)



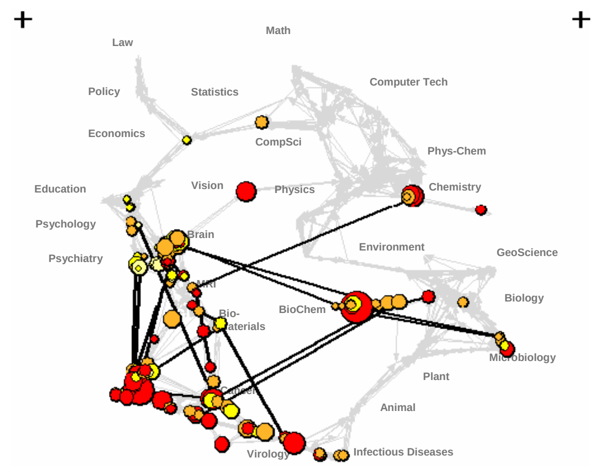
Science Map Applications: Identifying Core Competency

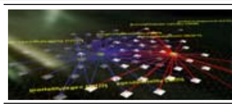
Funding patterns of the National Science Foundation (NSF)



Science Map Applications: Identifying Core Competency

Funding patterns of the National Institutes of Health (NIH)





3. Challenges and Opportunities

Map sciences on a small (regional) and a large scale:

- Develop techniques, tools, and infrastructures that can continuously harvest, integrate, analyze, and visualize the growing stream of scholarly data.
- Educate scholars, practitioners, and the general public about alternative means to access humanity's collective knowledge.

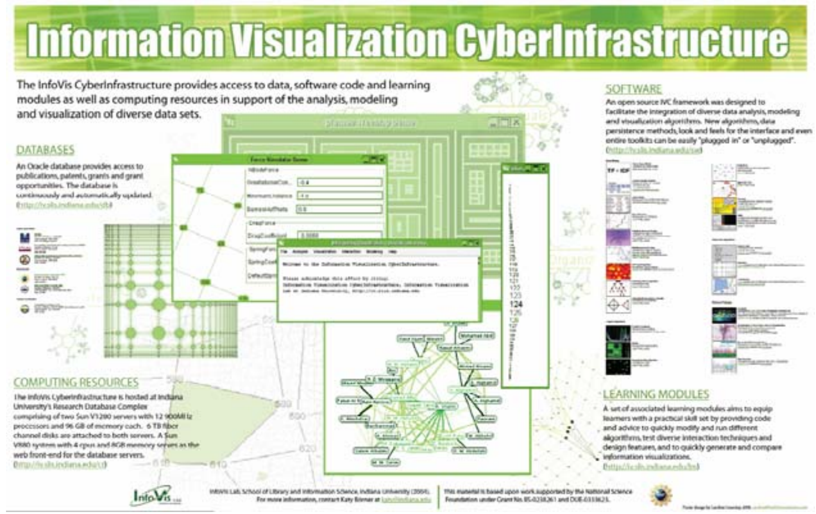
Increase our understanding of the structure and evolution of sciences:

- Model the co-evolution of scholarly networks

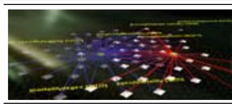
  Börner, Katy, Maru, Jeegar and Goldstone, Robert. (2004). The Simultaneous Evolution of Author and Paper Networks. Proceedings of the National Academy of Sciences of the United States of America, 101(Suppl_1):5266-5273. Also available as cond-mat/0311459.
- Model the diffusion of knowledge in evolving network ecologies.

Mapping Knowledge Domains, Katy Börner, Indiana University 42

InfoVis Cyberinfrastructure at IUB
http://iv.slis.indiana.edu/



Mapping Knowledge Domains, Katy Börner, Indiana University 43



3. Challenges and Opportunities

Map sciences on a small (regional) and a large scale:

- Develop techniques, tools, and infrastructures that can continuously harvest, integrate, analyze, and visualize the growing stream of scholarly data.
- Educate scholars, practitioners, and the general public about alternative means to access humanity's collective knowledge.

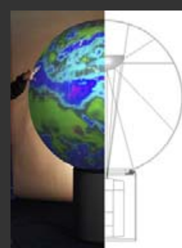
Increase our understanding of the structure and evolution of sciences:

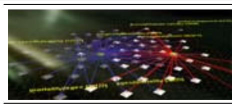
- Model the co-evolution of scholarly networks
  Börner, Katy, Maru, Jeegar and Goldstone, Robert. (2004). The Simultaneous Evolution of Author and Paper Networks. Proceedings of the National Academy of Sciences of the United States of America, 101(Suppl_1):5266-5273. Also available as cond-mat/0311459.
- Model the diffusion of knowledge in evolving network ecologies.

Mapping Knowledge Domains, Katy Börner, Indiana University 44

This physical & virtual science exhibit compares and contrasts first maps of our entire planet with the first maps of all of sciences.

http://vw.indiana.edu/places&spaces/





3. Challenges and Opportunities

Map sciences on a small (regional) and a large scale:

- Develop techniques, tools, and infrastructures that can continuously harvest, integrate, analyze, and visualize the growing stream of scholarly data.
- Educate scholars, practitioners, and the general public about alternative means to access humanity's collective knowledge.

Increase our understanding of the structure and evolution of sciences:

- Model the co-evolution of scholarly networks
  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.
- Model the diffusion of knowledge in evolving network ecologies.

Mapping Knowledge Domains, Katy Börner, Indiana University 46

Acknowledgements

I would like to thank the students in the InfoVis Lab at IU and my collaborators for their contributions to this work.

Support comes from the School of Library and Information Science, Indiana University's High Performance Network Applications Program, a Pervasive Technology Lab Fellowship, an Academic Equipment Grant by SUN Microsystems, and an SBC (formerly Ameritech) Fellow Grant. This material is based upon work supported by the National Science Foundation under Grant No. DUE-0333623 and IIS-0238261.

Mapping Knowledge Domains, Katy Börner, Indiana University 47