

# Visualizing Science & Technology

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*ONR Distinguished Lecture Series*

*Bobby Junker Executive Conference Center, Office of Naval Research*

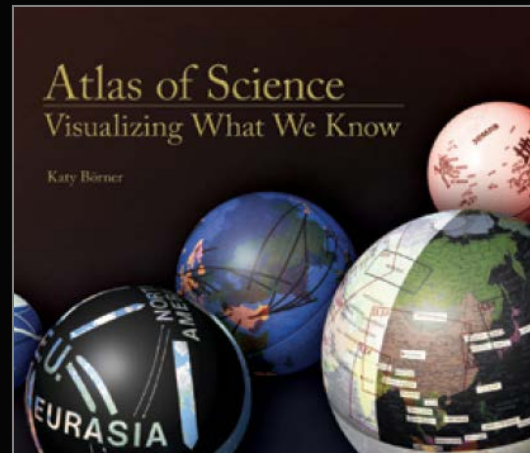
*875 N Randolph Street, Arlington, VA*

*November 6, 2017*



# Maps of Science & Technology

Using large scale datasets, advanced data mining and visualization techniques, and substantial computing resources.



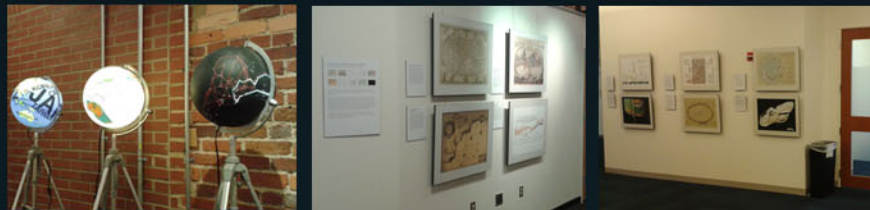
# Maps of Science & Technology



101st Annual Meeting of the Association of American Geographers, Denver, CO.  
April 5th - 9th, 2005 (First showing of Places & Spaces)



University of Miami, Miami, FL.  
September 4 - December 11, 2014.

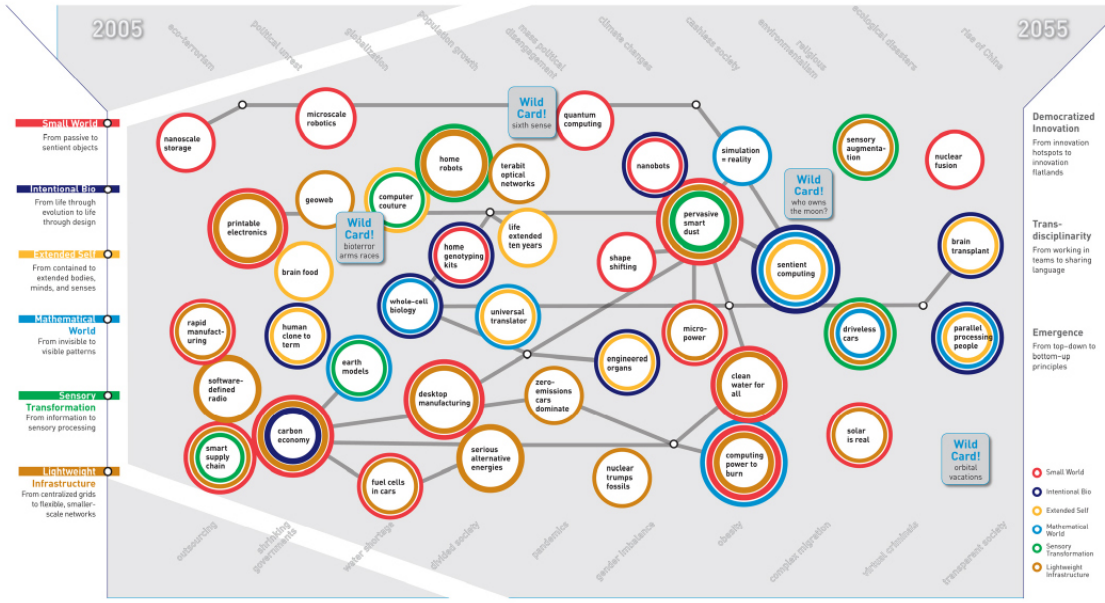


Duke University, Durham, NC.  
January 12 - April 10, 2015



The David J. Sencer CDC Museum, Atlanta, GA.  
January 25 - June 17, 2016.





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**MAP THEMES**

**Small World**

After 20 years of basic research and development at the 100-nanometer scale, the importance of nanotechnology as a source of innovations and new capabilities in everything from materials science to medicine is already well-understood. Three trends, however, will define how nanotechnology will unfold, and what impacts it will have. First, nanotechnology is not a single field with a coherent intellectual program; it's an opportunistic hybrid, shaped by a combination of fundamental research questions, promising technical applications, and venture and state capital. Second, nanotechnology is moving away from the original vision of small-scale mechanical engineering—in which assemblers build mechanical systems from individual atoms—toward one in which molecular biology and biochemistry contribute essential tools (such as proteins that build nanowires). Finally, nanotechnology will also serve as a model for transdisciplinary science. It will support both fundamental research and commercially oriented innovation, and it will be conducted not within the boundaries of conventional academic or corporate research departments, but in institutional and social milieus that emphasize heterogeneity.

**Intentional Bio**

For 3.6 billion years, evolution has governed biology on this planet. But today, Mother Nature has a collaborator: Inexpensive tools to read and rewrite the genetic code of life will bootstrap our ability to manipulate biology from the bottom up. We'll not only genetically re-engineer existing life but actually create new life forms with purpose. Still, we will not be blind to what nature has to teach us. Evolution's elegant engineering at the smallest scales will be a rich source of inspiration as we build the bio-nanotechnology of the next 50 years.

**Extended Self**

In the next 50 years, we will be faced with broad opportunities to remake our minds and bodies in profoundly different ways. Advances in biotechnology, brain science, information technology, and robotics

will result in an array of methods to dramatically alter, enhance, and extend the mental and physical hand that nature has dealt us. Wielding these tools on ourselves, humans will begin to define a variety of different "transhumanist" paths—that is, ways of being and living that extend beyond what we today consider natural for our species. In the very long term, following these paths could someday lead to an evolutionary leap for humanity.

**Mathematical World**

The ability to process, manipulate, and ultimately understand patterns in enormous amounts of data will allow decoding of previously mysterious processes in everything from biological to social systems. Scientists are learning that at the core of many biological phenomena—reproduction, growth, repair, and others—are computational processes that can be decoded and simulated. Using techniques of combinatorial science to uncover such patterns—whether these are physical, biological, or social—will likely occupy an increasing share of computing cycles in the next 50 years. Such massive computation will also make simulation widespread. Computer simulation will be used not only to help make decisions about large complex scientific and social problems but also to help individuals make better choices in their daily lives.

**Sensory Transformation**

In the next ten years, physical objects, places, and even human beings themselves will increasingly become embedded with computational devices that can sense, understand, and act upon their environment. They will be able to react to contextual clues about the physical, social, and even emotional state of people and things in their surroundings. As a result, increasing demands will be placed on our visual, auditory, and other sensory abilities. Information previously encoded as text and numbers will be displayed in richer sensory formats—as graphics, pictures, patterns, sounds, smells, and tactile experiences. This enriched sensory environment will coincide with major breakthroughs in our understanding of the brain—in how we process sensory information and connect various sensory functions.

Humans will become much more sophisticated in their ability to understand, create, and manage sensory information and ability to perform such tasks will become keys to success.

**Lightweight Infrastructure**

A confluence of new materials and distributed intelligence is pointing the way toward a new kind of infrastructure that will dramatically reshape the economics of moving people, goods, energy, and information. From the molecular level to the macro-economic level, these new infrastructure designs will emphasize smaller, smarter, more independent components. These components will be organized into more efficient, more flexible, and more secure ways than the capital-intensive networks of the 20th century. These lightweight infrastructures have the potential to boost emerging economies, improve social connectivity, mitigate the environmental impacts of rapid global urbanization, and offer new future paths in energy.

**META-THEMES**

**Democratized Innovation**

Before the 20th century, many of the greatest scientific discoveries and technical inventions were made by amateur scientists and independent inventors. In the last 100 years, a professional class of scientists and engineers, supported by universities, industry, and the state, pushed amateurs aside as a creative force. At the national scale, the capital-intensive character of scientific research made world-class research the property of prosperous advanced nations. In the new century, a number of trends and technologies will lower the barriers to participation in science and technology again, both for individuals and for emerging countries. The result will be a renaissance of the serious amateurs, the growth of new scientific and technical centres of excellence in developing countries, and a more global distribution of world-class scientists and technologists.

**Transdisciplinarity**

In the last two centuries, natural philosophy and natural history fractured into the now-familiar disciplines of physics, chemistry, biology, and so on. The sciences evolved into their current form in response to intellectual and professional opportunities, philanthropic priorities, and economic and state needs. Through most of the 20th century, the growth of the sciences, and academic and career pressures, encouraged ever-greater specialization. In the coming decades, transdisciplinary research will become an imperative. According to Howard Rheingold, a prominent forecaster and author, "transdisciplinarity goes beyond bringing together researchers from different disciplines to work in multidisciplinary teams. It means educating researchers who can speak languages of multiple disciplines—biologists who have understanding of mathematics, mathematicians who understand biology."

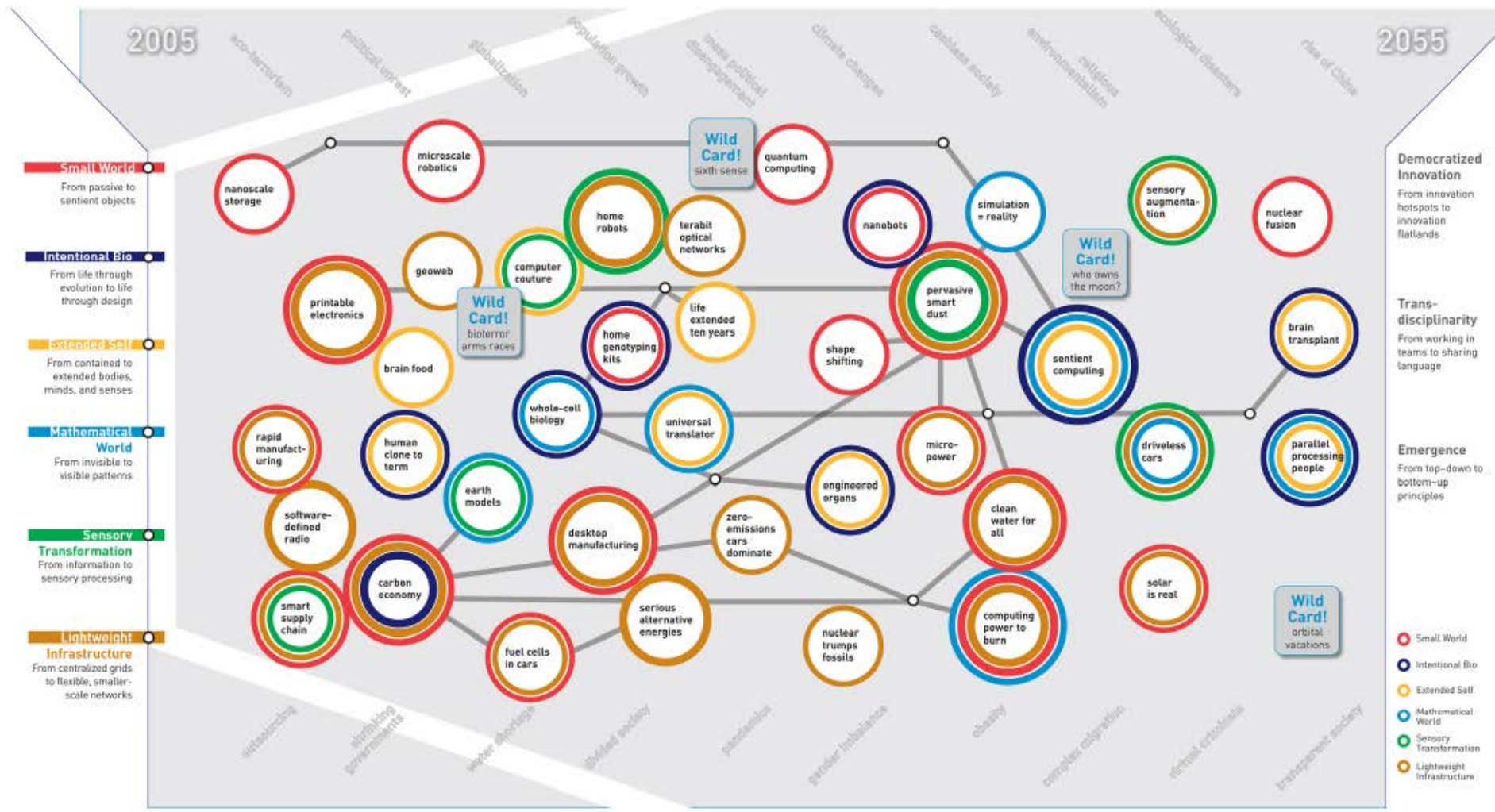
**Emergence**

The phenomenon of self-organizing swarms that generate complex behavior by following simple rules—will likely become an important research area, and an important model for understanding how the natural world works and how artificial worlds can be designed. Emergent phenomena have been observed across a variety of natural phenomena, from physics to biology to sociology. The concept has broad appeal due to the diversity of fields and problems to which it can be applied. It is proving useful for making sense of a very wide range of phenomena. Meanwhile, emergence can be modeled using relatively simple computational tools, although those models often require substantial processing power. More generally, it is a richly suggestive way of thinking about designing complex, robust technological systems. Finally, emergence is an accessible and vivid metaphor for understanding nature. Just as classical physics profited from popular treatments of Newtonian mechanics, so too will scientific study and technical reproductions of emergent phenomena likely draw benefits from the popularization of its underlying concepts.

A map is a tool for navigating an unknown terrain. In the case of this map, **Science & Technology Outlook: 2005–2055**, the terrain we're navigating is the uncharted territory of science and technology [S&T] in the next 50 years. However, the map of the future is not a tool for prediction or, for that matter, the product of predictions. Nor is it comparable to modern navigation techniques in which we rely on a shrinking number of strong signals, like GPS coordinates, to show the right path. Rather, it's more akin to classical low-tech navigational techniques with their reliance on an array of weak signals such as wind direction, the look and feel of the water, and the shape of cloud formations. Taken together, these signals often prove more useful for navigation than high-tech methods because, in addition to aiding travelers in selecting the "right" path, the signals contextualize information and reveal interdependencies and connections between seemingly unrelated events, thus enriching our understanding of the landscape. That's precisely the intention of this map of the future of S&T—to give the reader a deeper contextual understanding of the landscape and to point to the intricacies and interdependencies between trends.

While developing the map, the **Institute for the Future (ITFI)** team listened for and connected a variety of weak signals, including those generated during interviews and workshop conversations involving more than 100 eminent U.K. and U.S. experts in S&T—academicians, policymakers, journalists, and corporate researchers. The ITFI team also compiled a database of outlooks on developments that are likely to impact the full range of S&T disciplines and practice areas over the next 50 years. We also relied on ITFI's 40 years of experience in forecasting S&T developments to create the map and an accompanying set of **S&T Perspectives** that discuss issues emerging on the S&T horizon and are important for organizations, policymakers, and society-at-large to understand.

On this map, six themes are woven together across the 50-year horizon, often resulting in important breakthroughs. These are supported by key technologies, innovations, and discoveries. In addition to the six themes, three meta-themes—democratized innovation, transdisciplinarity, and emergence—will overlay the future S&T landscape influencing how we think about, learn about, and practice science. Finally, S&T trends won't operate in a vacuum. Wider social, demographic, political, economic, and environmental trends will both influence S&T trends and will be influenced by them. Some of these wider trends surround the map to remind us of the larger picture.



III.5 Science & Technology Outlook: 2005-2055 – Marina Gorbis, Jean Hagan, Alex Soojung-Kim Pang, and David Pescovitz - 2006





# Map of Scientific Collaborations from 2005-2009



Computed Using Data from Elsevier's Scopus

*Stream of Scientific Collaborations Between World Cities* - Olivier H. Beauchesne - 2012



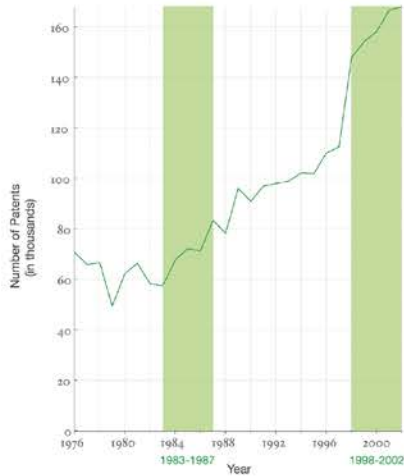
# Examining the Evolution & Distribution of Patent Classifications

## Managing Growing Patent Portfolios

Organizations, businesses, and individuals rely on patents to protect their intellectual property and business models. As market competition increases, patenting innovation and intellectual property rights becomes ever more important.

Managing the staggering number of patents demands new tools and methodologies. Grouping patents by their classifications offers an ideal resolution for better understanding how intellectual borders are established and change over time.

The charts below show the annual number of patents granted from January 1, 1976 to December 31, 2002 in the United States Patent and Trademark Office (USPTO) patent archive; slow and fast growing patent classes; the top 10 fast growing patent subclasses; and two evolving patent portfolios.



## The Structure and Evolution of the Patent Space

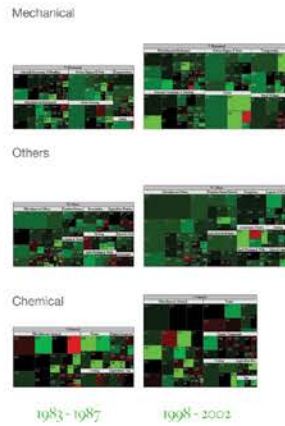
The United States Patent and Trademark Office assigns each patent to one of more than 450 classes covering broad application domains. For example, class 514 encompasses all patents dealing with 'Drug, Bio-Affecting and Body Treating Compositions.' Classes are further broken down by subclasses that have hierarchical associations. As one example, class 455 features subclass 99 entitled "with vehicle."

The top 10 fast growing patent classes for 1998–2002 are listed together with the number of patents granted. Most come from the 'Computer and Communications' and the 'Drugs and Medical' area.

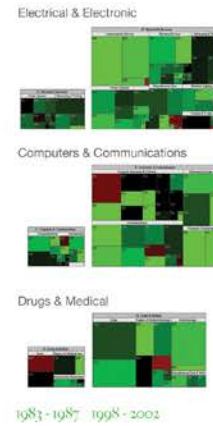
The evolving hierarchical structure of patent classes and their sizes is represented using treemaps, a space-filling visualization technique developed by Ben Shneiderman at the University of Maryland. A treemap presents a hierarchy as a collection of nested rectangles—demarkating a parent-child relationship between nodes by nesting the child within the parent rectangle. The size and color of each rectangle represent certain attributes of the nodes.

Here, each rectangle represents a class and the area size denotes the total number of patents in that class. The rectangle's color corresponds to percentage increase (green) or decrease (red) in the number of patents granted in that class from the previous interval.

### Slow Growing Classes



### Fast Growing Classes



### Top-10 Subclasses

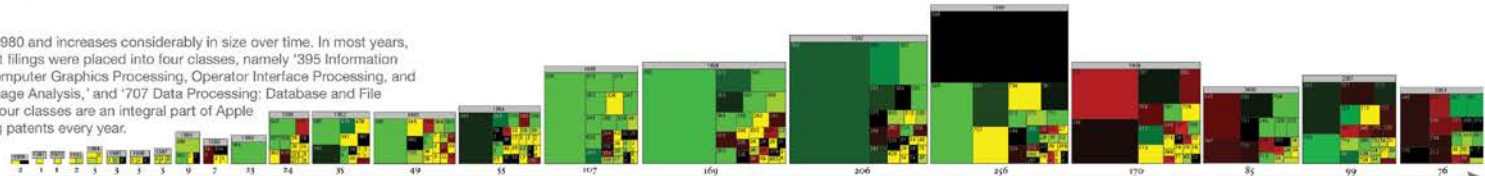
Class	Title	# of Patents
514	Drug, Bio-Affecting and Body Treating Compositions	18,778
438	Semiconductor Device Manufacturing:Process	17,775
435	Chemistry: Molecular Biology and Microbiology	17,474
424	Drug, Bio-Affecting and Body Treating Compositions	13,637
428	Stock Material or Miscellaneous Articles	13,314
257	Active Solid-State Devices (e.g., Transistors, Solid-State Diodes)	12,924
395	Information Processing System Organization	9,955
345	Computer Graphics Processing, Operator Interface Processing, and Selective Visual Display Systems	9,510
359	Optical: Systems and Elements	9,151
365	Static Information Storage and Retrieval	8,392
	Total	130,910

## Patent Portfolio Analysis

A longitudinal analysis of portfolios reveals different patenting strategies. For each year (given in gray above each treemap), a treemap of all new patents granted to the assignee is shown. The number of patents is given below each treemap. The same size and color coding as above was used. In addition, yellow indicates that no patent has been granted in that class in the last 5 years.

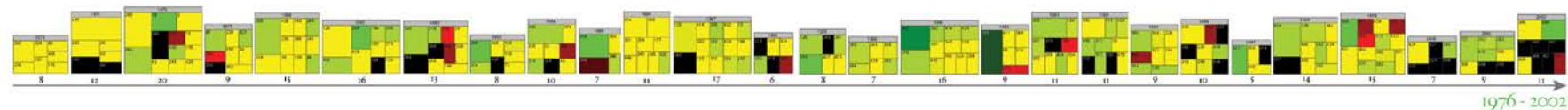
### Apple Computer, Inc.

Apple Computer, Inc.'s portfolio starts in 1980 and increases considerably in size over time. In most years, more than half of Apple Computer's patent filings were placed into four classes, namely '395 Information Processing System Organization,' '345 Computer Graphics Processing, Operator Interface Processing, and Selective Visual Display Systems,' '382 Image Analysis,' and '707 Data Processing: Database and File Management or Data Structures.' These four classes are an integral part of Apple Computer, Inc.'s patent portfolio, receiving patents every year.

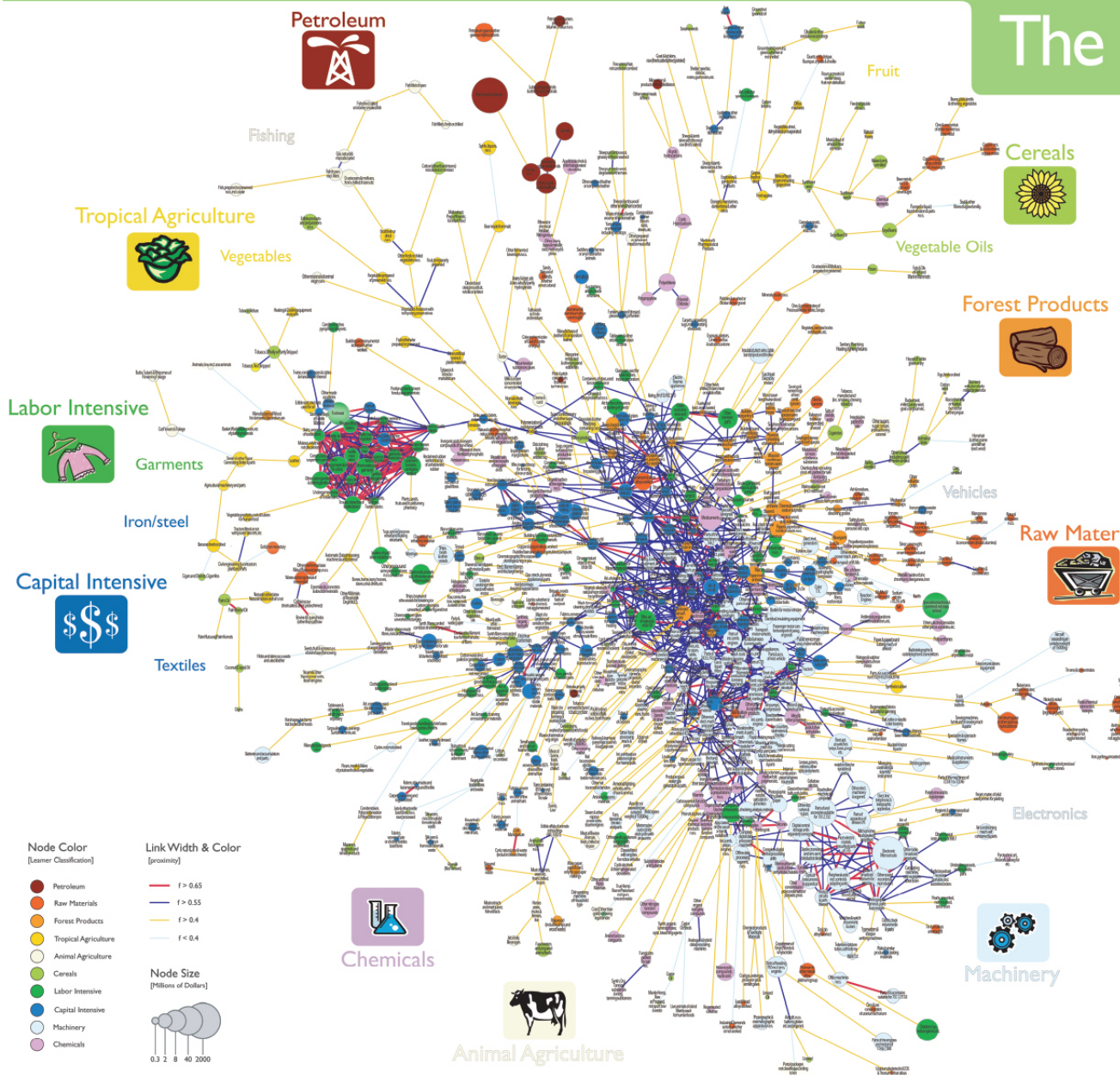


### Jerome Lemelson

The patent portfolio of Jerome Lemelson shows a very different activity pattern. Starting in 1976, he publishes between 6–20 patents each year. However, the predominance of yellow shows that there is little continuity from previous years in regards to the classes into which patents are filed. No class dominates. Instead, more and more new intellectual space is claimed.



# The Product Space



World trade flow data compiled by Feenstra et al. and available at the National Bureau of Economic Research were used to identify the complete co-export matrix of 775 industrial products for 1998-2000. A Maximum Spanning Tree (MST) algorithm was used to reduce the complete co-export matrix to less than 1% of the links. The resulting network, which combines the MST plus all links with a co-export frequency of at least 0.55, was laid out using a force-directed layout algorithm. Node sizes represent the value of traded products in millions of U.S. dollars. Their color corresponds to ten product groups identified using the Leamer classification. Each product class is labeled by an icon. Link color and width indicate the frequency of joint exports.

## Economic Footprint

■ Indicate Relevant Exports

Industrialized Countries



The network has a core-periphery structure with higher value product classes, e.g., machinery and chemicals, in the core and lower quality classes, e.g., fishing and garments, in the periphery. Products at the core of the network are highly interconnected while products in the periphery are sparsely interlinked.

East Asia Pacific



Each country has a certain product export footprint. Relevant exports by 'Industrialized Countries', 'East Asia Pacific' and 'Latin America & the Caribbean' are given on the right.

Latin America & the Caribbean



Traditional growth theory assumes that there is always a more sophisticated product within reach. However, given the core-periphery structure of the product space, the distances between products differ considerably.

Countries that operate at the core have capabilities to develop and manufacture a wide range of products. Yet, countries that mostly operate in the periphery of the product space have much fewer opportunities for diversification. A country's current footprint and the structure of the product space have a major impact on a country's future development.

Node Color  
[Leamer Classification]

- Petroleum
- Raw Materials
- Forest Products
- Tropical Agriculture
- Animal Agriculture
- Cereals
- Labor Intensive
- Capital Intensive
- Machinery
- Chemicals

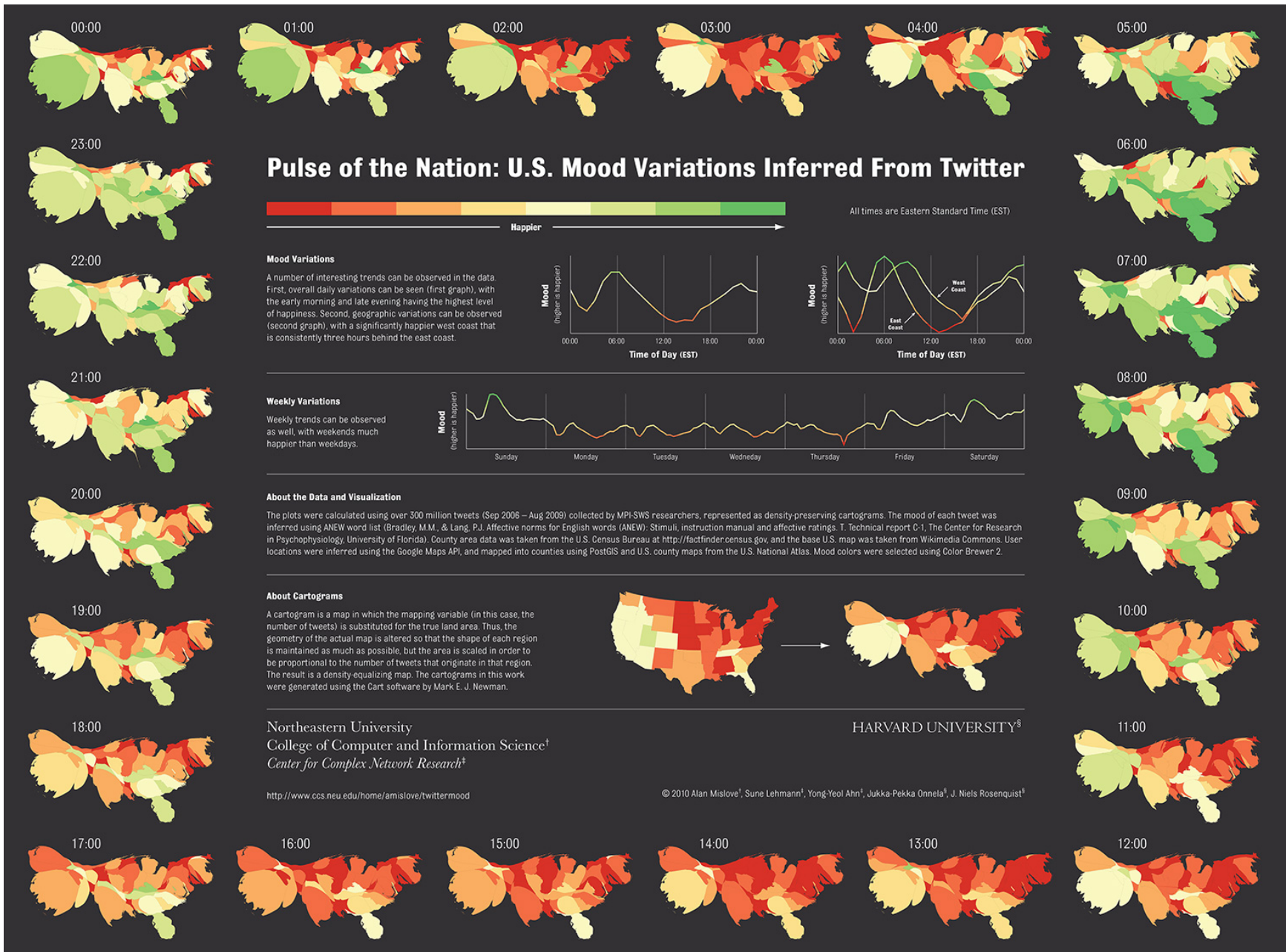
Link Width & Color  
[proximity]

- $f > 0.65$
- $f > 0.55$
- $f > 0.4$
- $f < 0.4$

Node Size  
[Millions of Dollars]







# The EMERGENCE of NANOTECHNOLOGY

## MAPPING THE NANO REVOLUTION

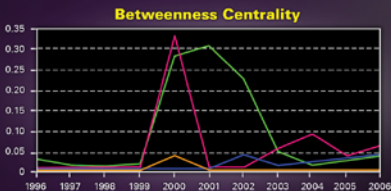
The emergence of nanotechnology has been one of the major scientific-technological revolutions in the last decade and it led to a structural reorganization of major fields of science. Price (1965) showed that fields of science and their development can be mapped using aggregated citations among the journals in the fields and their relevant environments.

The frames to the right show the evolving journal citation network for the years 1998-2003. Distances are proportional to cosine values between the citation patterns of the respective journals. Textual descriptions of key events during the development of *Nanotechnology* are given below each frame. Most notably, leading papers in *Science* and *Nature* catalyzed the breakthrough around 2000.

## CHANGING ROLES OF DIFFERENT JOURNALS

The interdisciplinarity of a journal can be measured using betweenness centrality (BC)—journals that occur on many shortest paths between other journals in a network have higher BC value than those that do not. In the maps, sizes of nodes are proportional to the betweenness centrality of the respective journal in the citation network.

From being a specialist journal in applied physics, the journal *Nanotechnology* obtains a high BC value in the years of the transition, ca. 2001. This is preceded by the "intervention" of *Science*. After the transition, the new field of nanotechnology is established, new journals such as *Nano Letters* published by the influential American Chemical Society take the lead, and a new specialty structure with low BC value journals results.



An animated sequence of this evolution is at: <http://www.leydesdorff.net/journals/nanotech>.

## References

Leydesdorff, L. and T. Schank. 2008. Dynamic Animations of Journal Maps: Indicators of Structural Change and Interdisciplinary Developments. *Journal of the American Society for Information Science and Technology*, 59(11), 1810-1818.

Price, Derek J. de Solla (1965). Networks of scientific papers. *Science*, 149, no. 3683, 510-515.

**1998**

During the period 1996-2000, the journal *Nanotechnology* is part of a group of journals in applied physics.

**1999**

Increasingly, chemistry journals play a role in the citation impact environment of the journal *Nanotechnology*.

## LEGEND

- Science
- Nature
- Nanotechnology
- Nano Letters

## Values

- 0.8
- 0.22
- 0.33

**2003**

The journal *Science* is relevant in the citation impact environment, but now functions as one of the specialist journals in nanotechnology. *Nanoscience* further develops as an increasingly integrated network of journals.

**2002**

Other journals in nanoscience and technology begin to emerge, and the bridging role of the journal *Nanotechnology* gradually subsides. *Nano Letters* and the *Journal of Nanoscience and Nanotechnology* join the new field of nanotechnology.

**2000**

The journal *Science* interfaces with relevant journals in both sets: chemistry and applied physics. *Nanotechnology* emerges as core journal.

**2001**

The journal *Nanotechnology* now provides the interface between chemistry and physics. The "intervention" by *Science* is no longer needed.

Design by Michael J. Stammer and Katy Börner  
Cyberinfrastructure for Network Science Center | Indiana University  
[cns.indiana.edu](http://cns.indiana.edu)



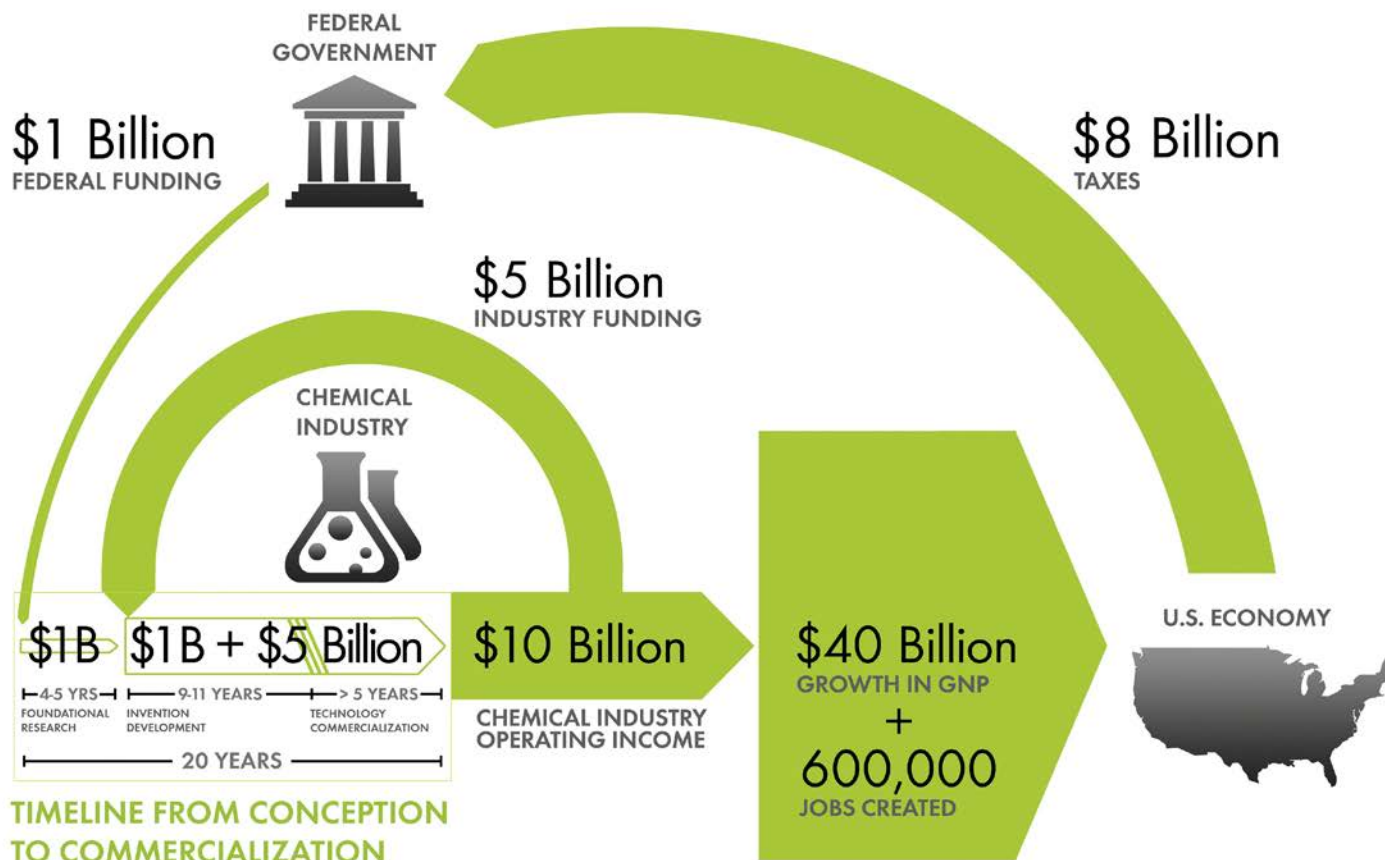
# Chemical Research & Development Powers the U.S. Innovation Engine

Macroeconomic Implications of Public and Private R&D Investments in Chemical Sciences



has provided the U.S. Congress and government policy makers with important results regarding the impact of Federal Research & Development (R&D) investments on U.S. innovation and global competitiveness through its commissioned 5-year two phase study. To take full advantage of typically brief access to policy makers, CCR developed the graphic below as a communication tool that distills the complex data produced by these studies in direct, concise, and clear terms.

## INVESTMENT IN CHEMICAL SCIENCE R&D



The design shows that an input of \$1B in federal investment, leveraged by \$5B in industry investment, brings new technologies to market and results in \$10B of operating income for the chemical industry, \$40B of growth in the Gross National Product (GNP) and further impacts the US economy by generating approximately 600,000 jobs, along with a return of \$8B in taxes. Additional details, also reported in the CCR studies, are depicted in the map to the left. This map clearly shows the two R&D investment cycles; the shorter industry investment at the innovation stage to commercialization cycle; and the longer federal investment cycle which begins in basic research and culminates in national economic and job growth along with the increase in tax base that in turn is available for investment in basic research.





# Check out our **Zoom Maps** online!

VII.10  
History of Science Fiction, by Ward Shelley

BROOKLYN, NY 2011  
Courtesy of Ward Shelley Studio

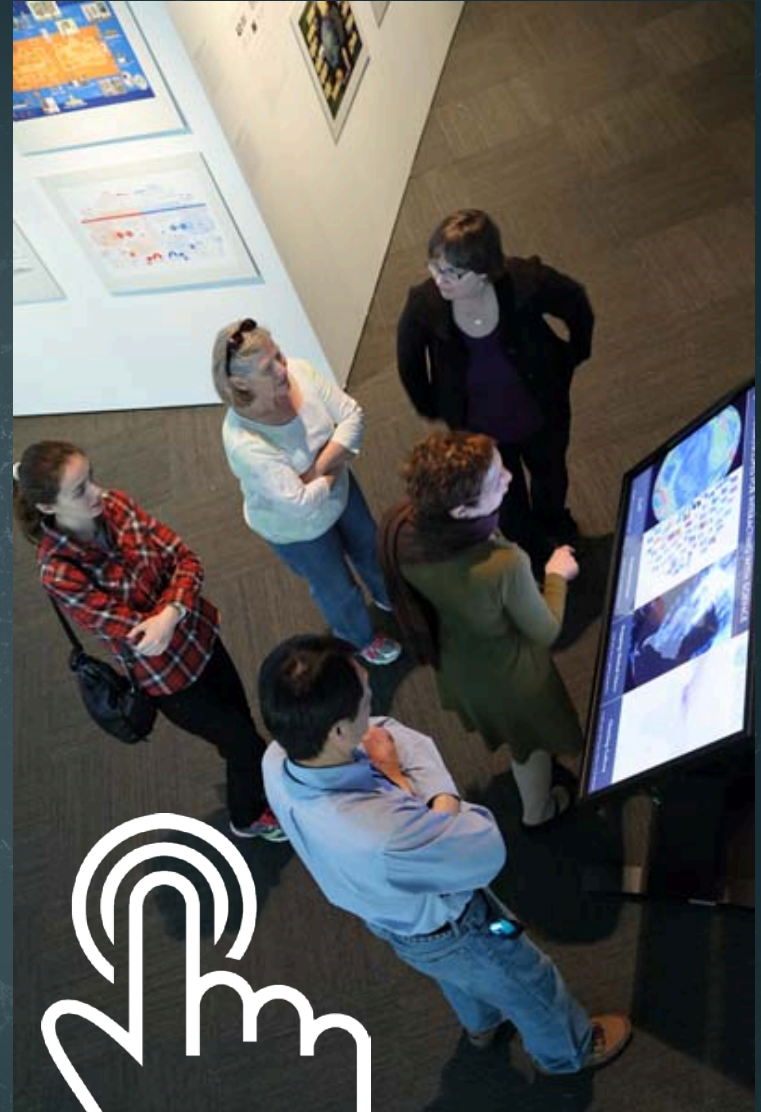
Ward Shelley is an artist identified with the Williamsburg scene in Brooklyn, New York. This map plots the science fiction literary genre from its nascent roots in the 18th century, emerging out of the data, here the narrative structure precedes and organizes the data. The map's structure and the monster whose tentacles are like trace roots to pre-historical sources and whose body is a map of the genre's evolution. Romanticism, which birthed gothic fiction, source not only of Sci-Fi, but also of critical theory. The map progressed through a number of distinct periods, which are charted, citing hundreds of authors and works.

PLACES & SPACES  
MAPPING ARTISTS

Visit [scimaps.org](http://scimaps.org) and check out all our maps in stunning detail!

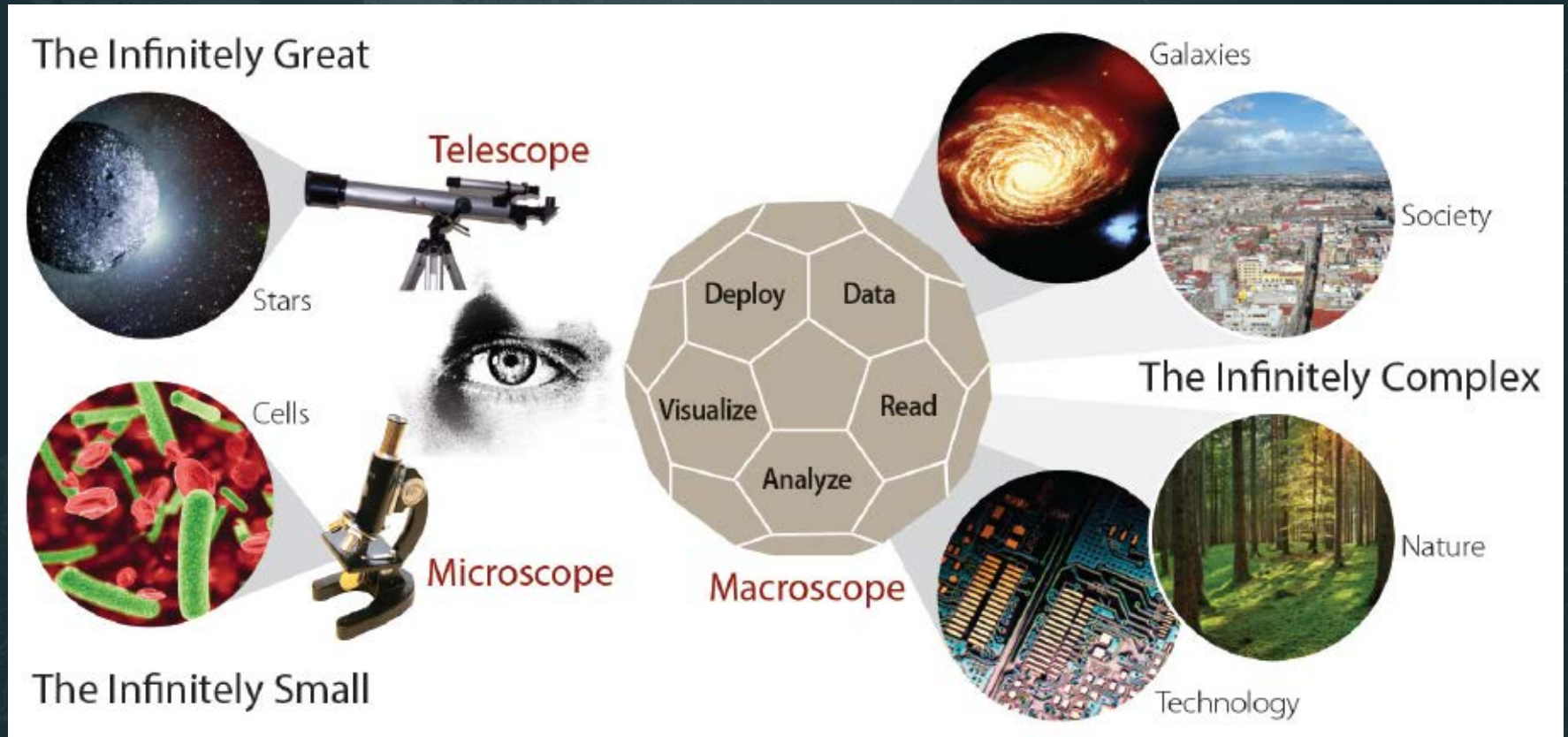


MAPS  
vs.  
MACROSCOPES

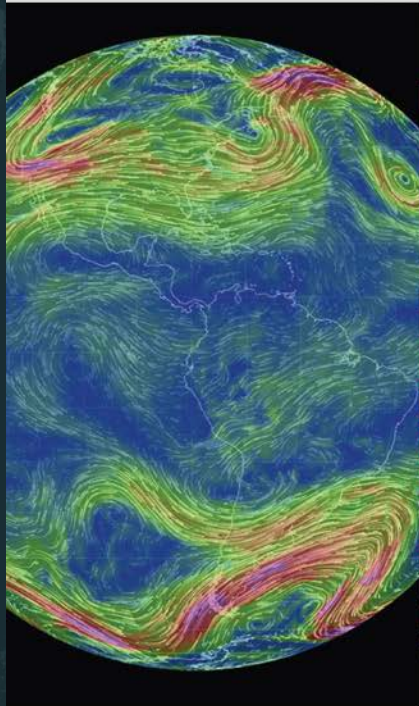




# Microscopes & Telescopes vs. MACROSCOPES



**i** **MACROSCOPES FOR INTERACTING WITH SCIENCE**



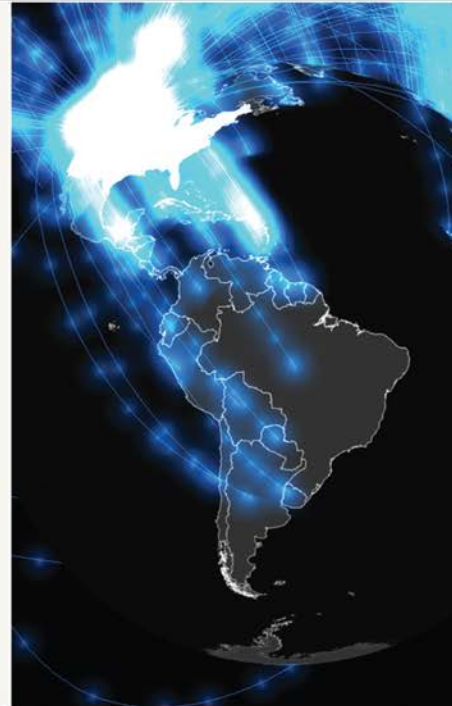
**Earth**

*Weather on a worldwide scale*



**AcademyScope**

*Exploring the scientific landscape*



**Mapping Global Society**

*Local news from a global perspective*



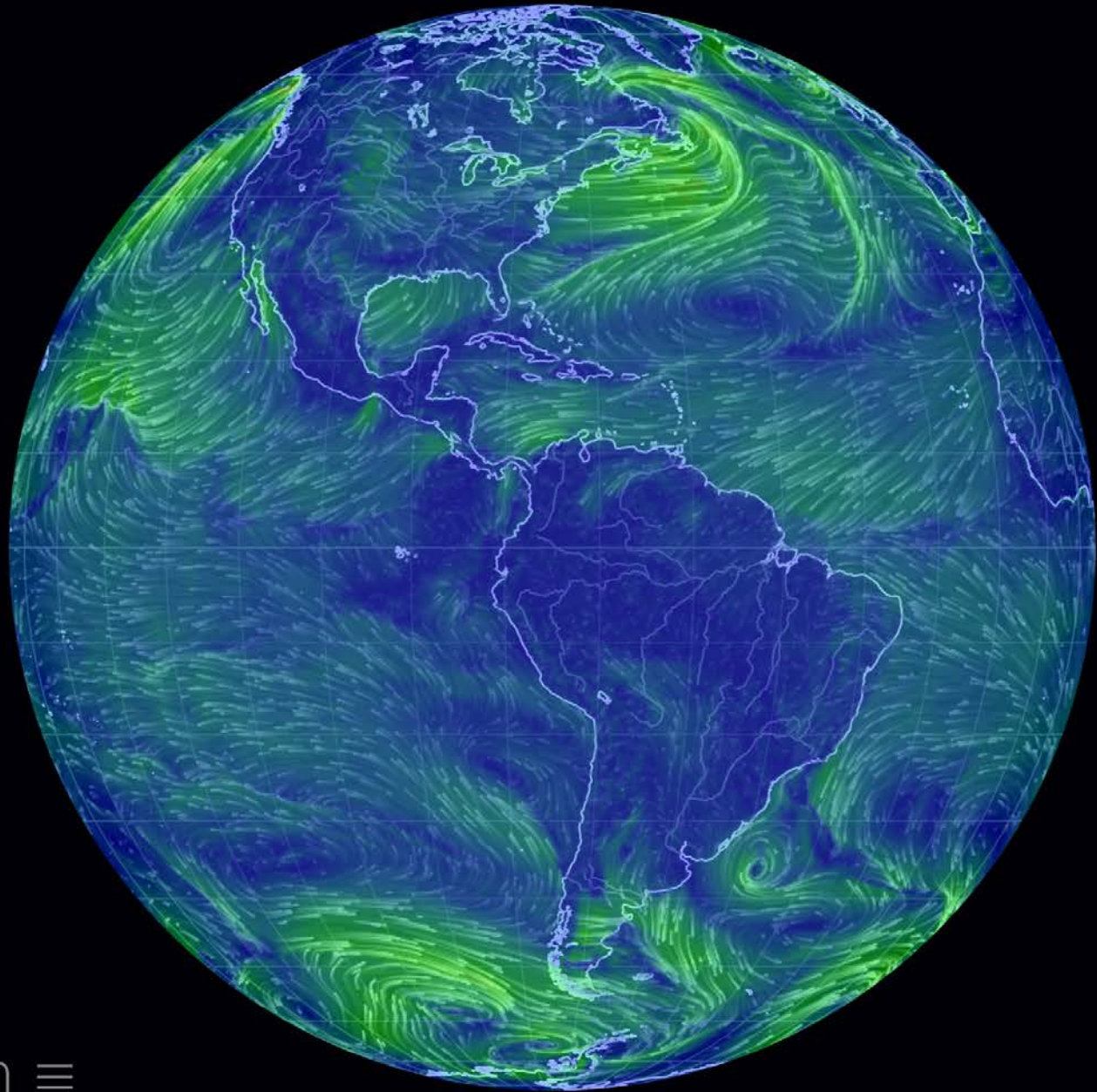
**Charting Culture**

*2,600 years of human history in 5 minutes*

**Iteration XI (2015): Macroscopes for Interacting with Science**

<http://scimaps.org/iteration/11>





earth ≡

*Earth* – Cameron Beccario





# The News Co-occurrence Globe

An interactive visualization of how countries are mentioned together in the world's news media

+ - UNITED KINGDOM SEARCH ABOUT



2.92K  
COOCCUR%

**UNITED KINGDOM** cooccurrences in: 2,922%  
cooccurrences out: 80%

Timeline: Feb 22, Mar 1, Mar 8, Mar 15, Mar 22, Mar 29, Apr 5, Apr 12, Apr 19, Apr 26, May 3, May 10, May 17, May 24



COOCCUR

IN%

OUT%



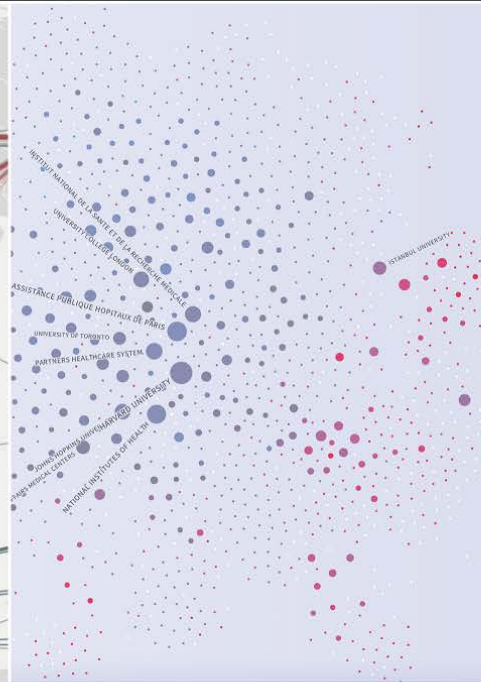
**Smelly Maps**

*Charting urban smellscapes*



**HathiTrust**

*Storehouse of knowledge*



**Excellence Networks**

*Publish or perish together*



**FleetMon Explorer**

*Tracking the seven seas*

## Iteration XII (2016): Macrosopes for Making Sense of Science

<http://scimaps.org/iteration/12>



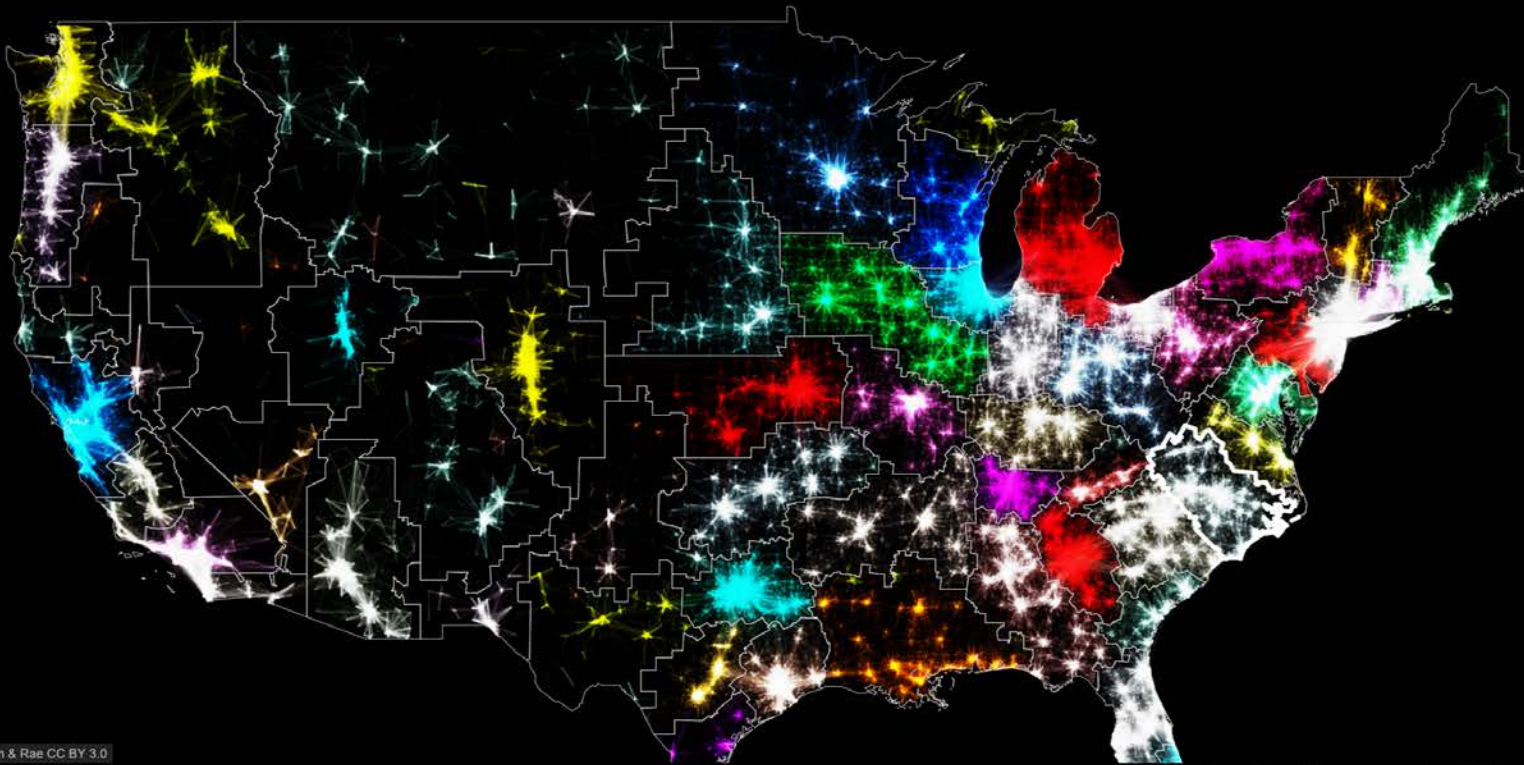


*Smelly Maps* – Daniele Quercia, Rossano Schifanella, and Luca Maria Aiello – 2015



## THE MEGAREGIONS OF THE US

Explore the new geography of commuter connections in the US.  
Tap to identify regions. Tap and hold to see a single location's commuted.



Leaflet | Nelson & Rae CC BY 3.0

This is the Roanoke (Raleigh) megaregion.

 **FleetMon**  
Tracking the Seven Seas



00:08

01:31

*FleetMon Explorer* – FleetMon – 2012

# Models of Science & Technology

Using large scale datasets, advanced data mining, modeling, and visualization techniques, and substantial computing resources.







# Modeling Science, Technology & Innovation Conference

WASHINGTON D.C. | MAY 17-18, 2016

[View Agenda](#)

Government, academic, and industry leaders discussed challenges and opportunities associated with using big data, visual analytics, and computational models in STI decision-making.

Conference slides, recordings, and report are available via <http://modsti.cns.iu.edu/report>





- PROGRAMS
- Awards
- Koshland Science Museum
- Cultural Programs
- Sackler Colloquia
  - About Sackler Colloquia
  - Upcoming Colloquia
  - Completed Colloquia
  - Video Gallery
  - Connect with Sackler Colloquia
  - Give to Sackler Colloquia
- Kavli Frontiers of Science
- Distinctive Voices



## Upcoming Colloquia

Unless otherwise indicated, most Sackler colloquia are held at the Arnold and Mabel Beckman Center, in Irvine, California.

### *Reproducibility of Research: Issues and Proposed Remedies*

March 8-10, 2017; Washington, D.C.  
Organized by David B. Allison, Richard Shiffrin and Victoria Stodden  
Registration now open

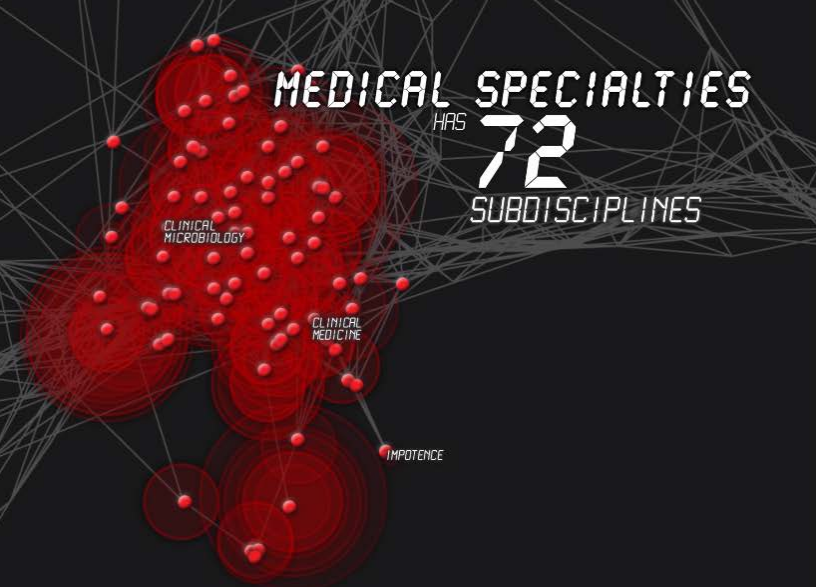
### *Science of Science Communication III*

November 15-16, 2017; Washington, D.C.  
Organized by Karen Cook, Baruch Fischhoff, Alan I. Leshner and Dietram A. Scheufele  
Registration will open May 2017

### *Modelling and Visualizing Science and Technology Developments*

December 4-5, 2017; Irvine, CA  
Organized by Katy Börner, William Rouse and H. Eugene Stanley  
Registration will open August 2017





# Science Forecast S1:E1



# Science Forecast S1:E1

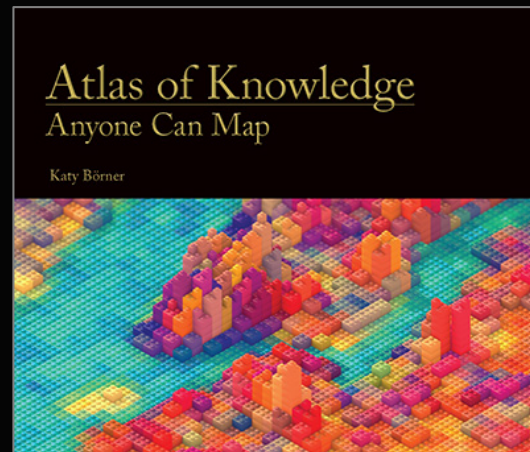


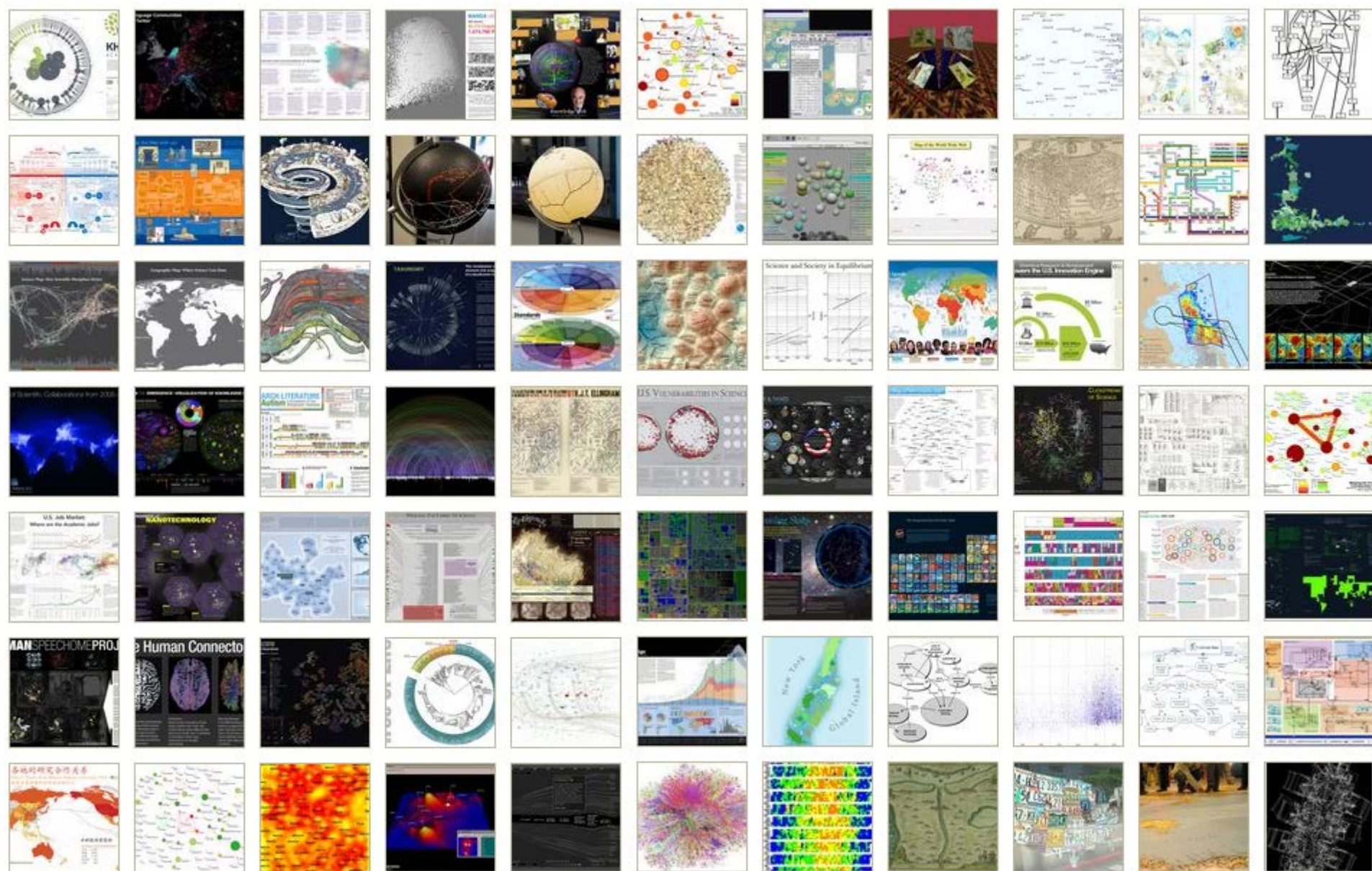
[https://www.youtube.com/watch?v=lByX2\\_eb\\_QQ](https://www.youtube.com/watch?v=lByX2_eb_QQ)



# Making Science & Technology Visualizations

Using a theoretically grounded visualization framework that defines key terminology and processes together with valid workflows and data mappings.





*Places & Spaces: Mapping Science* Exhibit, online at <http://scimaps.org>



# How to Classify (Name & Make) Different Visualizations?

By

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

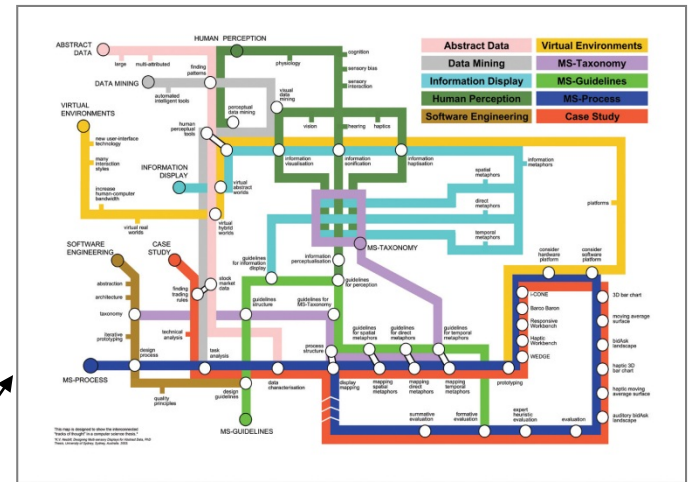


# Different Question Types



Terabytes of data

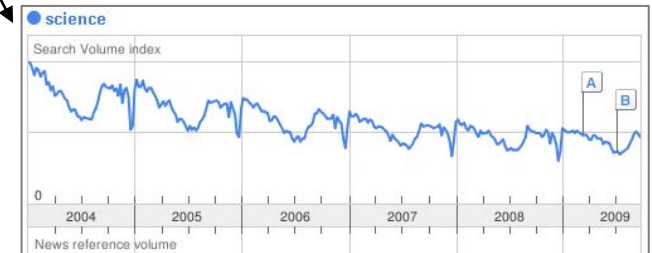
Descriptive & Predictive Models



Find your way



Find collaborators, friends

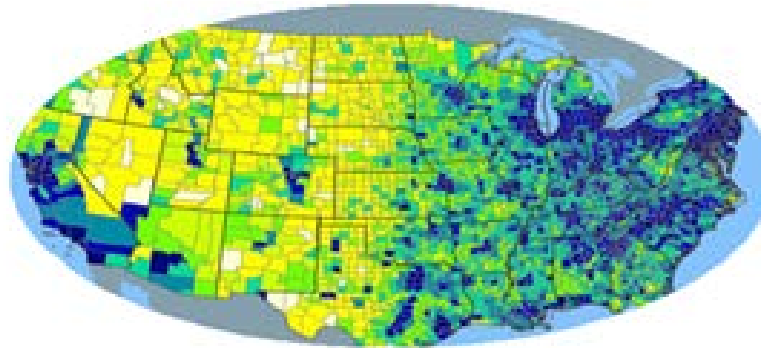


Identify trends

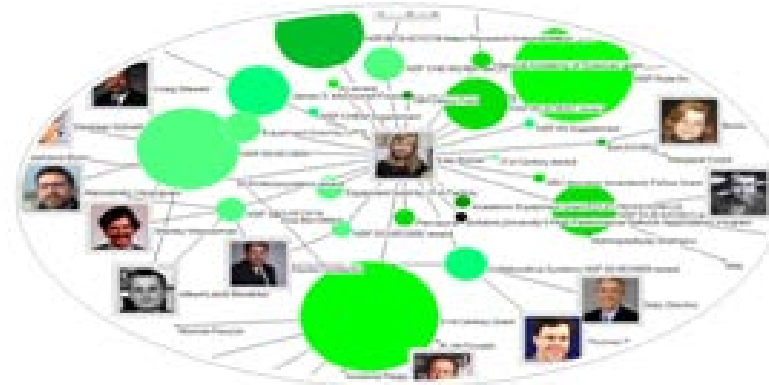


# Different Levels of Abstraction/Analysis

Macro/Global  
Population Level



Meso/Local  
Group Level



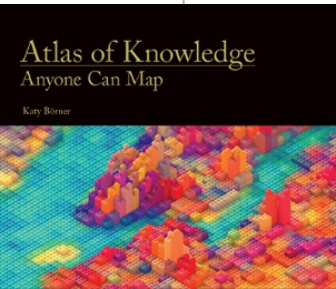
Micro  
Individual Level



# Tasks

## LEVELS

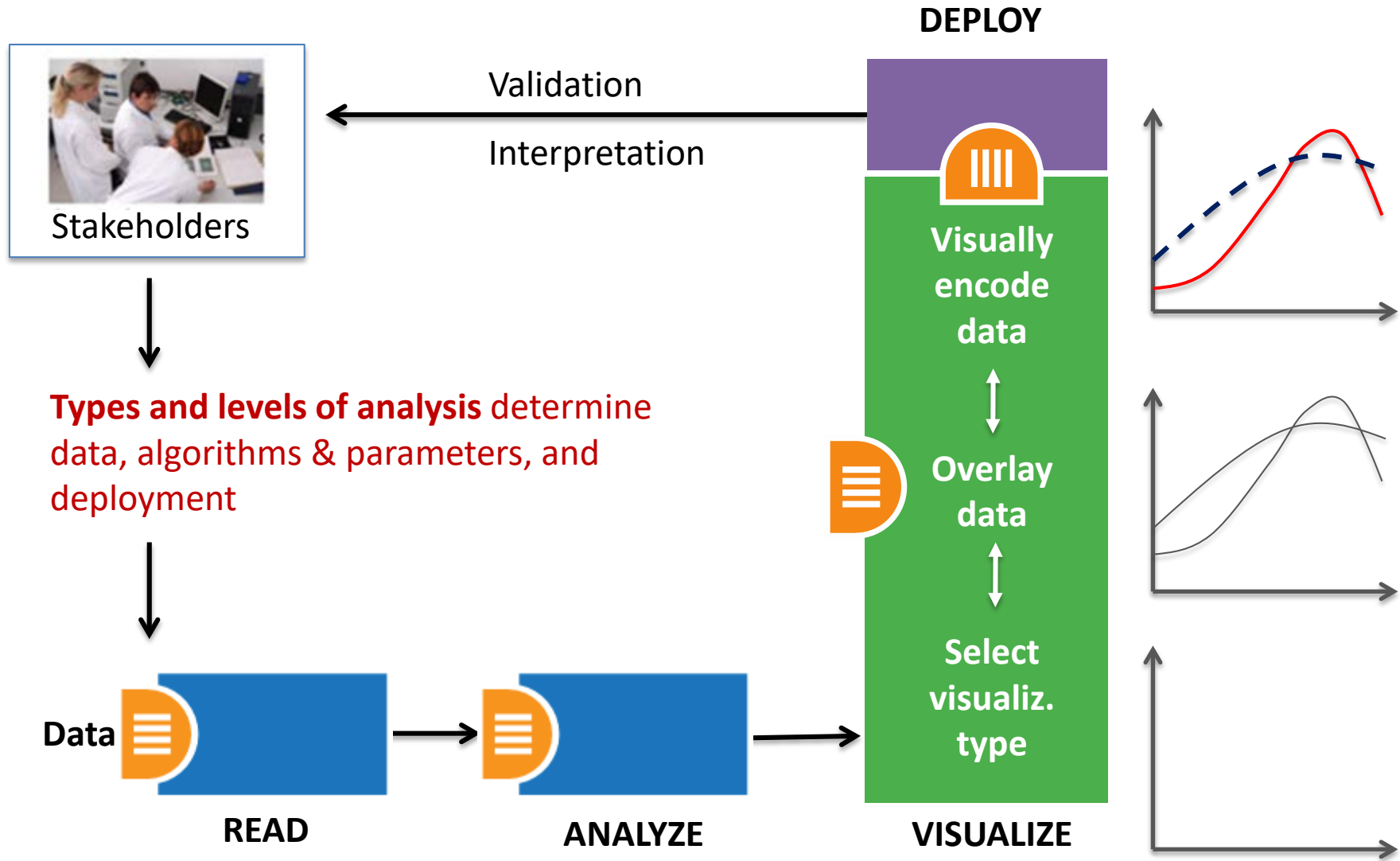
	<b>MICRO: Individual Level</b> about 1–1,000 records page 6	<b>MESO: Local Level</b> about 1,001–100,000 records page 8	<b>MACRO: Global Level</b> more than 100,000 records page 10
<b>TYPES</b>			
<b>Statistical Analysis</b> page 44	 Knowledge Cartography page 135	 Productivity of Russian life sciences research teams page 105	 Number of scientists versus population and R&D costs versus GNP. 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 93
<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



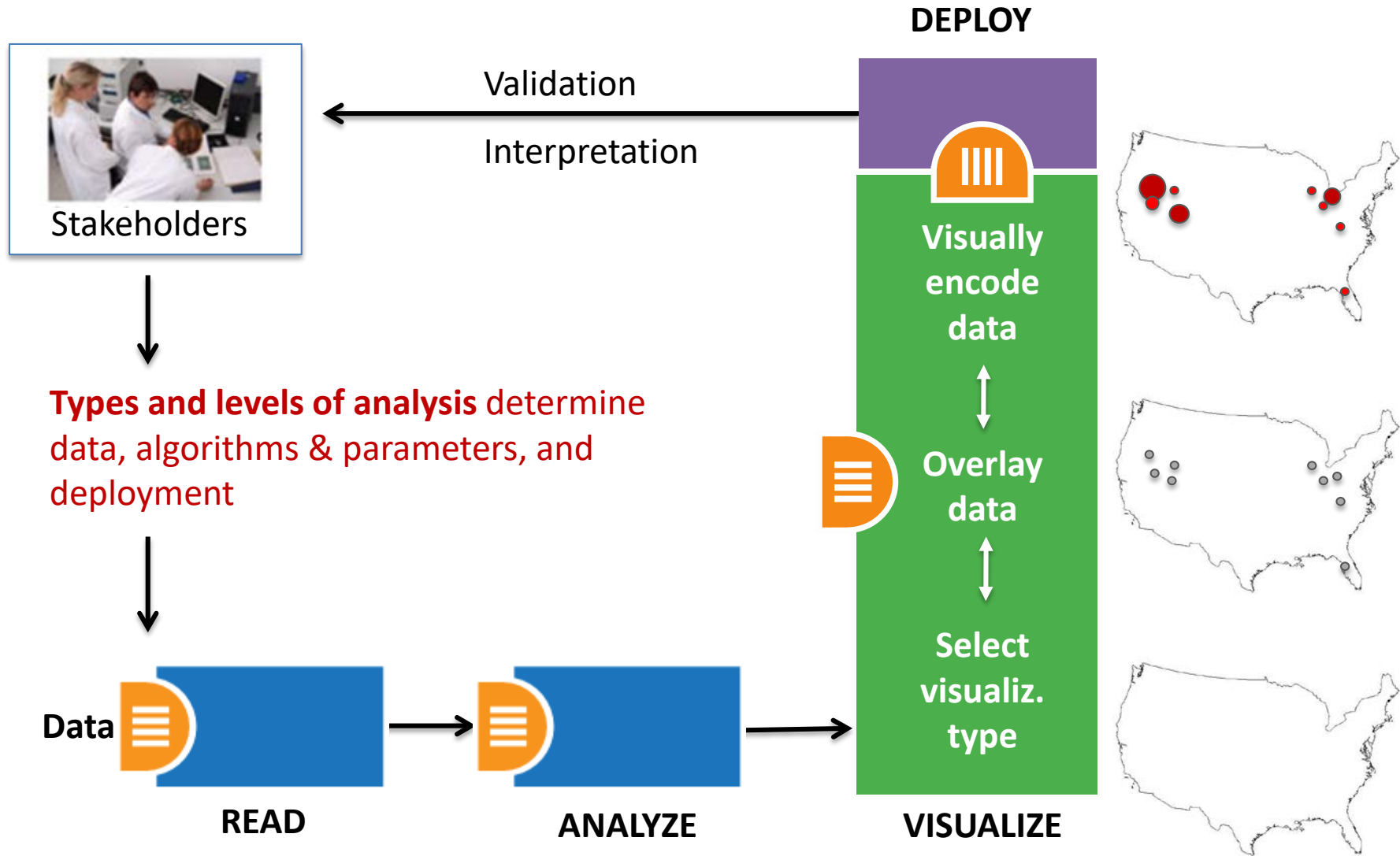
See *Atlas of Science: Anyone Can Map*, page 5



# Needs-Driven Workflow Design



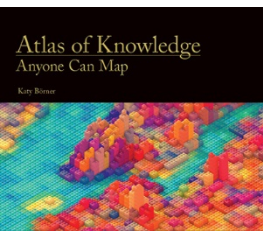
# Needs-Driven Workflow Design





# Visualization Framework

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>



See page 24

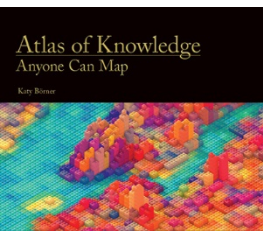
# Visualization Framework

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



# Visualization Framework

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 24

# 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				
Color	Value	quantitative						
	Hue	qualitative						
	Saturation	quantitative						



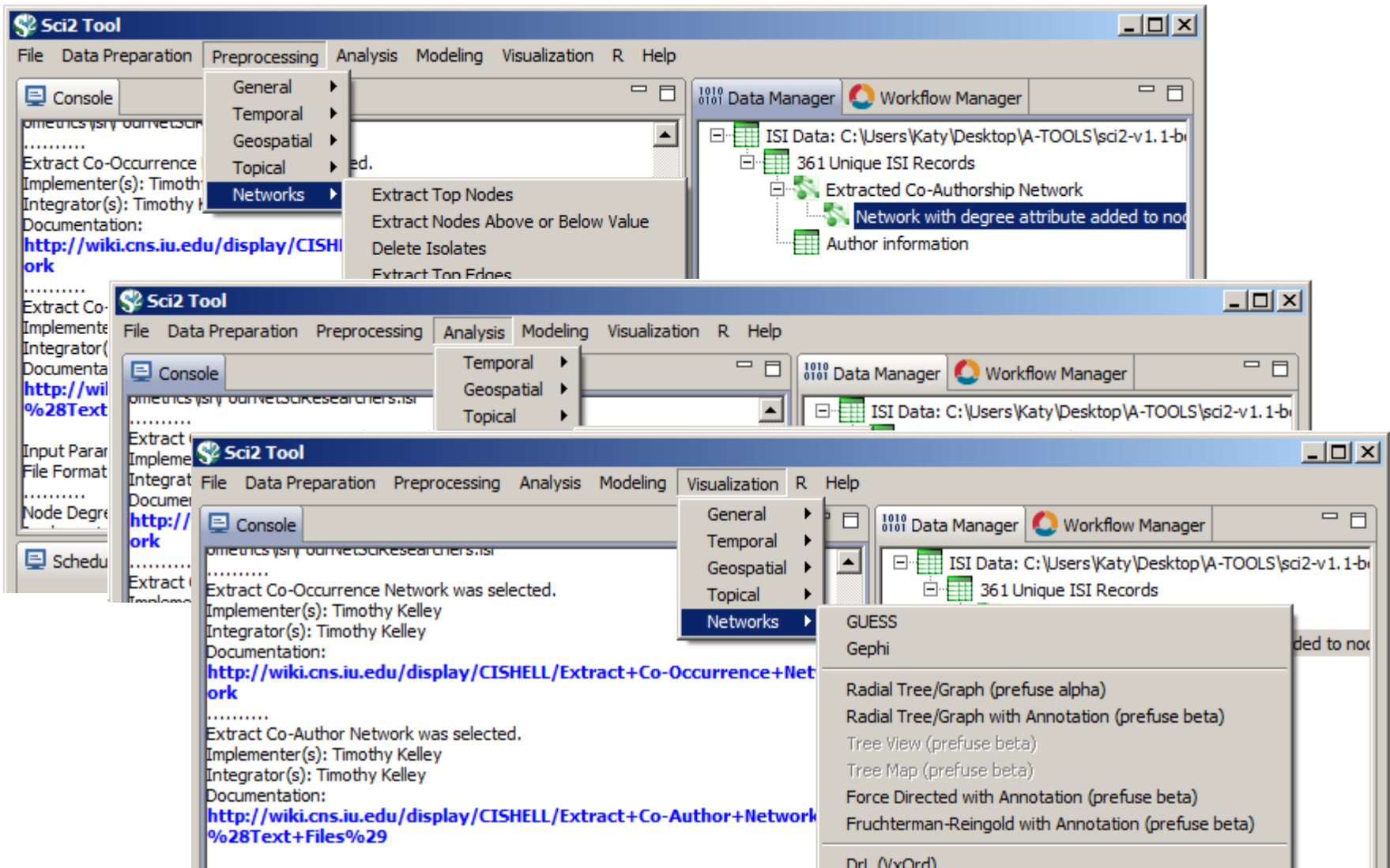
# Graphic Variable Types Versus Graphic Symbol Types

			Geometric Symbols			Linguistic Symbols Text, Numerals, Punctuation Marks		Pictorial Symbols Images, Icons, Statistical Glyphs	
Spatial	x	quantitative							
	y	quantitative							
	z	quantitative							
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							

			Geometric Symbols			Linguistic Symbols Text, Numerals, Punctuation Marks		Pictorial Symbols Images, Icons, Statistical Glyphs	
Texture	Spacing	quantitative							
	Granularity	quantitative							
	Pattern	qualitative							
	Orientation	quantitative	NA						
	Gradient	quantitative							
	Blur	quantitative							
	Transparency	quantitative							
Optics	Shading	quantitative							
	Stereoscopic Depth	quantitative	Point in foreground -- background	Line in foreground -- background	Area in foreground -- background	Surface in foreground -- background	Volume in foreground -- background	Text in foreground -- background	Icons in foreground -- background
	Speed	quantitative							
Motion	Velocity	quantitative							
	Rhythm	quantitative	Blinking point slow -- fast	Blinking line slow -- fast	Blinking area slow -- fast	Blinking surface slow -- fast	Blinking volume slow -- fast	Blinking text slow -- fast	Blinking icons slow -- fast

# Sci2 Tool Interface Components Implement Vis Framework

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





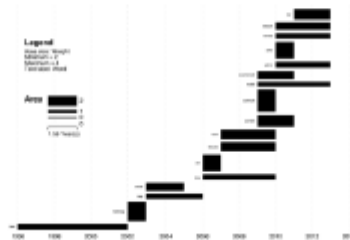
# Load **One** File and Run **Many** Analyses and Visualizations

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 Microscopes	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, N Fiore, SM Hall, KL Keyton, J 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, N Falk-Krzesinski, HJ Fiore, SM Hall, KL Keyton, J 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

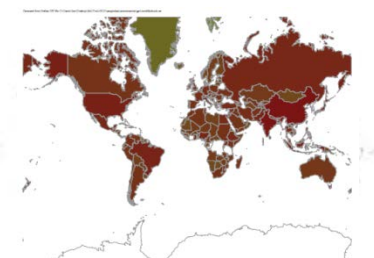
## Temporal Burst Analysis—p. 48



## Geospatial Analysis—p. 52



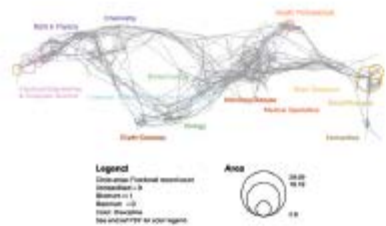
## Geospatial Analysis—p. 52



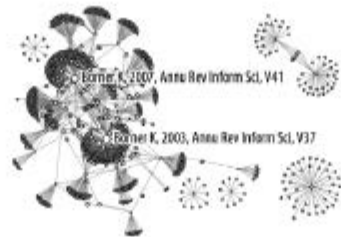
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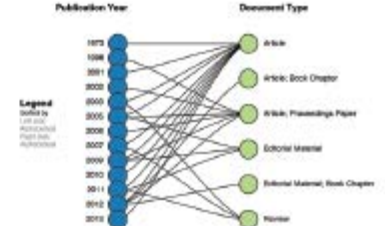
Topical Analysis—p. 56



Paper Citation Network—p. 60



Bi-Modal Network—p. 60



Co-author and many other bi-modal networks.





Register for free: <http://ivmooc.cns.iu.edu>. Class restarts Jan 9, 2018.

# 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.

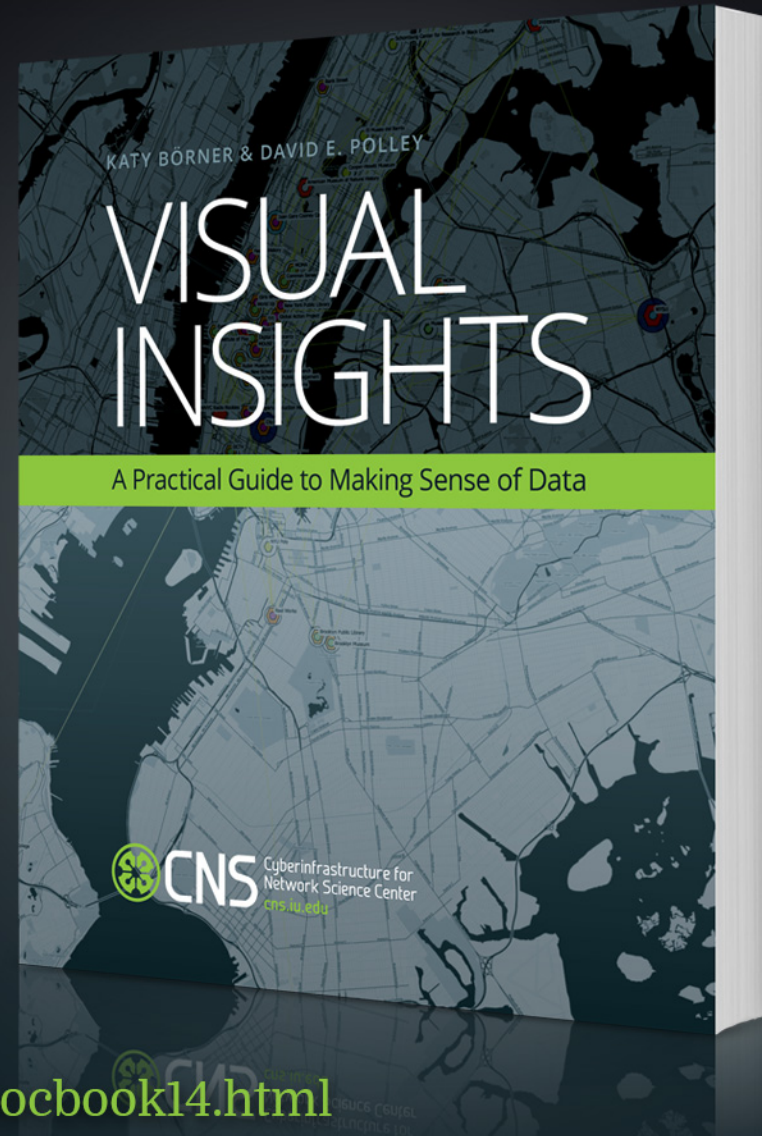
Final grade is based on Homework and Quizzes (**10%**), Midterm (**20%**), Final (**30%**), Client Project (**30%**), and Class Participation (**10%**).



# The IVMOOC Companion Textbook

This textbook offers a gentle introduction to the design of insightful visualizations. It seamlessly blends theory and practice, giving readers both the theoretical foundation and the practical skills necessary to render data into insights.

The book accompanies the Information Visualization MOOC that attracted students, scholars, and practitioners from many fields of science and more than 100 different countries.



[cns.iu.edu/ivmooobook14.html](http://cns.iu.edu/ivmooobook14.html)



# 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/vol101/suppl\\_1](http://www.pnas.org/content/vol101/suppl_1)

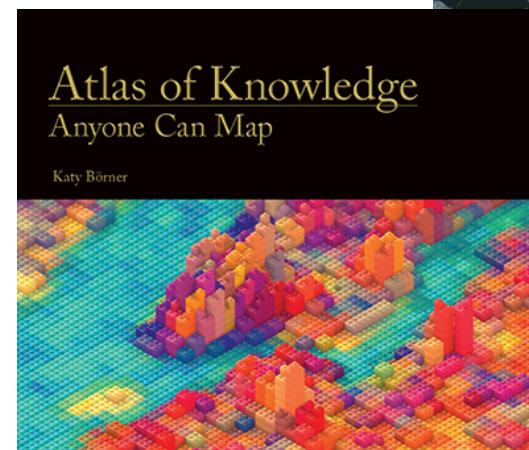
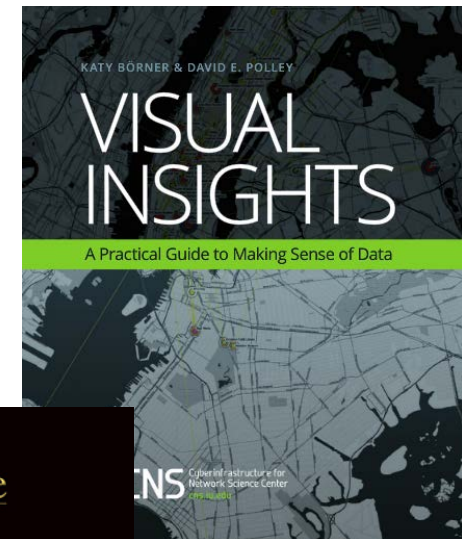
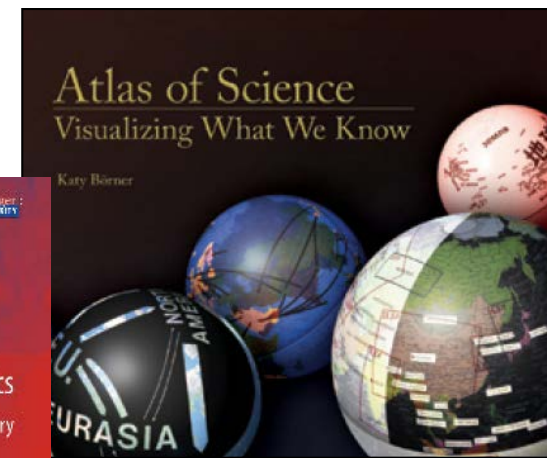
Börner, Katy (2010) **Atlas of Science: Visualizing What We Know**. The MIT Press. <http://scimaps.org/atlas>

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>






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- OCT 1** Katy Börner attends PIUG 2013 Northeast Conference
- 10.13** Katy Börner presents Mapping Science Exhibit at WSSF
- 10.15** Ted Polley & Google Team present IVMOOC at EDUCAUSE
- 10.22** Katy Börner presents at the SciELO 15 Years Conference


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