

# Improving Data Visualization Literacy: Empowering Anyone to Read and Make Visualizations

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## CARTOGRAPHIC SUMMIT THE FUTURE OF MAPPING

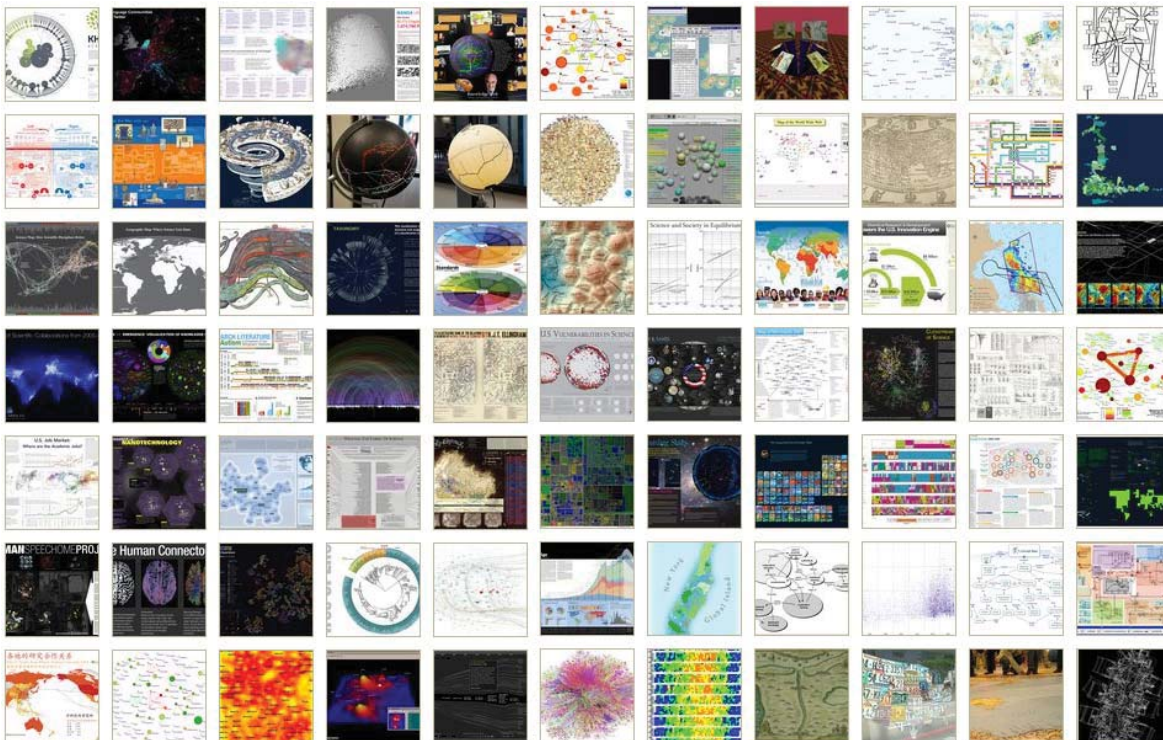
Hosted by the International Cartographic Association & Esri  
February 8–10, 2016 | Redlands, CA

Part 1



PLACES &  
SPACES &  
MAPPING SCIENCE

[scimaps.org](http://scimaps.org)



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

INSTITUTE FOR THE FUTURE  
Science & Technology Outlook: 2005-2055

Technology Horizons Program  
Institute for the Future  
124 University Avenue, 2nd Floor, Palo Alto, CA 94301  
1.650.854.0372 1.650.854.7050 [www.iftf.org](http://www.iftf.org)



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 uncertain territory of science and technology (S&T) in the next 50 years. However, the map of the future is not a tool for prediction so, for that matter, the product of predictions. After all, comparable to modern navigation techniques in which we rely on a shrinking number of strong signals, like GPS coordinates, to locate the right path, 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 offer 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 the map of the future of S&T—to give the reader a deeper contextual understanding of the landscape and to point to the interlink and interdependencies between trends.

While developing the map, the Institute for the Future (IFF) team looked for and connected a variety of weak signals, including those generated during interviews and workshop conversations involving more than 100 eminent UK and U.S. experts in S&T—academicians, policymakers, journalists, and corporate researchers. The IFFT team also compiled a database of outcomes 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 IFFT'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—interdisciplinary innovation, transdisciplinary, and emergence—will define the future S&T landscape illustrating 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 of the larger picture.

**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. Two 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 assemblies 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 push both fundamental research and commercially oriented innovation, and it will be conducted not within the boundaries of conventional academic or corporate departments, but in institutional and social milieu that emphasize heterogeneity.

**Mathematical World**  
The ability to process, compute, 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 50 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 bandwidth will be placed on our visual, auditory, and other sensory abilities. Information previously encoded as text and numbers will be displayed in rich 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—how we process sensory information and connect various sensory functions.

**Extended Self**  
In the next 50 years, we will be faced with broad opportunities to rethink our needs and desires 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. Weaving these tools on ourselves, humans will begin to define a variety of different "transformed" paths—paths, ways of being and being 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.

**Material World**  
A combination 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, and information. From the molecular level to the macro-economy 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 invention aside as a creative force. At the national scale, the capital-intensive character of scientific research made world-class research the property of government 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 centers of excellence in developing countries, and a more global distribution of world-class scientists and technologists.

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.

**Emergence**  
The phenomenon of self-organizing systems 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. Metaphorically, emergence can be modeled using relatively simple computational tools, although those models often require substantial processing power. More generally, it is a richly legitimate 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 popularizations of its underlying concepts.

**Globalization**  
In the last two centuries, national physiology 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 state needs. Through most of the 20th century, the growth of the sciences, and academic and career priorities, encouraged ever-greater specialization. According to Howard Rheingold, a prominent futurist and author, "transdisciplinary" 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.











April, 2005: 101st Annual Meeting of the Association of American Geographer, Denver, Colorado.

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Science Maps in "Expedition Zukunft" science train visited 62 cities in 7 months. Opening on April 23<sup>rd</sup>, 2009 by German Chancellor Merkel

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*Places & Spaces at Northwestern University*  
May 14 - September 23, 2015

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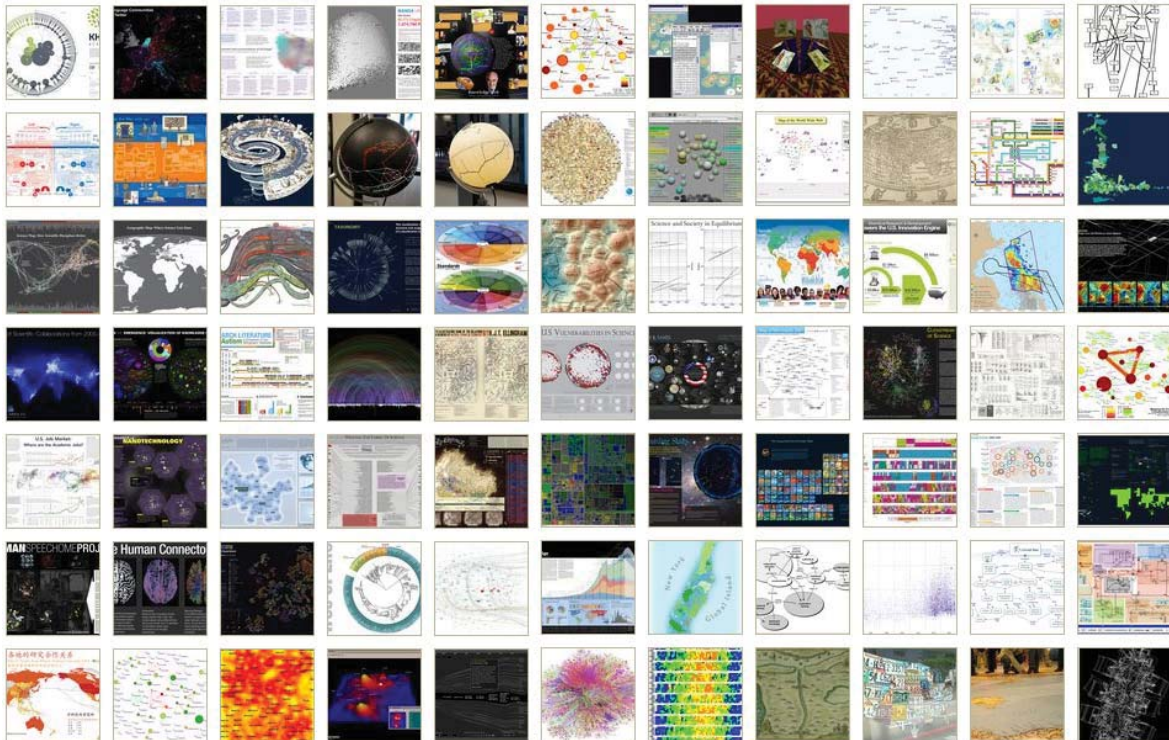
*Places & Spaces Exhibit at the David J. Sencer CDC Museum, Atlanta, GA*  
January 25-June 17, 2016

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Seeing for Action - Using Maps and Graphs to Protect the Public's Health.



**CDC Opening Event: Maps of Health**  
Tutorial and Symposium  
February 4-5, 2016

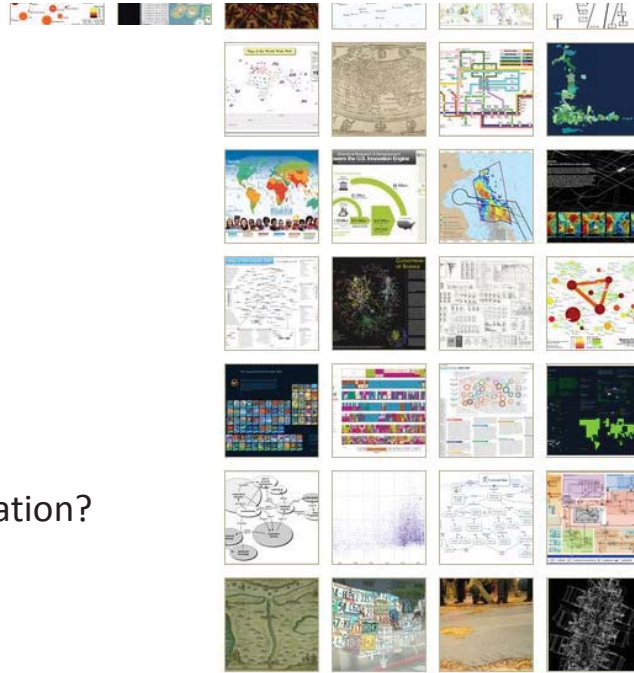




# How to Classify (Name & Make) Different Visualizations?

By

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



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Part 2

Information Visualization MOOC

**VISUAL INSIGHTS**  
A Practical Guide to Making Sense of Data  
Katy Börner & David S. Foray  
CNS

*Atlas of Knowledge*  
Anyone Can Map  
Katy Börner



# Different Question Types



Terabytes of data

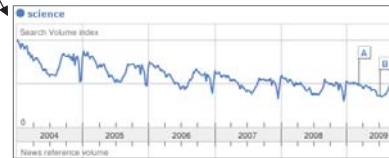
Descriptive & Predictive Models



Find your way



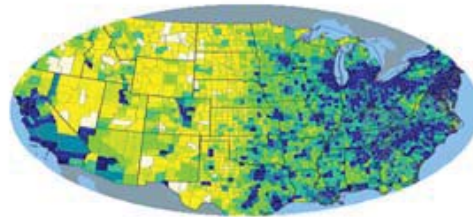
Find collaborators, friends



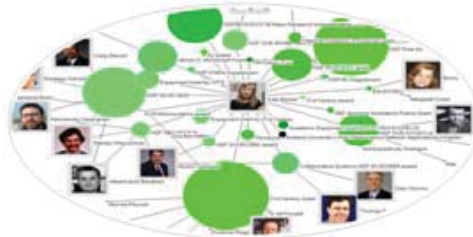
Identify trends

# Different Levels of Abstraction/Analysis

Macro/Global  
Population Level



Meso/Local  
Group Level



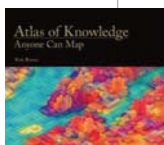
Micro  
Individual Level



# Tasks

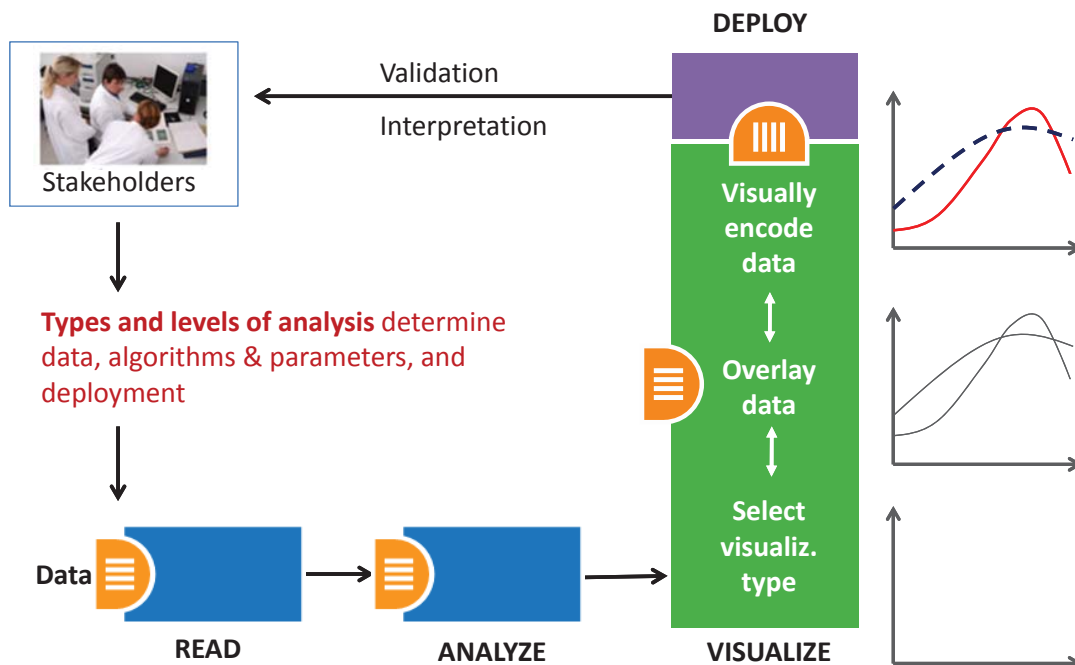
## LEVELS

	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>Statistical Analysis</b> page 44	Knowledge Cartography page 135	Productivity of Russian life sciences research teams page 105	Scientists and Society in Equilibrium 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 137



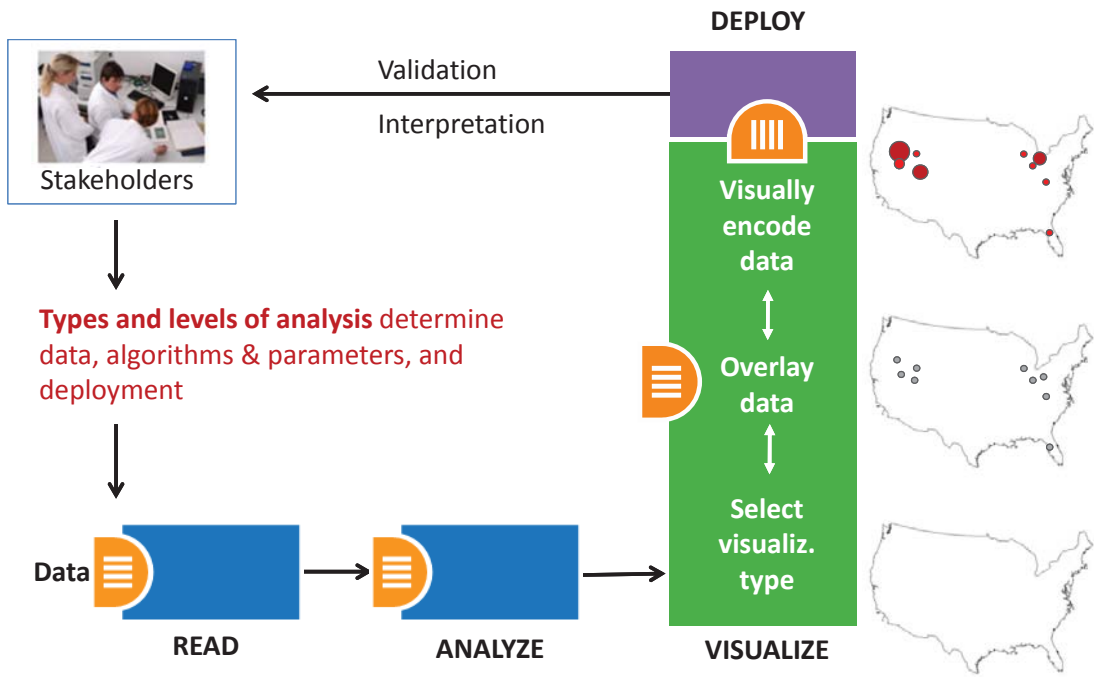
See page 5

# Needs-Driven Workflow Design

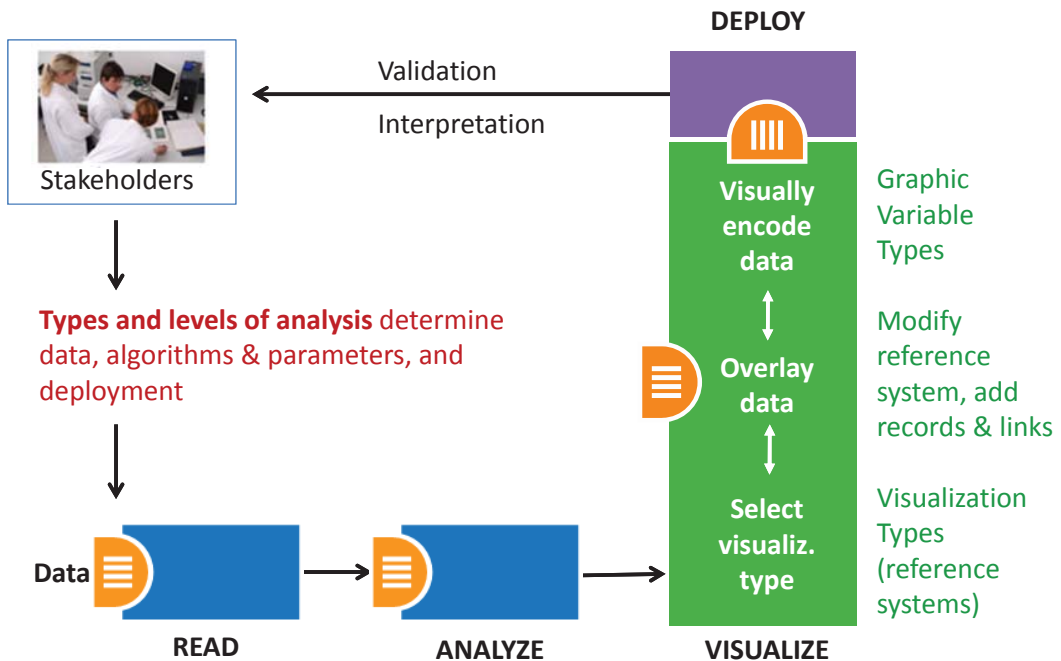




# Needs-Driven Workflow Design



# Needs-Driven Workflow Design



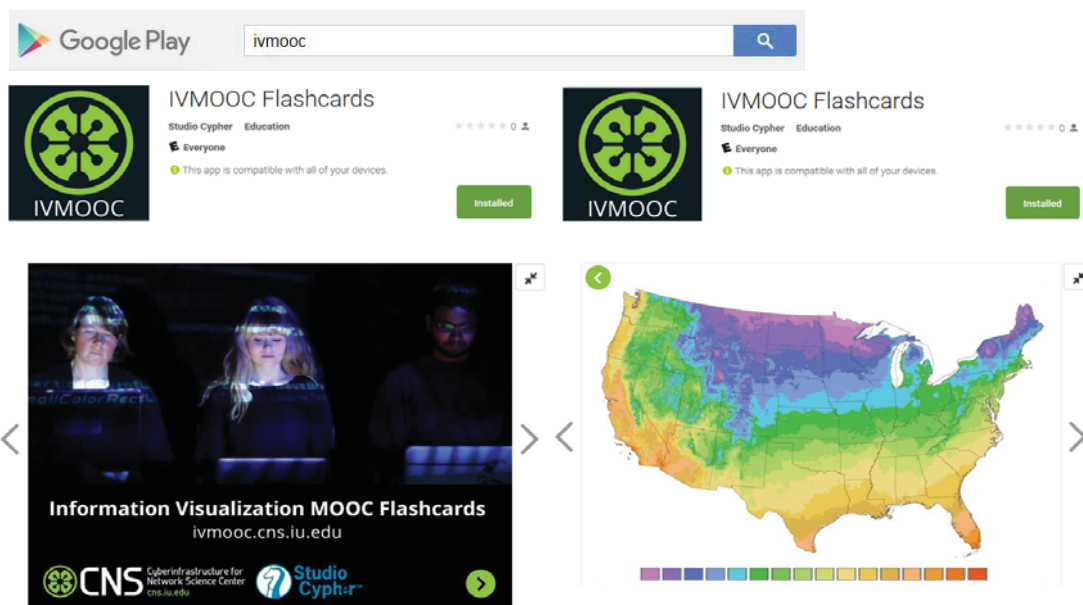
## Visualization Types (Reference Systems)

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 graphs:** Node position might depend on node attributes or node similarity. **Tree graphs:** hierarchies, taxonomies, genealogies. **Networks:** social networks, migration flows.

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## IVMOOC App – More than 60 visualizations

The “IVMOOC Flashcards” app can be downloaded from Google Play and Apple iOS stores.

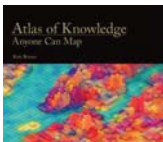


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# Visualization Framework

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

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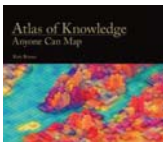
# Visualization Framework

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

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# Visualization Framework

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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	Color	Value	quantitative	
Hue	qualitative					
Saturation	quantitative					



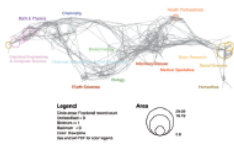
## Graphic Variable Types Versus Graphic Symbol Types

		Point	Line	Geometric Symbols	Surface	Volume	Linguistic Symbols Text, Numbers, Punctuation Marks	Pictorial Symbols Images, Icons, Statistical Graphs
Type	x							
	y							
	z							
Value	size	Not that applicable						
	shape	HA						
	rotation	HA						
	curvature	HA						
	angle	HA						
	tilt/turn	HA						
	color							
Material	opacity							
	contour/shading							
	rotation	HA						
	orientation	HA						
	eccentricity							
	size							
	transparency							
	shading							
	shading depth	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
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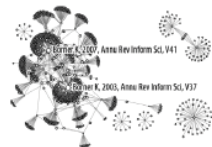
## Load **One** File and Run **Many** Analyses and Visualizations

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 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

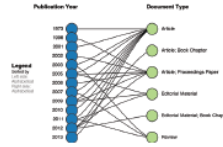
Topical Analysis—p. 56




Paper Citation Network—p. 60




Bi-Modal Network—p. 60




Co-author and many other bi-modal networks.


IVMOOC 2016

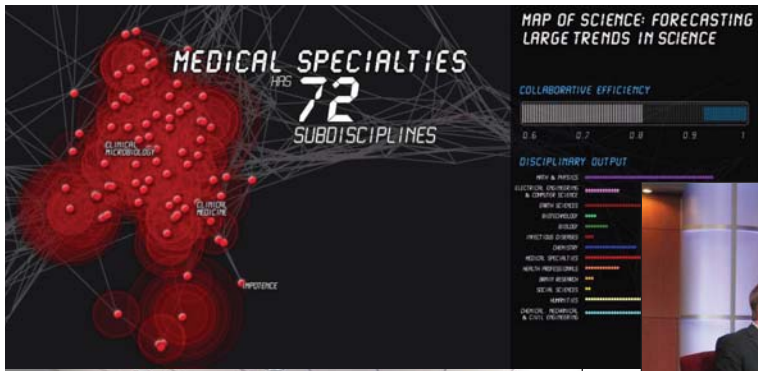
MENU



Information Visualization MOOC
ivmooc.cns.iu.edu 

Register for free: <http://ivmooc.cns.iu.edu>. Class started Jan 12, 2016.

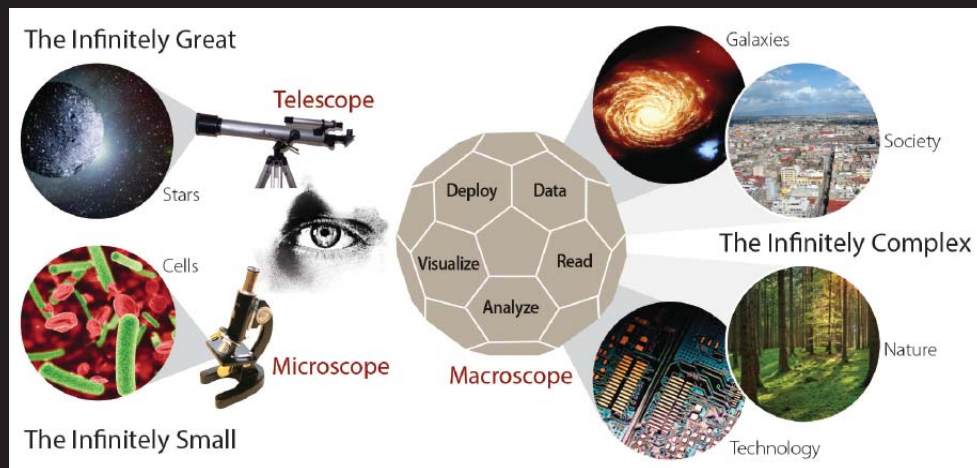




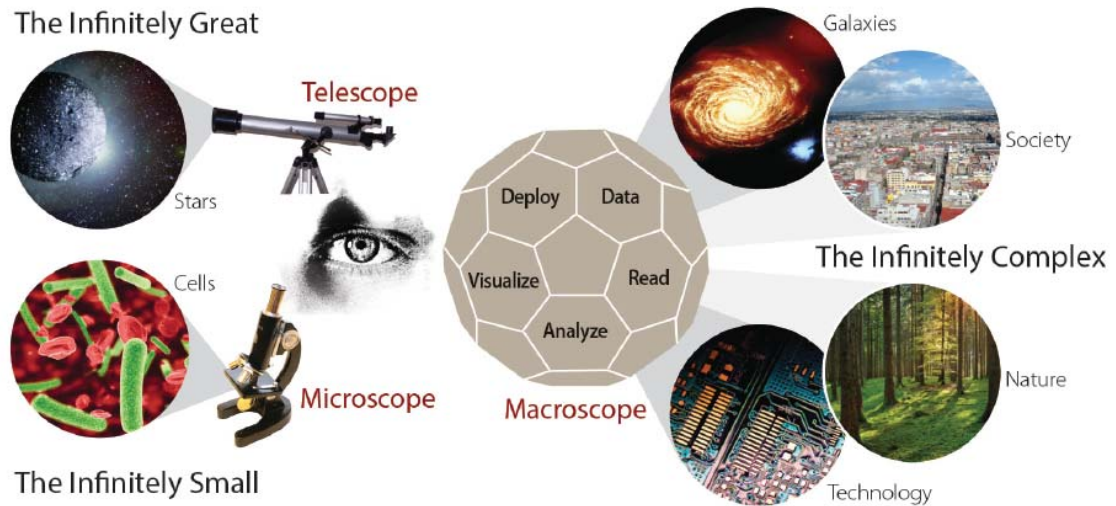
Science Forecast  
S1:E1, 2015



Part 3



# Microscopes, Telescopes, Macrosopes Plug-and-Play Macrosopes



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**MACROSCOPES FOR INTERACTING WITH SCIENCE**

**PLACES & SPACES**  
MAPPING SCIENCE  
scimaps.org

Earth

AcademyScope

Mapping Global Society

Charting Culture

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





Illuminated Diagram Display  
on display at the Smithsonian in DC.  
[http://scimaps.org/exhibit\\_info/#ID](http://scimaps.org/exhibit_info/#ID)

### Geographic Map: Where Science Gets Done

North America, Central America, South America, Oceania, Asia, Africa, Europe, North & West Asia, South & East Asia, Antarctica

### Science Map: How Scientific Disciplines Relate

Math & Physics, Chemistry, Health Professionals, Astronomical, Chemical, Mechanical & Civil Engineering, Medical Operations, Social Sciences, Electrical, Engineering & Computer Science, Biotechnology, Biomaterials, Earth Sciences, Biology, Humanities, Stem Research, Infectious Diseases

Copyright © 2006 The Regents of the University of California

**About**

This Illuminated Diagram display adds the flexibility of an interactive program to the incredibly high data density of a print. This technique is generally useful when there is too much pertinent data to be displayed on a screen but the data is relatively stable. The computer can direct the eye to what's important by using projectors or screens as smart spotlights, animating the research impact of individuals, giving a "grand tour" of science, or highlighting query results (as when you touch the lectern or use the keyboard) with an overlay of moving light.

**Top Five Continents**

North America - 4,000 records  
South & East Asia - 3,589  
Australia - 2,431  
Africa - 2,206  
South America - 1,562

**Top Five Scientific Disciplines**

Math & Physics - 4,000 records  
Health Professionals - 3,589  
Social Sciences - 2,431  
Aeronautical, Chemical, Mechanical & Civil Engineering - 2,206  
Humanities - 1,562

Input your search query here.

Q	W	E	R	T	Y	U	I	O	P
A	S	D	F	G	H	J	K	L	"
Z	X	C	V	B	N	M			
Space									Go

**Search**

The keyboard supports retrieval and display of papers based on their Medical Subject Headings (MeSH) and MeSH qualifier terms. If multiple terms are entered in a field, they are automatically combined using "OR". So, "breast cancer" matches any record with "breast" or "cancer" in that field. You can put AND between terms to combine with "AND". Thus "breast AND cancer" would only match records that contain both terms. Double quotation can be used to match compound terms, e.g., "breast cancer" retrieves records with the phrase "breast cancer", and not records where "breast" and "cancer" are both present, but the exact phrase.

<http://scimaps.org>

People & Topics

### Geographic Map: Where Science Gets Done

### Science Map: How Scientific Disciplines Relate

**About**

This Illuminated Diagram display adds the flexibility of an interactive program to the incredibly high data density of a print. This technique is generally useful when there is too much pertinent data to be displayed on a screen but the data is relatively stable. The computer can direct the eye to what's important by using projectors or screens as smart spotlights, animating the research impact of individuals, giving a "grand tour" of science, or highlighting query results (as when you touch the lectern or use the keyboard) with an overlay of moving light.

**Elinor Ostrom - Nobel Prize in Economic Sciences 2009**

**Born:** 7 August 1933, New York, NY, USA

**Affiliation at the time of the award:** Indiana University, Bloomington, IN, USA, Arizona State University, Tempe, AZ, USA

**Prize motivation:** "for her analysis of economic governance, especially the commons"

**Field:** Economic governance

**Contribution:** Challenged the conventional wisdom by demonstrating how local property can be successfully managed by local commons without any regulation by central authorities or privatization.

Cancer	Cloning	HIV	Robert G. Edwards	Roger D. Kornberg	Elinor Ostrom
Obesity	Quality of Life	Smoking	Stanley B. Prusiner	Ahmed H. Zewail	View All

**Keyword Search**



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Hidalgo, César A., Bailey Klinger, Albert-László Barabási, and Ricardo Hausmann. 2007. See also *The Product Space* map from Phase I of *Places & Spaces*.

## Call for Macroscopic Tools for the *Places & Spaces: Mapping Science* Exhibit (2016) <http://scimaps.org/call>

### Background and Goals

The *Places & Spaces: Mapping Science* exhibit was created to in communicate human activity and scientific progress on a glog that enable the close inspection of large-scale maps in public conferences; (2) novel, interactive macroscopic tools that let

Themes for the upcoming iterations/years are:

- 11th Iteration (2015): Macroscopes for Interacting With Science
- 12th Iteration (2016): Macroscopes for Making Sense of Science
- 13th Iteration (2017): Macroscopes for Forecasting Science
- 14th Iteration (2018): Macroscopes for Economic Decision Makers
- 15th Iteration (2019): Macroscopes for Science Policy Makers



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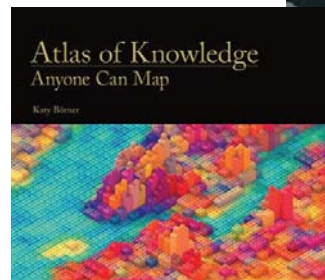
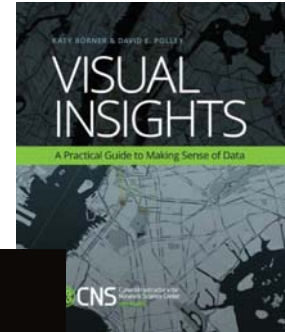
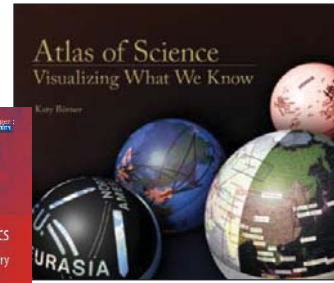
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All papers, maps, tools, talks, press are linked from <http://cns.iu.edu>

These slides are at <http://cns.iu.edu/docs/presentations>

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Mapping Science Exhibit Facebook: <http://www.facebook.com/mappingscience>

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