

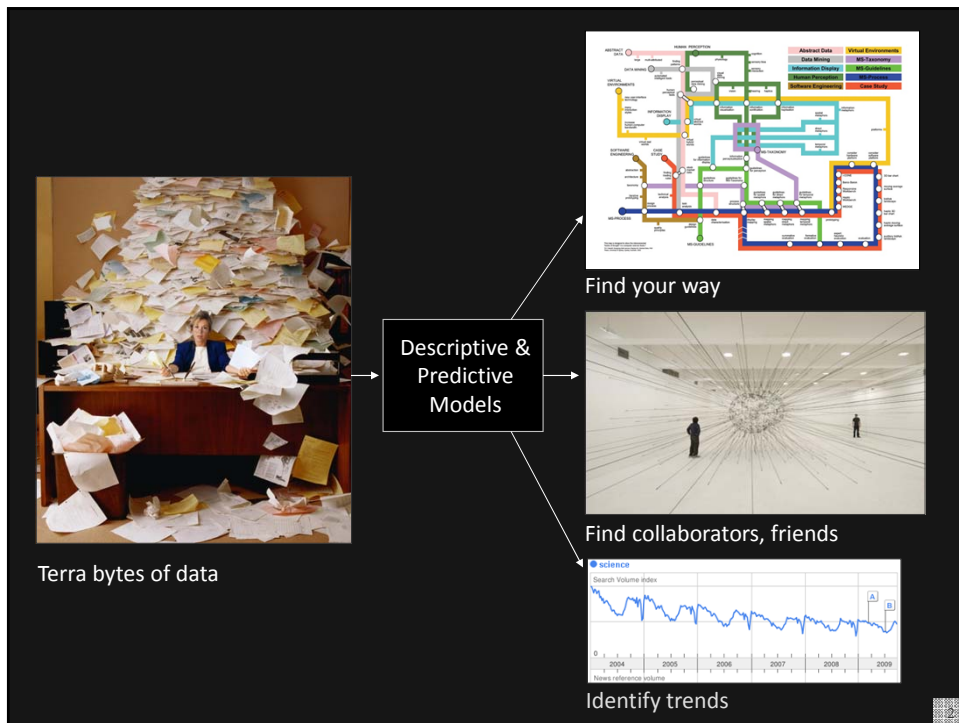
# Scalable Multi-Scale Visual Analytical Tools for Health Science

Katy Börner, Robert Light, Daniel Halsey

Cyberinfrastructure for Network Science Center  
School of Informatics and Computing, Indiana University, USA

Regenstrief Institute, Indianapolis, IN  
April 29, 2015

*Language Communities of Twitter - Eric Fischer - 2012*



## *Descriptive Models*

*Multiple levels: Micro ... Macro*

*Answering: When? Where? What? With Whom?*



### **Different Levels of Abstraction/Analysis**

Macro/Global  
Population Level



Meso/Local  
Group Level



Micro  
Individual Level

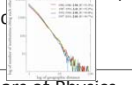
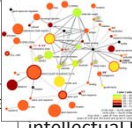





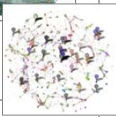

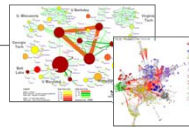
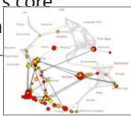


## Type of Analysis vs. Level of Analysis

	<b>Micro/Individual (1-100 records)</b>	<b>Meso/Local (101-100,000 records)</b>	<b>Macro/Global (100,000 &lt; records)</b>
<b>Statistical Analysis/Profiling</b>	Individual person and their expertise profiles	Larger labs, centers, universities, research domains, or states	All of NSF, all of USA, all of science.
<b>Temporal Analysis (When?)</b>	Funding portfolio of one individual	Mapping topic bursts in 20-years of PNAS	113 Years of Physics Research
<b>Geospatial Analysis (Where?)</b>	Career trajectory of one individual	Mapping a states intellectual landscape	PNAS publications
<b>Topical Analysis (What?)</b>	Base knowledge from which one grant draws.	Knowledge flows in Chemistry research	VxOrd/Topic maps of NIH funding
<b>Network Analysis (With Whom?)</b>	NSF Co-PI network of one individual	Co-author network	NIH's core competency

5

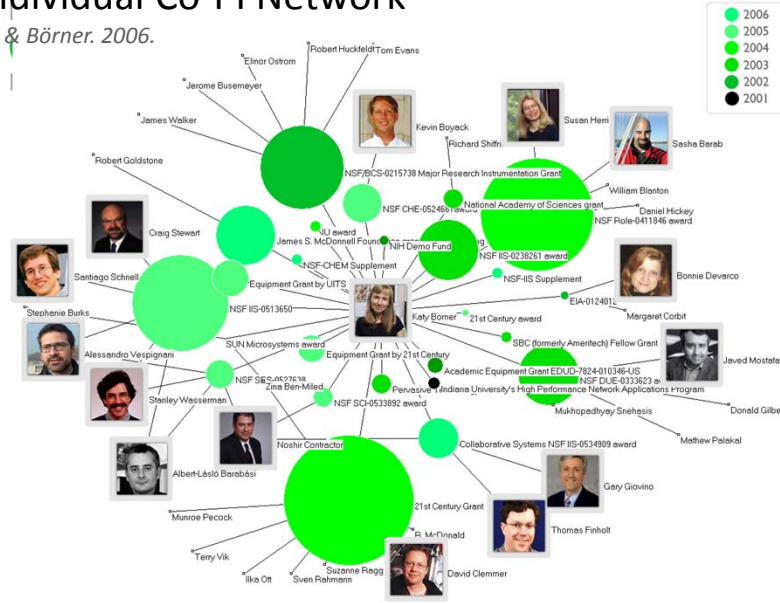
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# Individual Co-PI Network

Ke & Börner. 2006.

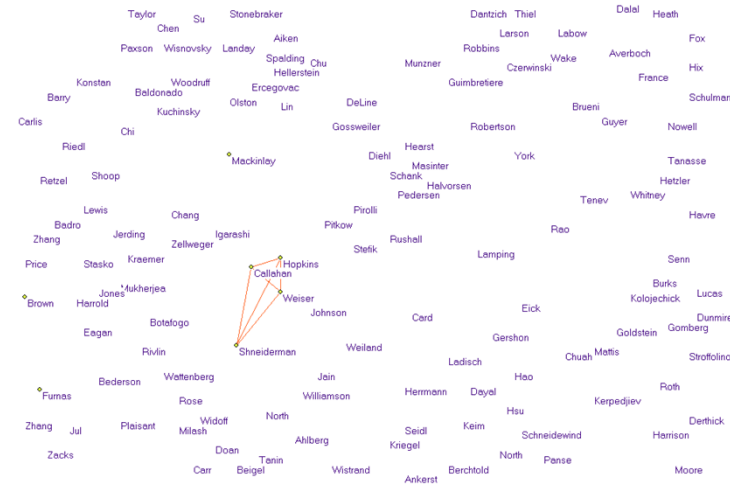


1

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# Mapping the Evolution of Co-Authorship Networks

Ke, Visvanath & Börner. 2004. Won 1st prize at the IEEE InfoVis Contest.



**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	Edge Color Code
0 - 9	85 - 90
10 - 19	91 - 95
20 - 29	96 - 00
30 - 39	01 -
40 - 49	02 -
50 -	03 -

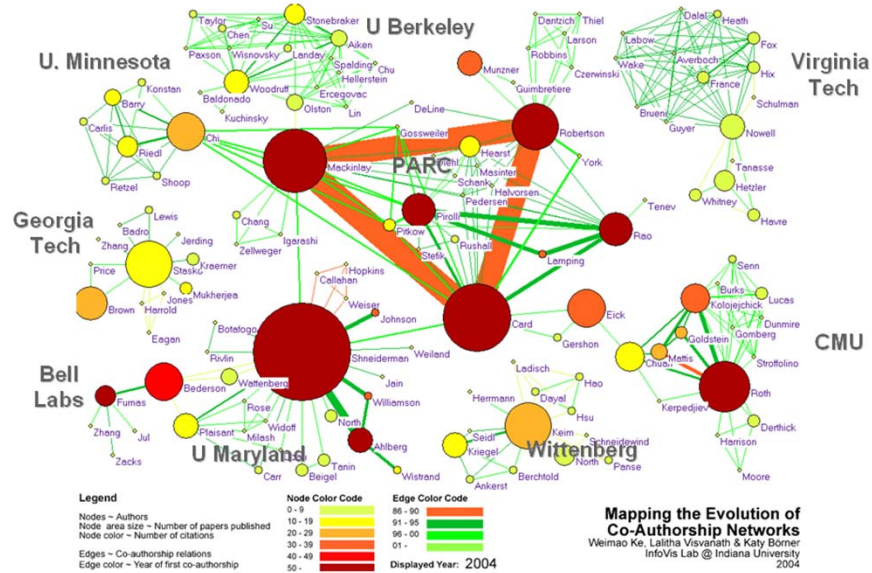
Displayed Year: 1988

**Mapping the Evolution of Co-Authorship Networks**  
 Weimao Ke, Latha Visvanath & Katy Börner  
 InfoVis Lab @ Indiana University  
 2004

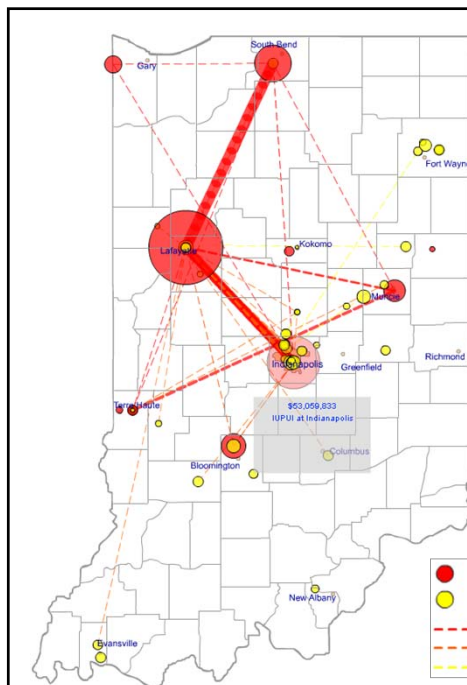
8

## Mapping the Evolution of Co-Authorship Networks 2

Ke, Visvanath & Börner. 2004. Won 1st prize at the IEEE InfoVis Contest.



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## Mapping Indiana's Intellectual Space

Identify

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

3

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## Mapping Transdisciplinary Tobacco Use Research Centers Publications

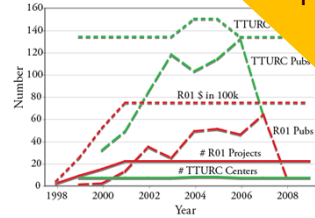
Compare R01 investigator-based funding with TTURC Center awards in terms of number of publications and evolving co-author networks.

Stipelman, Hall, Zoss, Okamoto, Stokols, Börner, 2014.

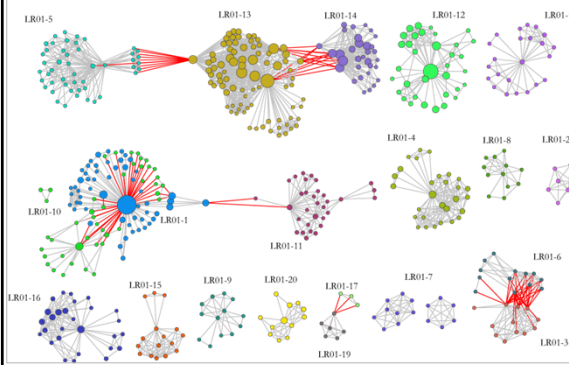
Supported by NIH/NCI Contract HHSN261200800812

R01 & TTURC Project Information

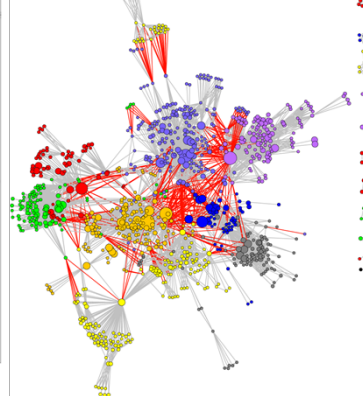
4



Longitudinal R01 Co-Authorship Network



TTURC Co-Authorship Network



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## Research Collaborations by the Chinese Academy of Sciences

Huang, Duhon, Hardy & Börner

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北京地区中科院各院所



### 中科院与世界各地的研究合作关系

黄维霞, Russell J. Duhon, Elisha F. Hardy, Katy Börner, Indiana University, USA

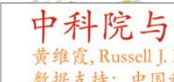
数据支持: 中国科学院国家科学图书馆科学前沿分析中心

金碧辉, 岳焯

甘肃省中科院各院所



上海地区中科院各院所



吉林省中科院各院所



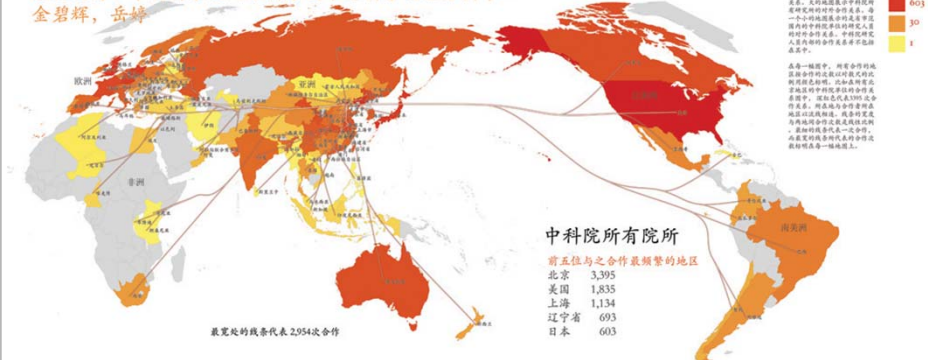
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黄维霞, Russell J. Duhon, Elisha F. Hardy, Katy Börner, Indiana University, USA

数据支持: 中国科学院国家科学图书馆科学前沿分析中心

金碧辉, 岳焯

合作次数



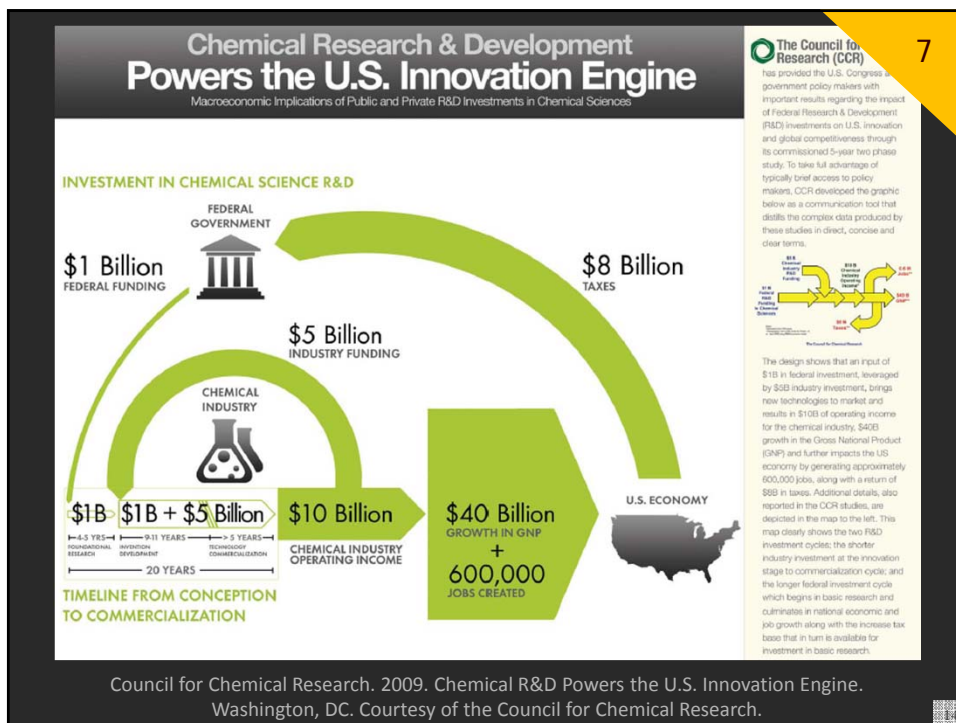
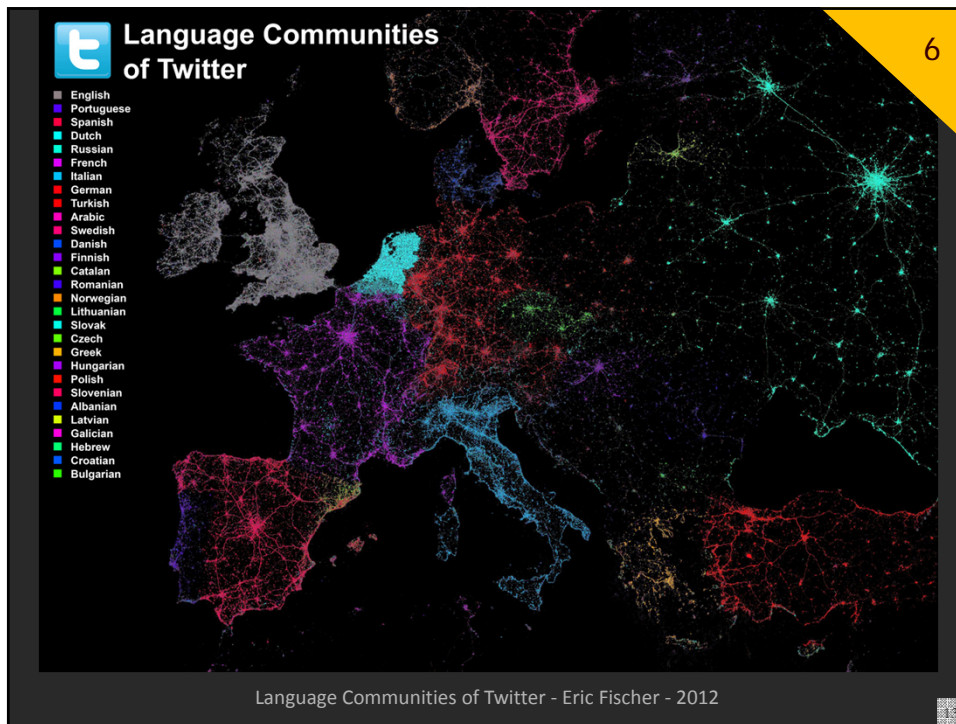
### 中科院所有院所

前五位与之合作最频繁的地区

- 北京 3,395
- 美国 1,835
- 上海 1,134
- 辽宁省 693
- 日本 603

最宽泛的代表代表 2,954 次合作

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## *Empowering Anyone to Visualize STI*

Example: The Information Visualization MOOC



Information Visualization MOOC 2015

INDIANA UNIVERSITY CNS

Information Visualization MOOC 2015

This course provides an overview about the state of the art in information visualization. It teaches the process of producing effective visualizations that take the needs of users into account.

The course can be taken for three Indiana University credits as part of the [Online Data Science Program](#), as part of the Information and Library Science M.S. program, and as part of the online Data Science M.S. Program offered by the School of Informatics and Computing. Students seeking enrollment information should contact Rhonda Spencer at 812-855-2018, [ilsmain@indiana.edu](mailto:ilsmain@indiana.edu) or [datasci@indiana.edu](mailto:datasci@indiana.edu).

Among other topics, the course covers:

- Data analysis algorithms that enable extraction of patterns and trends in data
- Major temporal, geospatial, topical, and network visualization techniques
- Discussions of systems that drive research and development.

Information Visualization MOOC

ivmooc.cns.iu.edu

Register for Course

Already registered? [Click here to go to the course.](#)  
Forgot your password? [Click here to reset it.](#)

Register for free at <http://ivmooc.cns.iu.edu>. Class restarted in January 13, 2015.

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## Course Schedule

### Part 1: Theory and Hands-On

- **Session 1** – Workflow Design and Visualization Framework
- **Session 2** – “When:” Temporal Data
- **Session 3** – “Where:” Geospatial Data
- **Session 4** – “What:” Topical Data

### Mid-Term

- **Session 5** – “With Whom:” Trees
- **Session 6** – “With Whom:” Networks
- **Session 7** – Dynamic Visualizations and Deployment

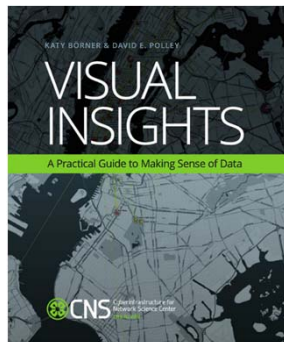
### Final Exam

### Part 2: Students work in teams on client projects.

Final grade is based on Class Participation (10%), Midterm (30%), Final Exam (30%), and Client Project(30%).

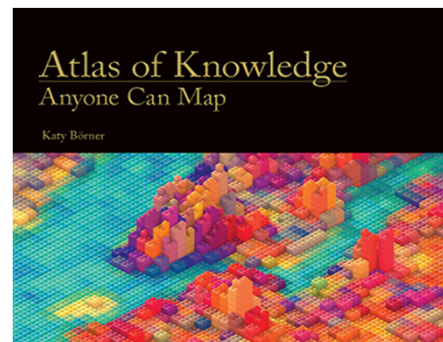


## Books Used in the IVMOOC



### Teaches timely knowledge:

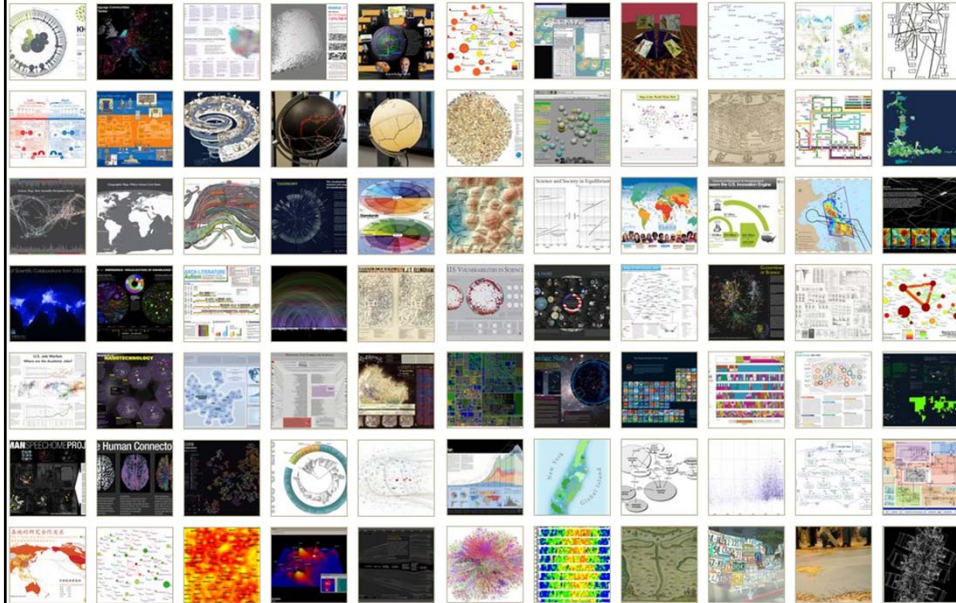
Advanced algorithms, tools, and hands-on workflows.



### Teaches timeless knowledge:

Visualization framework—exemplified using generic visualization examples and pioneering visualizations.

## Visualization Frameworks



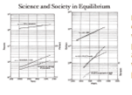


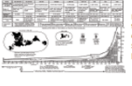
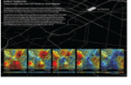
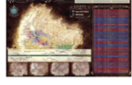









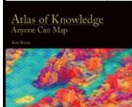
## How to Classify Different Visualizations?

By

- User insight needs?
- User task types?
  
- Data to be visualized?
- Data transformation?
  
- Visualization technique?
- Visual mapping transformation?
- Interaction techniques?
  
- Or ?

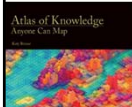


Tasks	LEVELS		
	MICRO: Individual Level about 1–1,000 records page 6	MESO: Local Level about 1,001–100,000 records page 8	MACRO: Global Level more than 100,000 records page 10
<b>TYPES</b>			
<b>Statistical Analysis</b> page 44	 Knowledge cartography page 135	 Productivity of Russian life sciences research teams page 105	 Science and Society in Equilibrium Number of scientists versus population and R&D costs versus GDP page 103
<b>WHEN: Temporal Analysis</b> page 48	 Visualizing decision-making processes page 95	 Key events in the development of the video tape recorder page 85	 Increased travel and communication speeds page 83
<b>WHERE: Geospatial Analysis</b> page 52	 Cell phone usage in Milan, Italy page 109	 Victorian poetry in Europe page 137	 Ecological footprint of countries page 99
<b>WHAT: Topical Analysis</b> page 56	 Evolving patent holdings of Apple Computer, Inc. and Jerome Lemelson page 89	 Evolving journal networks in nanotechnology page 139	 Product space showing co-export patterns of countries page 95
<b>WITH WHOM: Network Analysis</b> page 60	 World Finance Corporation network page 87	 Electronic and new media art networks page 133	 World-wide scholarly collaboration networks page 157



See page 5

<b>Insight Need Types</b> page 26	<b>Data Scale Types</b> page 28	<b>Visualization Types</b> page 30	<b>Graphic Symbol Types</b> page 32	<b>Graphic Variable Types</b> page 34	<b>Interaction Types</b> page 26
<ul style="list-style-type: none"> <li>• categorize/cluster</li> <li>• order/rank/sort</li> <li>• distributions (also outliers, gaps)</li> <li>• comparisons</li> <li>• trends (process and time)</li> <li>• geospatial</li> <li>• compositions (also of text)</li> <li>• correlations/relationships</li> </ul>	<ul style="list-style-type: none"> <li>• nominal</li> <li>• ordinal</li> <li>• interval</li> <li>• ratio</li> </ul>	<ul style="list-style-type: none"> <li>• table</li> <li>• chart</li> <li>• graph</li> <li>• map</li> <li>• network layout</li> </ul>	<ul style="list-style-type: none"> <li>• geometric symbols               <ul style="list-style-type: none"> <li>point</li> <li>line</li> <li>area</li> <li>surface</li> <li>volume</li> </ul> </li> <li>• linguistic symbols               <ul style="list-style-type: none"> <li>text</li> <li>numerals</li> <li>punctuation marks</li> </ul> </li> <li>• pictorial symbols               <ul style="list-style-type: none"> <li>images</li> <li>icons</li> <li>statistical glyphs</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• spatial               <ul style="list-style-type: none"> <li>position</li> </ul> </li> <li>• retinal               <ul style="list-style-type: none"> <li>form</li> <li>color</li> <li>optics</li> <li>motion</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• overview</li> <li>• zoom</li> <li>• search and locate</li> <li>• filter</li> <li>• details-on-demand</li> <li>• history</li> <li>• extract</li> <li>• link and brush</li> <li>• projection</li> <li>• distortion</li> </ul>



See page 24

Basic Task Types								
Bertin, 1967	Wehrend & Lewis, 1996	Few, 2004	Yau, 2011	Rendgen & Wiedemann, 2012	Frankel, 2012	Tool: Many Eyes	Tool: Chart Chooser	Börner, 2014
selection	categorize			category				categorize/ cluster
order	rank	ranking					table	order/rank/ sort
	distribution	distribution					distribution	distributions (also outliers, gaps)
	compare	nominal comparison & deviation	differences		compare and contrast	compare data values	comparison	comparisons
		time series	patterns over time	time	process and time	track rises and falls over time	trend	trends (process and time)
		geospatial	spatial relations	location		generate maps		geospatial
quantity		part-to- whole	proportions		form and structure	see parts of whole, analyze text	composition	compositions (also of text)
association	correlate	correlation	relationships	hierarchy		relations between data points	relationship	correlations/ relationships

Atlas of Knowledge  
Knowers Can Map

**See page 26**

Insight Need Types page 26	Data Scale Types page 28	Visualization Types page 30	Graphic Symbol Types page 32	Graphic Variable Types page 34	Interaction Types page 26
<ul style="list-style-type: none"> <li>categorize/cluster</li> <li>order/rank/sort</li> <li>distributions (also outliers, gaps)</li> <li>comparisons</li> <li>trends (process and time)</li> <li>geospatial</li> <li>compositions (also of text)</li> <li>correlations/relationships</li> </ul>	<ul style="list-style-type: none"> <li>nominal</li> <li>ordinal</li> <li>interval</li> <li>ratio</li> </ul>	<ul style="list-style-type: none"> <li>table</li> <li>chart</li> <li>graph</li> <li>map</li> <li>network layout</li> </ul>	<ul style="list-style-type: none"> <li>geometric symbols               <ul style="list-style-type: none"> <li>point</li> <li>line</li> <li>area</li> <li>surface</li> <li>volume</li> </ul> </li> <li>linguistic symbols               <ul style="list-style-type: none"> <li>text</li> <li>numerals</li> <li>punctuation marks</li> </ul> </li> <li>pictorial symbols               <ul style="list-style-type: none"> <li>images</li> <li>icons</li> <li>statistical glyphs</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>spatial               <ul style="list-style-type: none"> <li>position</li> </ul> </li> <li>retinal               <ul style="list-style-type: none"> <li>form</li> <li>color</li> <li>optics</li> <li>motion</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>overview</li> <li>zoom</li> <li>search and locate</li> <li>filter</li> <li>details-on-demand</li> <li>history</li> <li>extract</li> <li>link and brush</li> <li>projection</li> <li>distortion</li> </ul>

Atlas of Knowledge  
Knowers Can Map

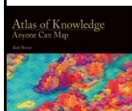
**See page 24**

## Visualization Types (Reference Systems)

1. **Charts:** No reference system—e.g., Wordle.com, pie charts
2. **Tables:** Categorical axes that can be selected, reordered; cells can be color coded and might contain proportional symbols. Special kind of graph.
3. **Graphs:** Quantitative or qualitative (categorical) axes. Timelines, bar graphs, scatter plots.
4. **Geospatial maps:** Use latitude and longitude reference system. World or city maps.
5. **Network layouts:** Node position might depend on node attributes or node similarity. **Trees:** hierarchies, taxonomies, genealogies. **Networks:** social networks, migration flows.

## Types

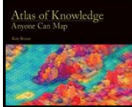
Insight Need Types page 26	Data Scale Types page 28	Visualization Types page 30	Graphic Symbol Types page 32	Graphic Variable Types page 34	Interaction Types page 26
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See page 25

# Graphic Variable Types Versus Graphic Symbol Types

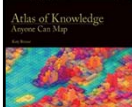
		Geometric Symbols				
		Point	Line	Area		
Spatial	x	quantitative				
	y	quantitative				
	z	quantitative				
Retinal	Form	Size	quantitative	NA (Not Applicable)		
		Shape	qualitative	NA		
		Rotation	quantitative	NA		
		Curvature	quantitative	NA		
		Angle	quantitative	NA		
		Closure	quantitative	NA		
		Value	quantitative			
Color	Hue	qualitative				
	Saturation	quantitative				



See page 36

# Graphic Variable Types Versus Graphic Symbol Types

		Geometric Symbols			Colorful Symbols			Patterned Symbols		
		Point	Line	Area	Point	Line	Area	Point	Line	Area
Spatial	x	quantitative								
	y	quantitative								
	z	quantitative								
Retinal	Form	Size	quantitative	NA (Not Applicable)						
		Shape	qualitative	NA						
		Rotation	quantitative	NA						
		Curvature	quantitative	NA						
		Angle	quantitative	NA						
		Closure	quantitative	NA						
		Value	quantitative							
Color	Hue	qualitative								
	Saturation	quantitative								
Textual	spacing	quantitative								
	contiguity	quantitative								
	pattern	qualitative								
	orientation	quantitative								
	eccentricity	quantitative								
	size	quantitative								
	transparency	quantitative								
	shading	quantitative								
	stroke-width length	quantitative								
	stroke-width width	quantitative								



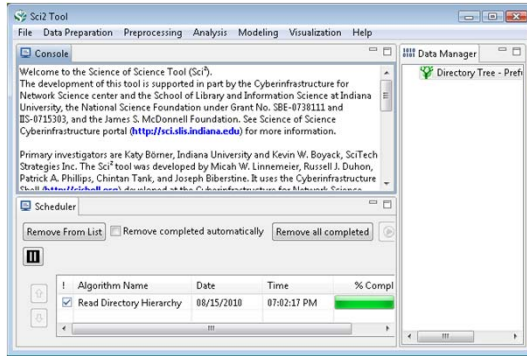
See pages 36-39

## Sci2 Tool – OSGi/CIShell-based Macroscope

Download for free at <http://sci2.cns.iu.edu>

### Use

- **Menu** to read data, run algorithms.
- **Console** to see work log, references to seminal works.
- **Data Manager** to select, view, save loaded, simulated, or derived datasets.
- **Scheduler** to see status of algorithm execution.

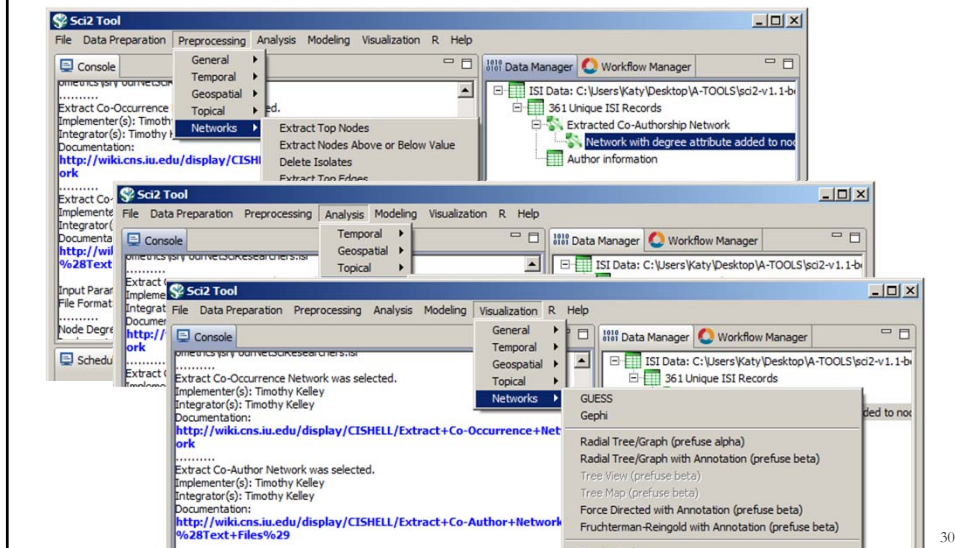


All workflows are recorded into a log file (see /sci2/logs/...), and can be re-run for easy replication. If errors occur, they are saved in a error log to ease bug reporting.

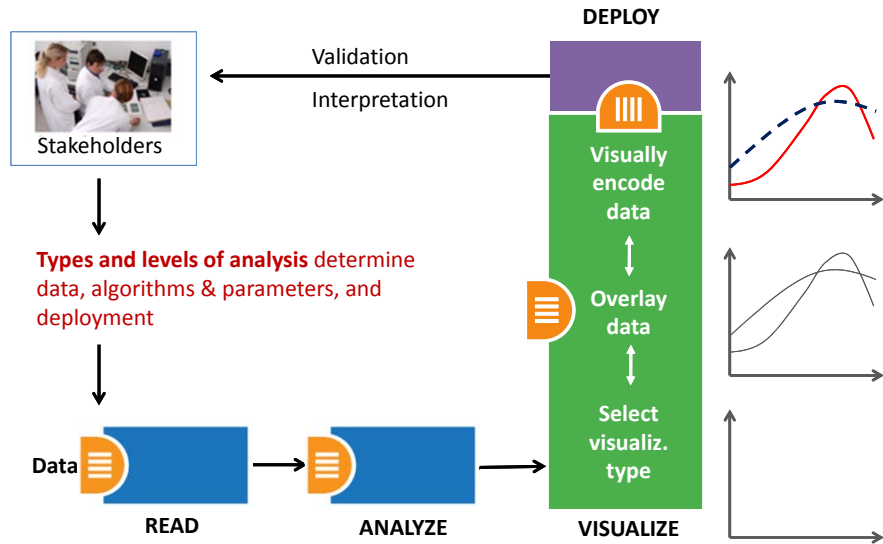
All algorithms are documented online; workflows are given in Sci2 Manual at <http://sci2.wiki.cns.iu.edu>

## Sci2 Tool Interface Components

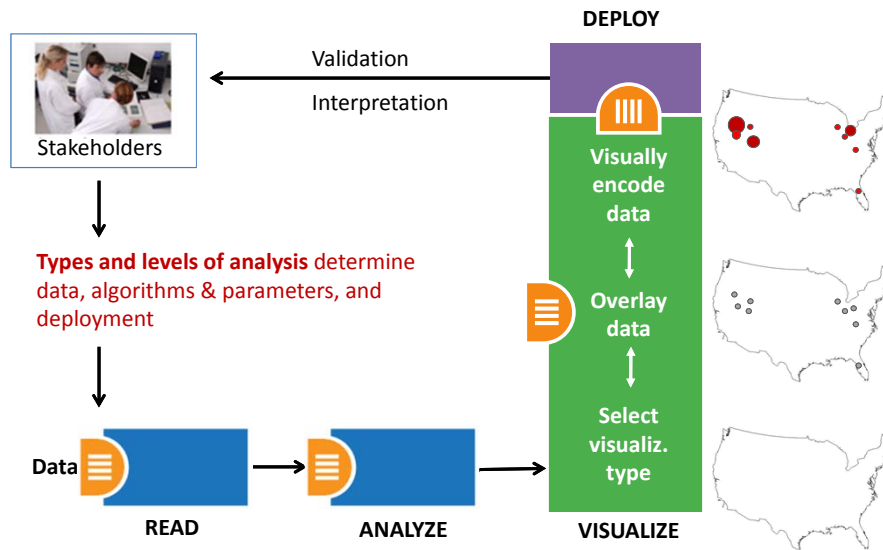
Download for free at <http://sci2.cns.iu.edu>



## Needs-Driven Workflow Design



## Needs-Driven Workflow Design





## Load **One** File and Run **Many** Analyses and Visualizations

Times Cited	Publication Year	City of Publisher	Country	Journal Title (Full)	Title	Subject Category	Authors
12	2011	NEW YORK	USA	COMMUNICATIONS OF THE ACM	Plug-and-Play Macroscopes	Computer Science	Borner, K
18	2010	MALDEN	USA	CTS-CLINICAL AND TRANSLATIONAL SCIENCE	Advancing the Science of Team Science	Research & Experimental Medicine	Falk-Krzesinski, HJ Borner, K Contractor, NJ Fiore, SM Hall, KL Keyton, JS Spring, B Stokols, D Trochim, W Uzzi, B
13	2010	WASHINGTON	USA	SCIENCE TRANSLATIONAL MEDICINE	A Multi-Level Systems Perspective for the Science of Team Science	Cell Biology   Research & Experimental Medicine	Borner, K Contractor, NJ Falk-Krzesinski, HJ Fiore, SM Hall, KL Keyton, JS Spring, B Stokols, D Trochim, W Uzzi, B

Statistical Analysis--p. 44

Location	Count	# Citations
Netherlands	13	292
United States	9	318
Germany	11	36
United Kingdom	1	2

Temporal Burst Analysis--p. 48



Geospatial Analysis--p. 52



Geospatial Analysis--p. 52

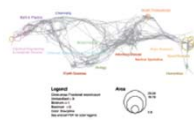


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## Load **One** File and Run **Many** Analyses and Visualizations

Times Cited	Publication Year	City of Publisher	Country	Journal Title (Full)	Title	Subject Category	Authors
12	2011	NEW YORK	USA	COMMUNICATIONS OF THE ACM	Plug-and-Play Macroscopes	Computer Science	Borner, K
18	2010	MALDEN	USA	CTS-CLINICAL AND TRANSLATIONAL SCIENCE	Advancing the Science of Team Science	Research & Experimental Medicine	Falk-Krzesinski, HJ Borner, K Contractor, NJ Fiore, SM Hall, KL Keyton, JS Spring, B Stokols, D Trochim, W Uzzi, B
13	2010	WASHINGTON	USA	SCIENCE TRANSLATIONAL MEDICINE	A Multi-Level Systems Perspective for the Science of Team Science	Cell Biology   Research & Experimental Medicine	Borner, K Contractor, NJ Falk-Krzesinski, HJ Fiore, SM Hall, KL Keyton, JS Spring, B Stokols, D Trochim, W Uzzi, B

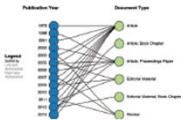
Topical Analysis--p. 56



Paper Citation Network--p. 60



Bi-Modal Network--p. 60



Co-author and many other bi-modal networks.

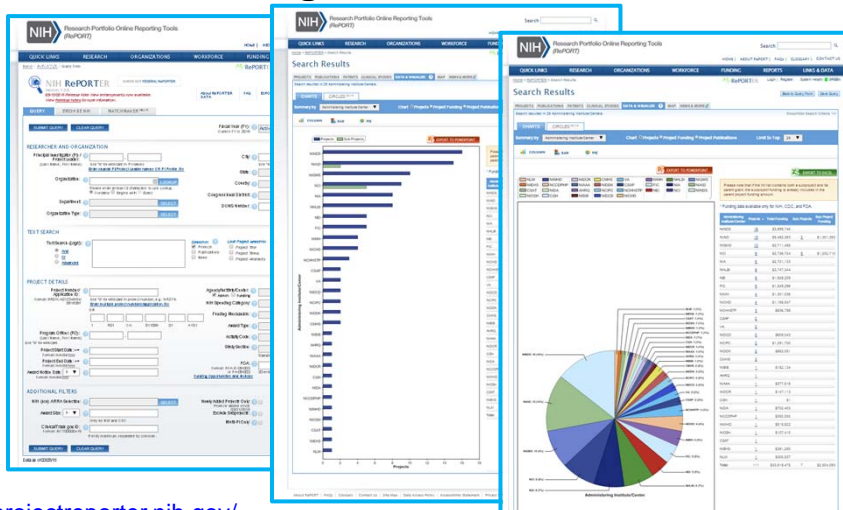
34

## Existing Interfaces for Health-related Data

- 9) NIH RePORTER: Visual Interface to Biomedical Funding Data in U.S.
- 10) CISHell/Sci2 World and Science Visualizations of NIH RePORTER Data
- 11) NIH RePORTER: NIH Map
- 12) BBSRC: Visual Interface to Biomedical Funding Data in UK
- 13) IAI Multidimensional Analysis
- 14) Scraawl: Twitter Analysis
- 15) Illuminated Diagram: Searchable World and Science Maps

## NIH RePORTER: Visual Interface to Biomedical Funding Data in US

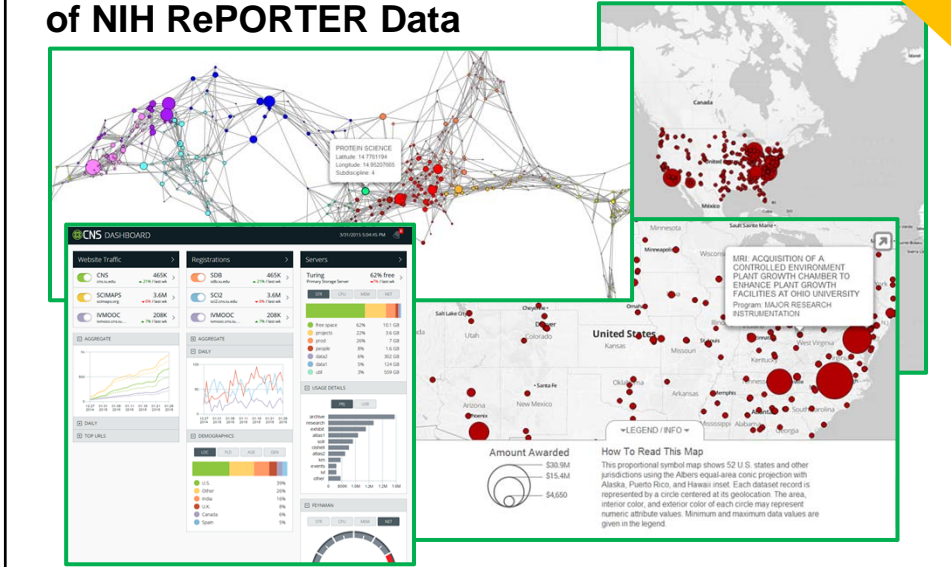
9



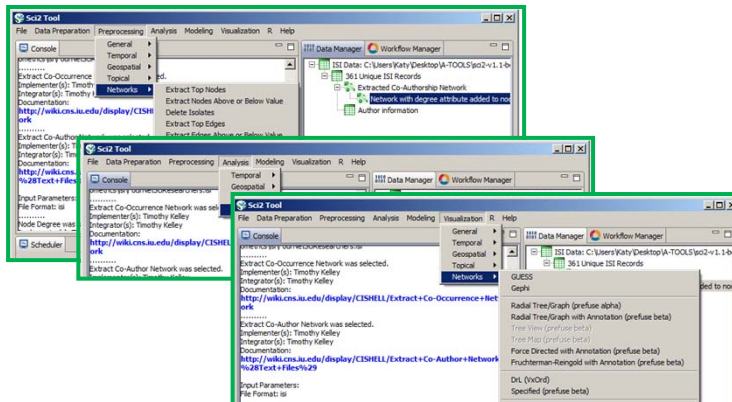
<http://projectreporter.nih.gov/>

# CIShell/Sci2 World and Science Visualizations of NIH RePORTER Data

10

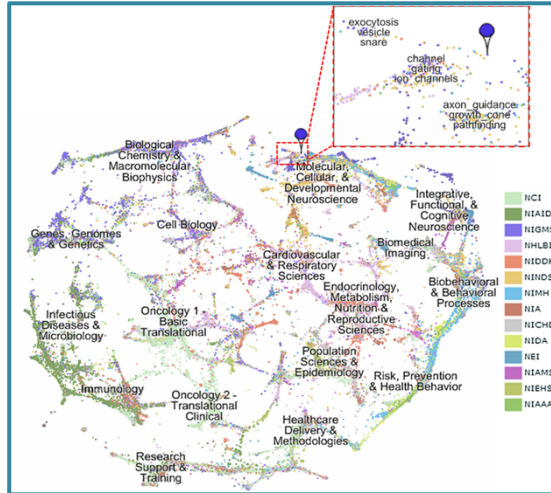


# Sci2 Desktop



# NIH RePORTER: NIH Map

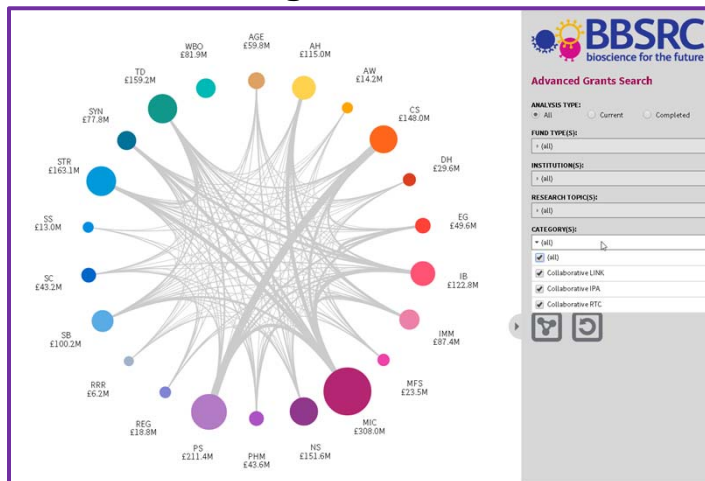
11



<http://nihmaps.org/>

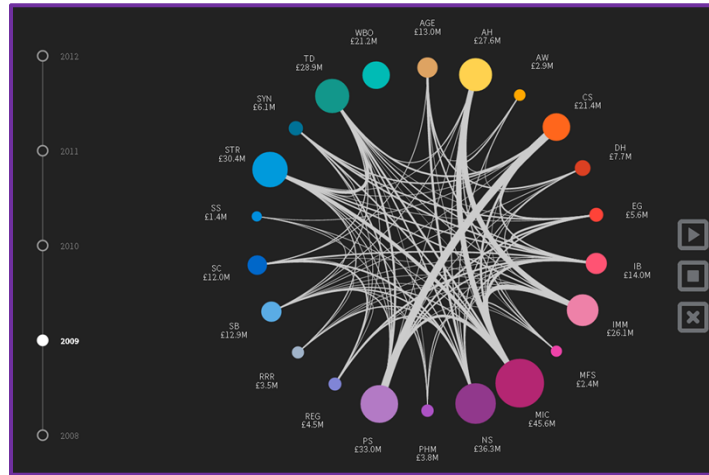
# BBSRC: Visual Interface to Biomedical Funding Data in UK

12



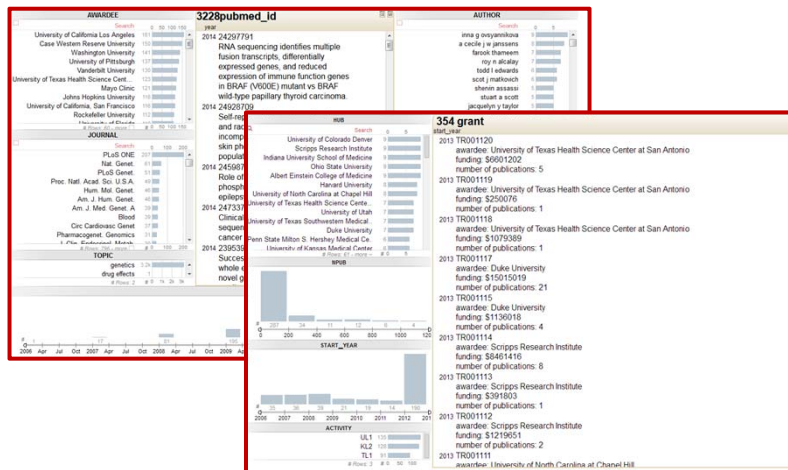
<http://www.bbsrc.ac.uk/>

## BBSRC: Temporal animation



## IAI Multidimensional Analysis

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## Scraawl: Twitter Analysis

**Top Users**

@hacellmley	4
@doughalmsghnd	2
@hewexp_ict	2
@genresearch	2
@medsci_news	2
80 total users	

**Top Words**

Cancer	45
Research	37
Medical	25
Mary	25
Lasker	25
197 total words	

**Top Hashtags**

#cancer	74
#h	27
#cancer	27
#nicabrala	6
#epidemiology	4
23 total hashtags	

**Top Mentions**

@h	100
@srandrems	6
@scifcancer	5
@lstm_maria	3
@realmediamy	3
29 total mentions	

**Top URLs**

http://nlp.ncsl.nih.gov/ncs...	14
http://nlp.ncsl.nih.gov/ncs...	8
http://www.scrib.com/health...	5
http://www.cancer.gov/ncats/...	7
http://www.nih.gov/health/ict...	5
26 total URLs	

**Top Retweets**

RT @GNH: Mary Lasker, com...	20
RT @GNH: Largely thanks to...	6
RT @GNH: President Nixon st...	6
RT @GNH: Cancer is a gene...	6
RT @GNH: #Cancer occurs w...	5
28 retweeted tweets	

**Top Languages**

English	96%
French	4%
2 total languages	

**Top Locations**

Espele	1
0 geotagged tweets	

**Tweet Timeline**

Timeline showing tweet frequency from 11 Mar 00:00 to 07:00.

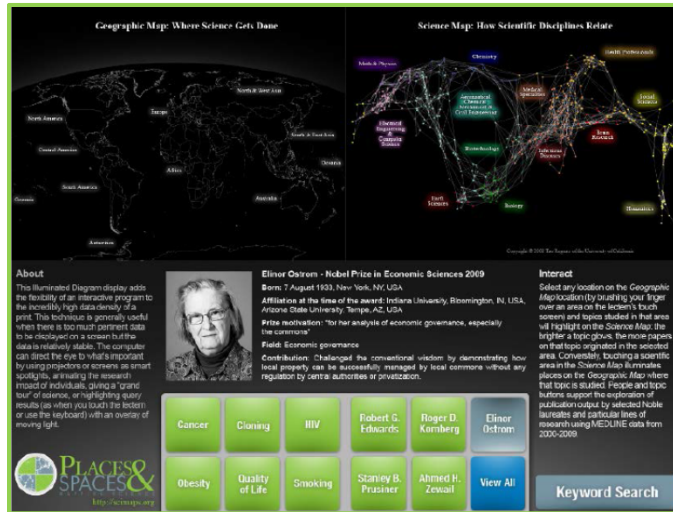
<https://www.scraawl.com/>

## Illuminated Diagram: Searchable World and Science Maps



[http://cns.iu.edu/interactive\\_displays.html](http://cns.iu.edu/interactive_displays.html)

## Illuminated Diagram: Search detail



## References

Börner, Katy, Chen, Chaomei, and Boyack, Kevin. (2003). **Visualizing Knowledge Domains**. In Blaise Cronin (Ed.), *ARIST*, Medford, NJ: Information Today, 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/vo1101/suppl\\_1/](http://www.pnas.org/content/vo1101/suppl_1/)

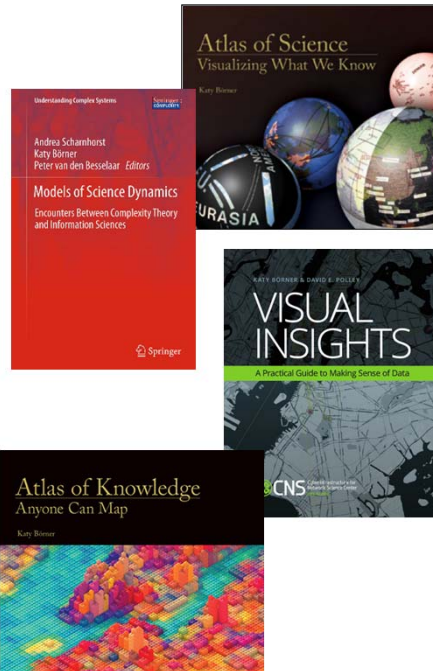
Börner, Katy (2010) **Atlas of Science: Visualizing What We Know**. The MIT Press. <http://scimaps.org/atlas>

Scharnhorst, Andrea, Börner, Katy, van den Besselaar, Peter (2012) **Models of Science Dynamics**. Springer Verlag.

Katy Börner, Michael Conlon, Jon Corson-Rikert, Cornell, Ying Ding (2012) **VIVO: A Semantic Approach to Scholarly Networking and Discovery**. Morgan & Claypool.

Katy Börner and David E Polley (2014) **Visual Insights: A Practical Guide to Making Sense of Data**. The MIT Press.

Börner, Katy (2015) **Atlas of Knowledge: Anyone Can Map**. The MIT Press. <http://scimaps.org/atlas2>



All papers, maps, tools, talks, press are linked from <http://cns.iu.edu>  
 These slides will soon be at <http://cns.iu.edu/docs/presentations>  
 CNS Facebook: <http://www.facebook.com/cnscenter>  
 Mapping Science Exhibit Facebook: <http://www.facebook.com/mappingscience>