From Judgment to Impact: Combining Human and Machine Perception & Intelligence to Invent and Implement Desirable Futures

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SFI Colloquium on "From Judgement to Impact"
Santa Fe Institute, Santa Fe, New Mexico

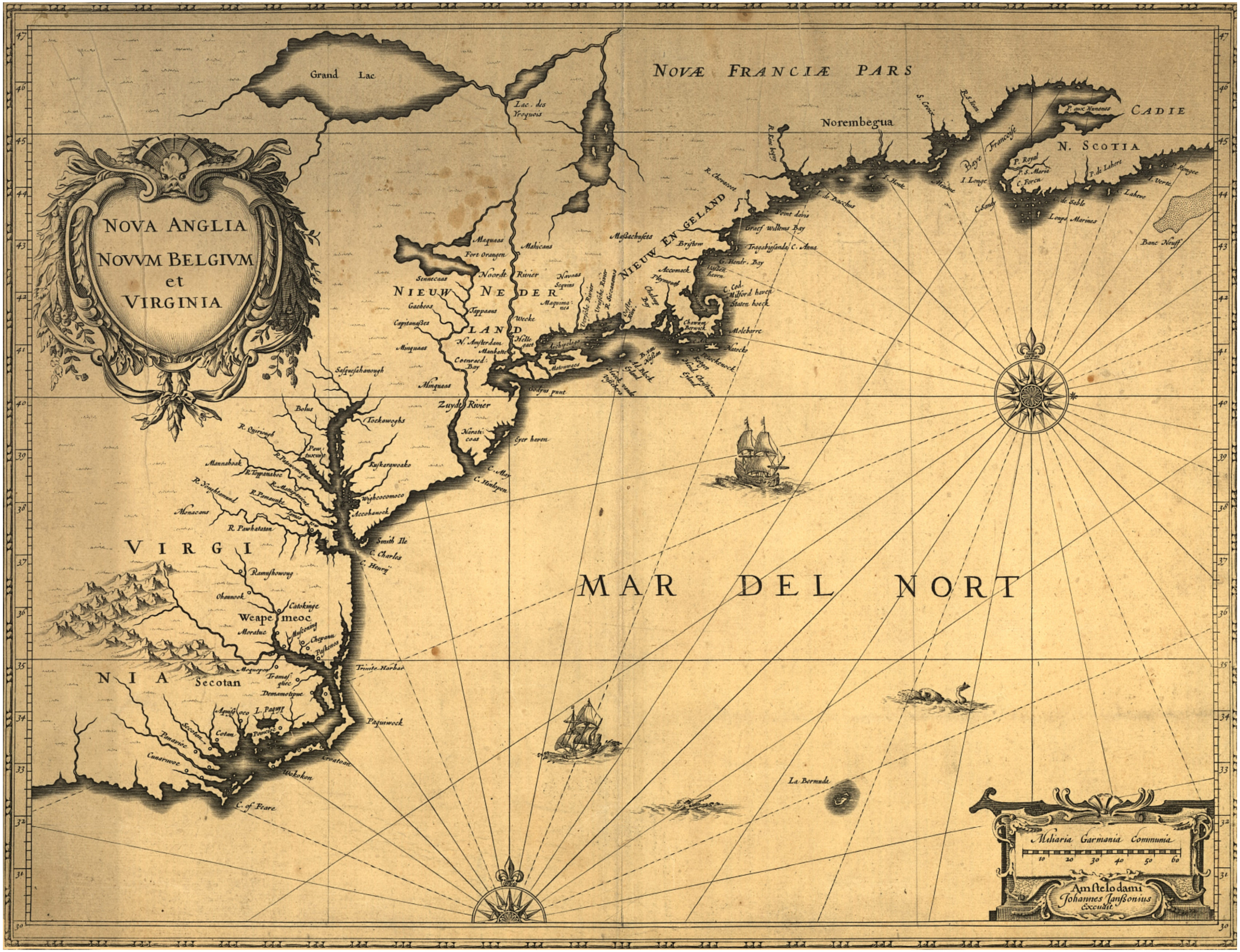
April 3, 2018

From Judgment to Impact:
Combining Human and Machine Perception & Intelligence to Invent and Implement Desirable Futures

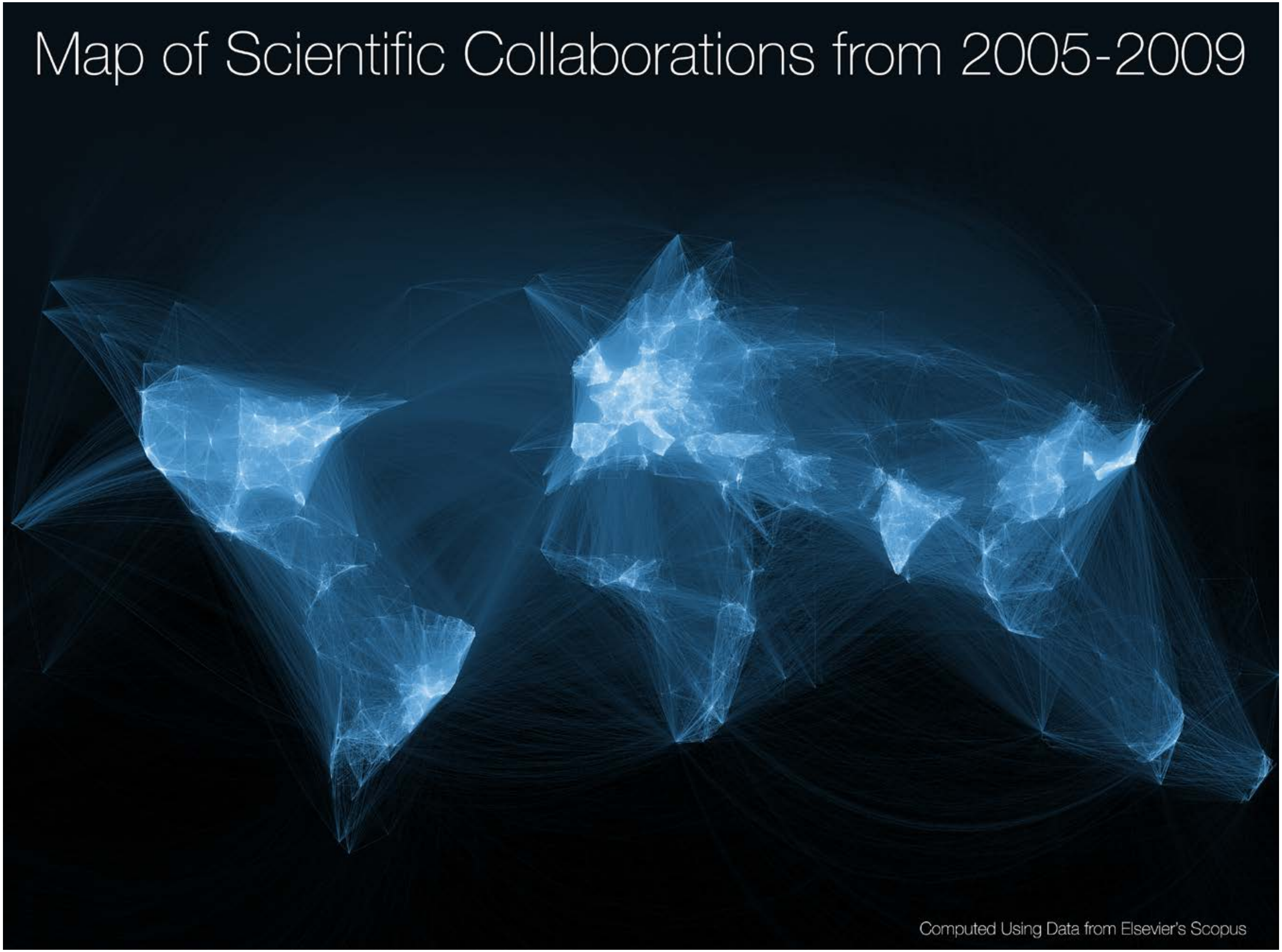
Four Options:

- Maps and Macroscopes
- Data Visualization Literacy
- Models and Maps of STI
- Embracing Human and Machine Intelligence Synergies

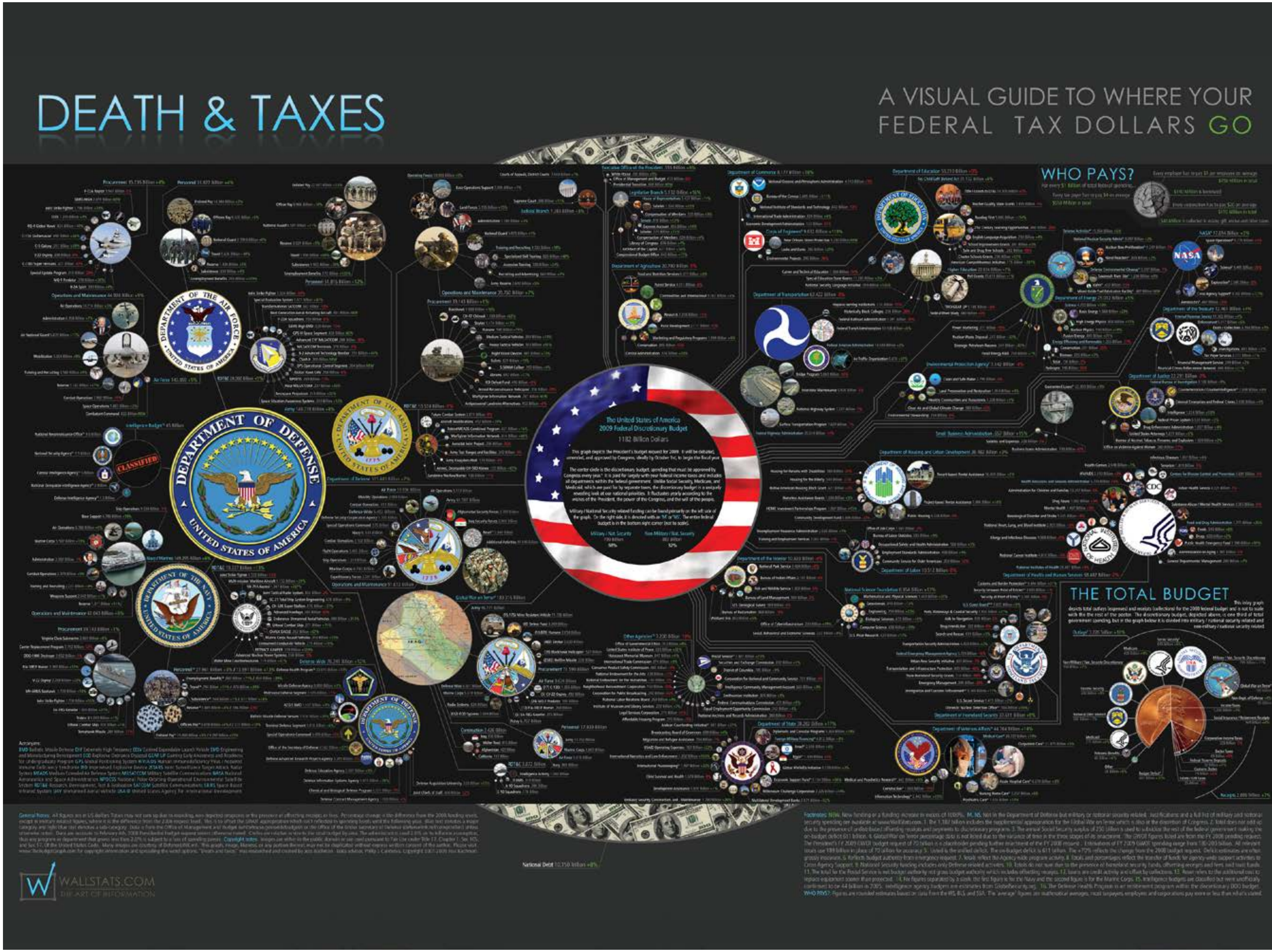
I.3 *A New Map of the Whole World with Trade Winds According to the Latest and Most Exact Observations* - Herman Moll - 1736



I.2 *Nova Anglia, Novvm Belgivm et Virginia* – Johannes Janssonius - 1642



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



V.5 *Death and Taxes 2009* - Jess Bachman - 2009

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.

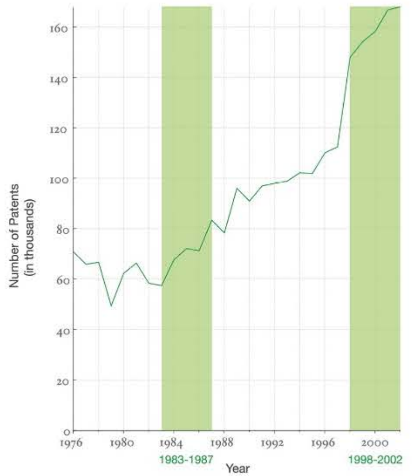
The Structure and Evolution of the Patent Space

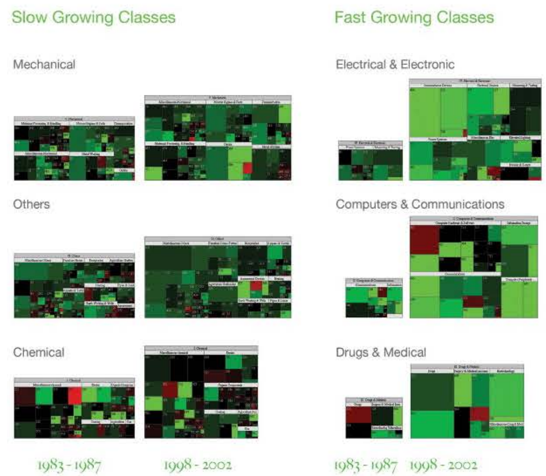
The United States Patent and Trademark Office assigns each patent to one of more than 450 classes covering broad application domains. For example, class 514 encompasses all patents dealing with 'Drug, Bio-Affecting and Body Treating Compositions.' Classes are further broken down by subclasses that have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





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

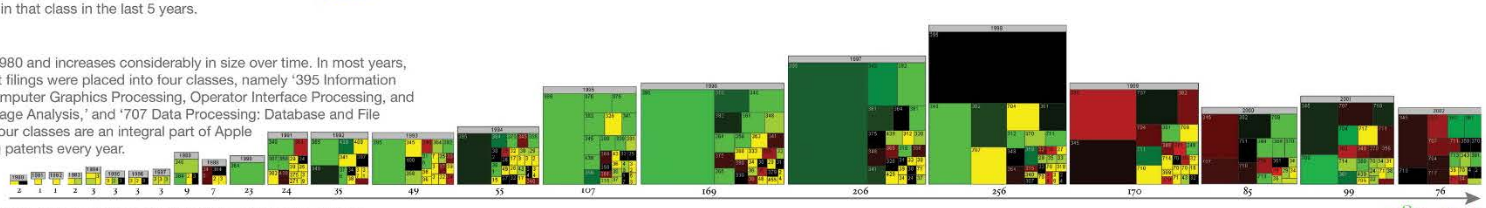
1998 - 2002

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.

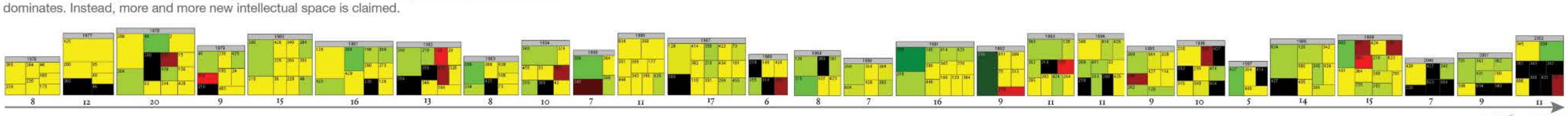
Apple Computer, Inc.

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.

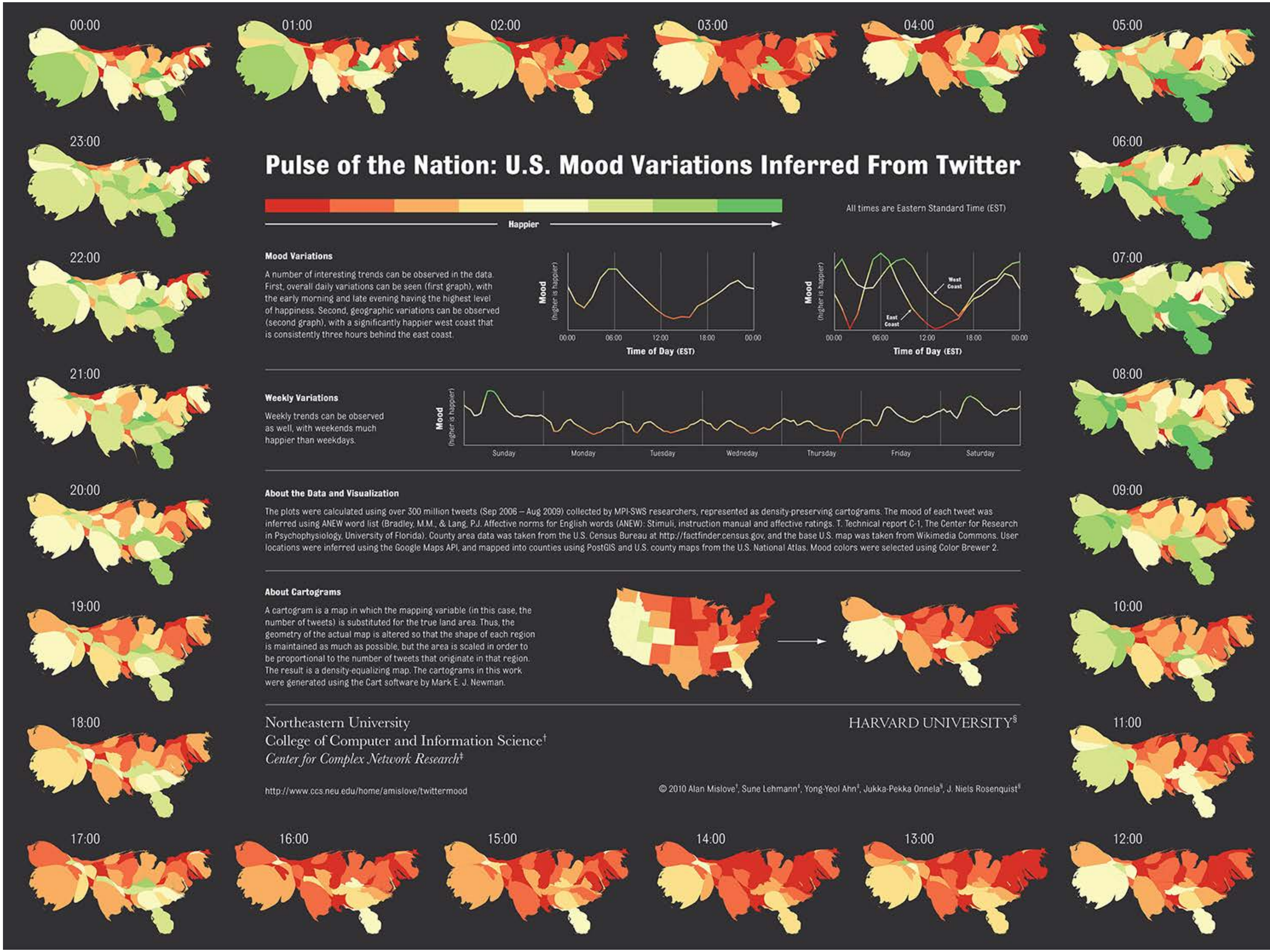


Jerome Lemelson

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.



IV.5 *Examining the Evolution & Distribution of Patent Classifications* - Daniel O. Kutz, Katy Borner, and Elisha F. Hardy - 2004



IX.4 *Pulse of the Nation* - Alan Mislove, Sune Lehmann, Yong-Yeol Ahn, Jukka-Pekka Onnela, and James Niels Rosenquist - 2010

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.

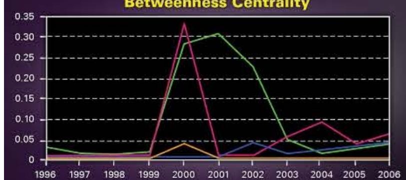
The frames to the right show the evolving journal citation network for the years 1998-2003. Distances are proportional to cosine values between the citation patterns of the respective journals. Textual descriptions of key events during the development of *Nanotechnology* are given below each frame. Most 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.

Betweenness Centrality

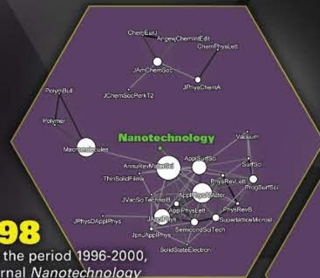


An animated sequence of this evolution is at: http://www.leydesdorff.net/journals/nanotech.

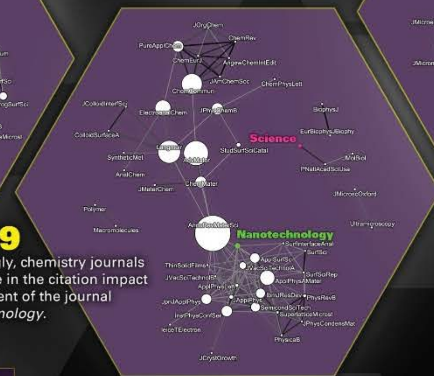
References

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.

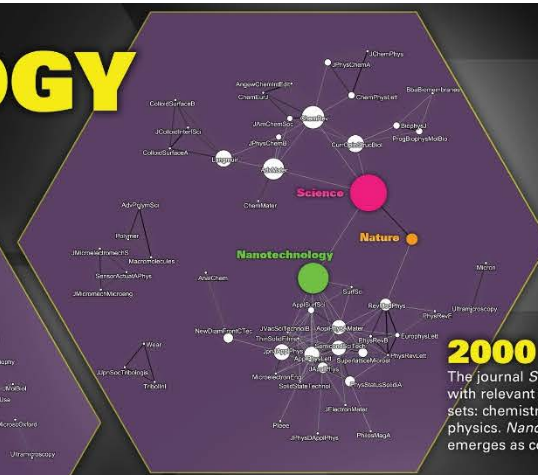
Price, Derek J. de Solla (1965). Networks of scientific papers. *Science*, 149, no. 3683, 510- 515.



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*.

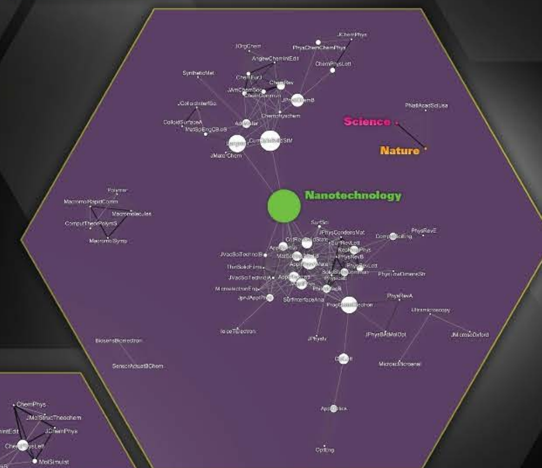


2000
The journal *Science* interfaces with relevant journals in both sets: chemistry and applied physics. *Nanotechnology* emerges as core journal.

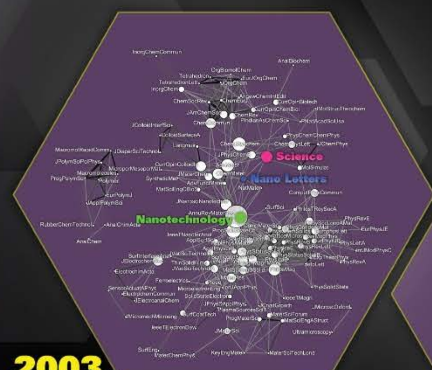
LEGEND

- *Science*
- *Nature*
- *Nanotechnology*
- *Nano Letters*

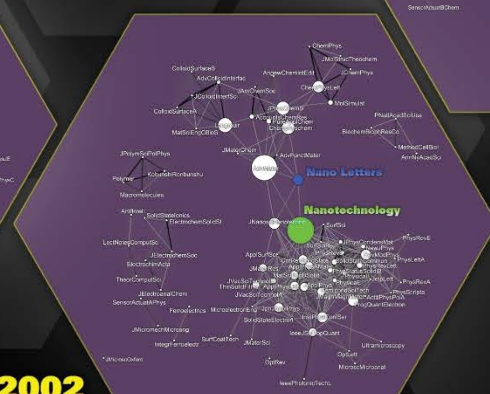
Values: 0.8, 0.22, 0.33



2001
The journal *Nanotechnology* now provides the interface between chemistry and physics. The "intervention" by *Science* is no longer needed.



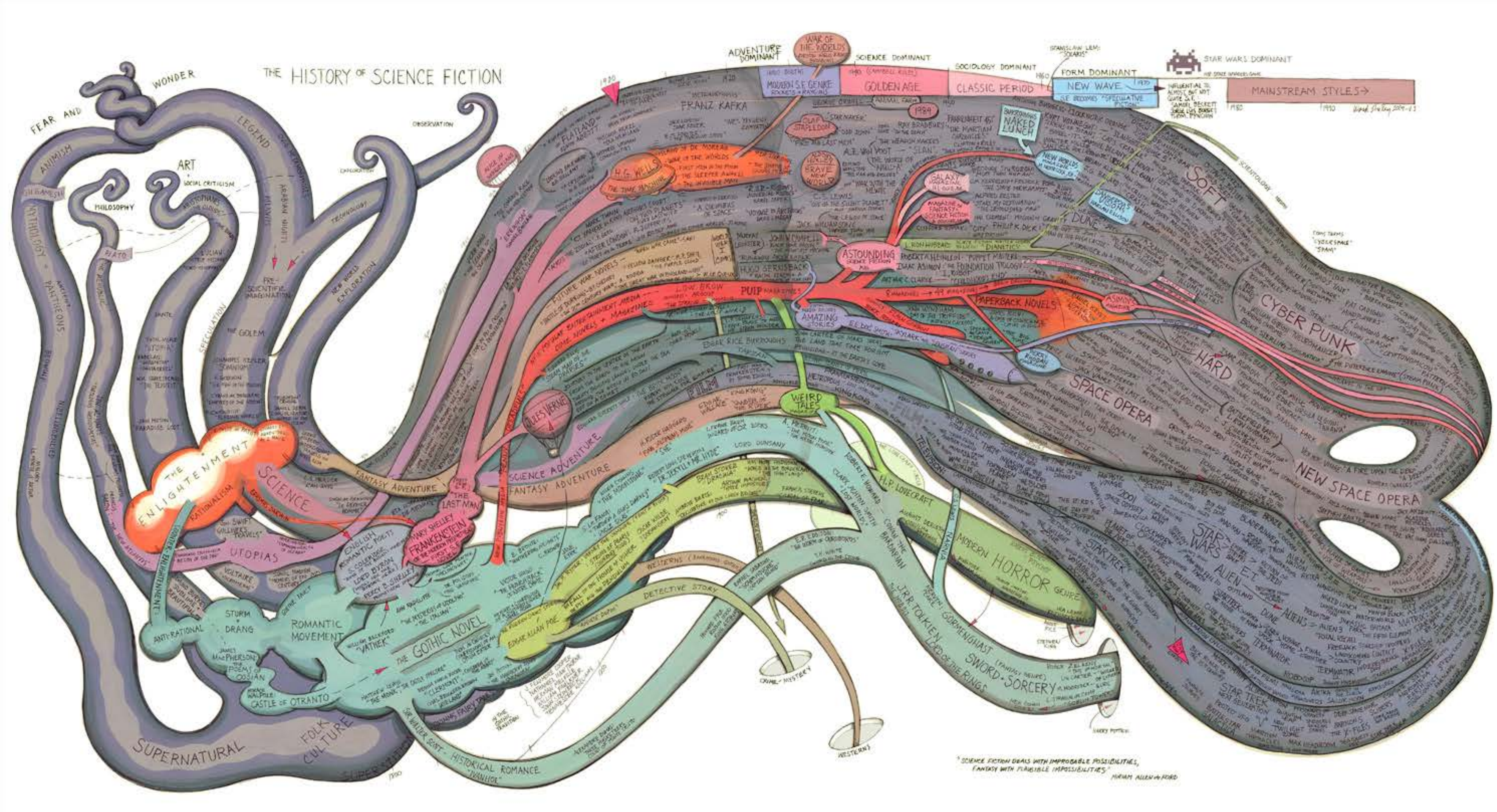
2003
The journal *Science* is relevant in the citation impact environment, but now functions as one of the specialist journals in nanotechnology. *Nanoscience* further develops as an increasingly integrated network of journals.



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.

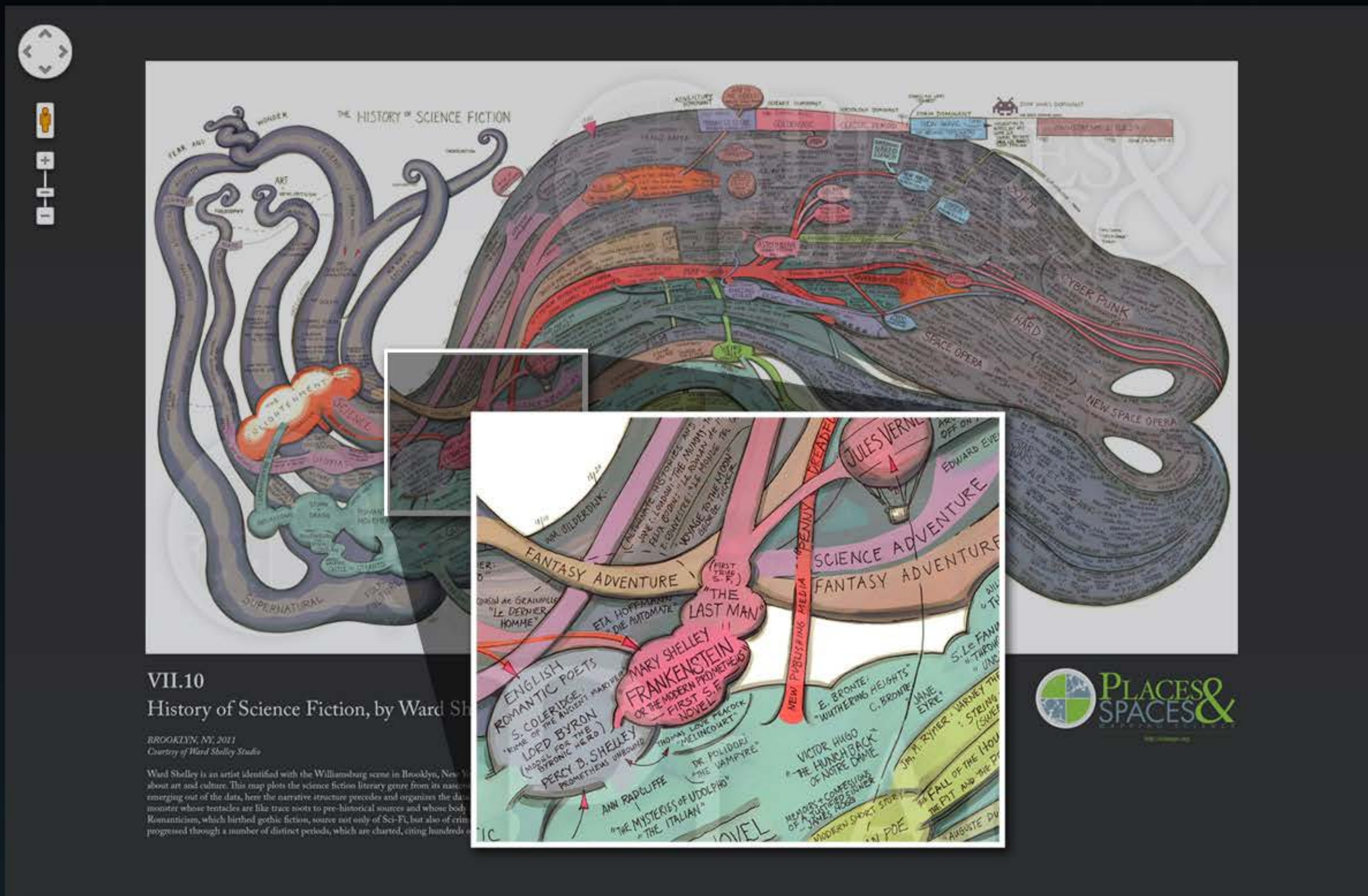
Design by Michael J. Stamper and Katy Börner
Cyberinfrastructure for Network Science Center | Indiana University
cns.iu.edu

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

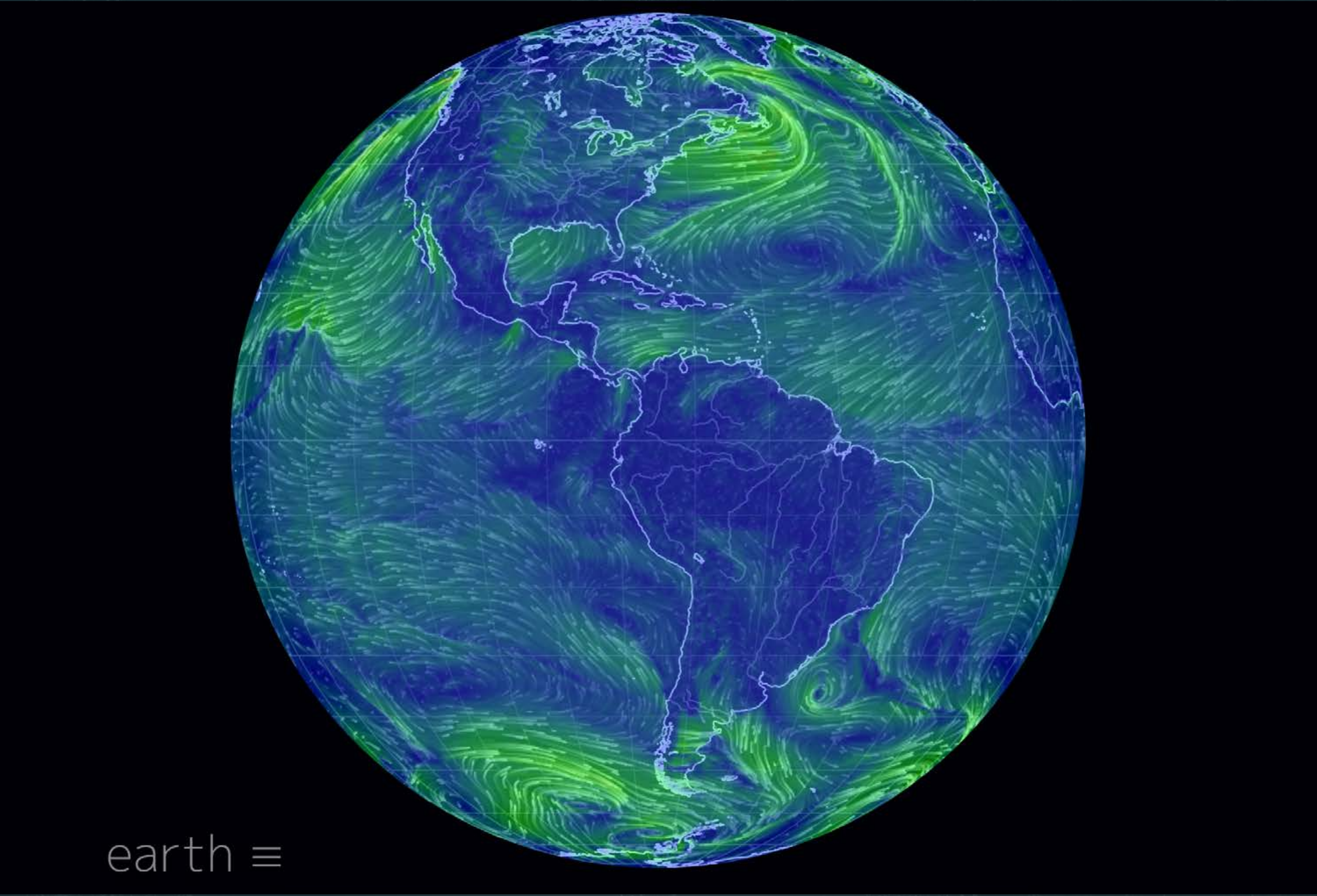


VII.10 *History of Science Fiction* - Ward Shelley - 2011

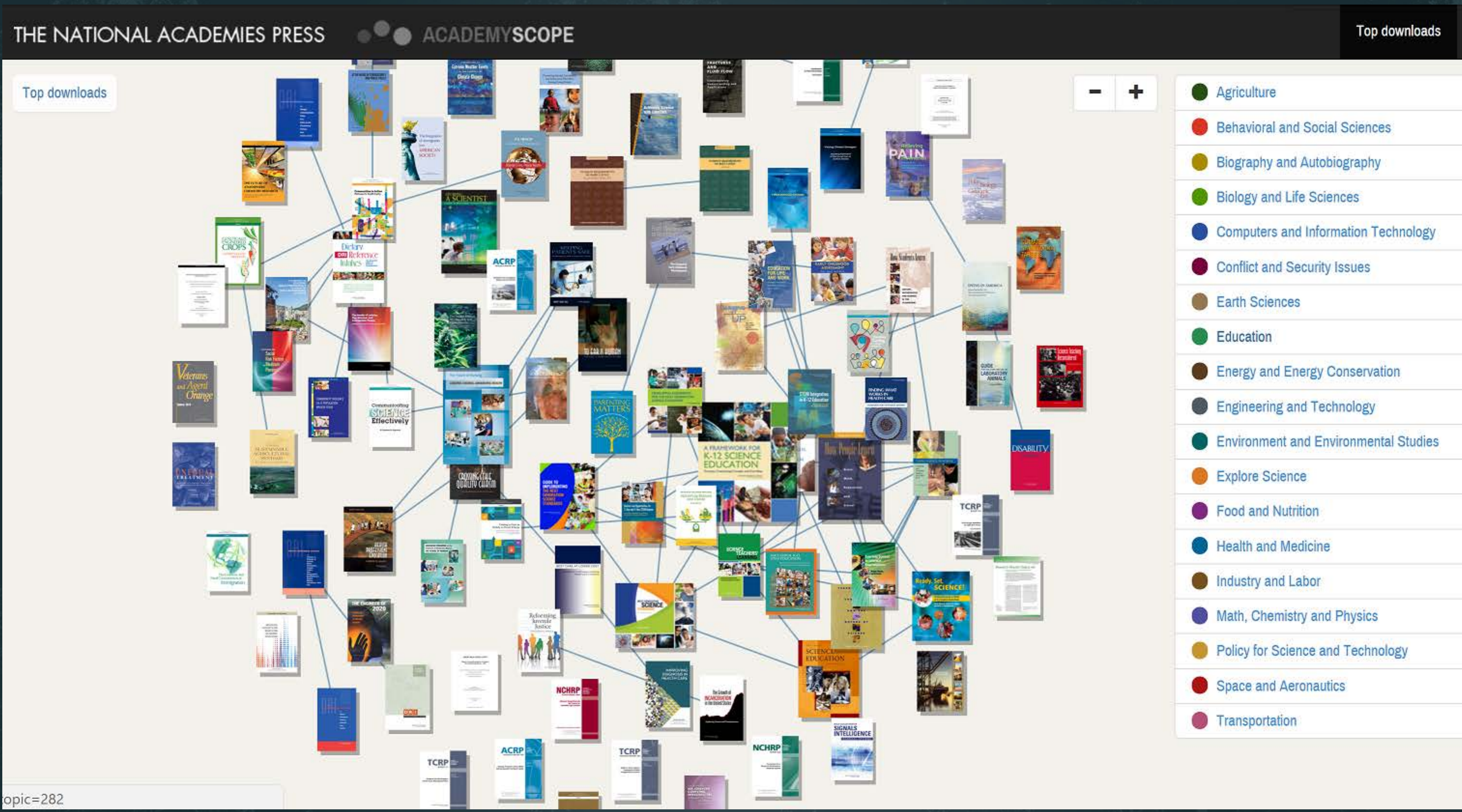
Check out our Zoom Maps online!



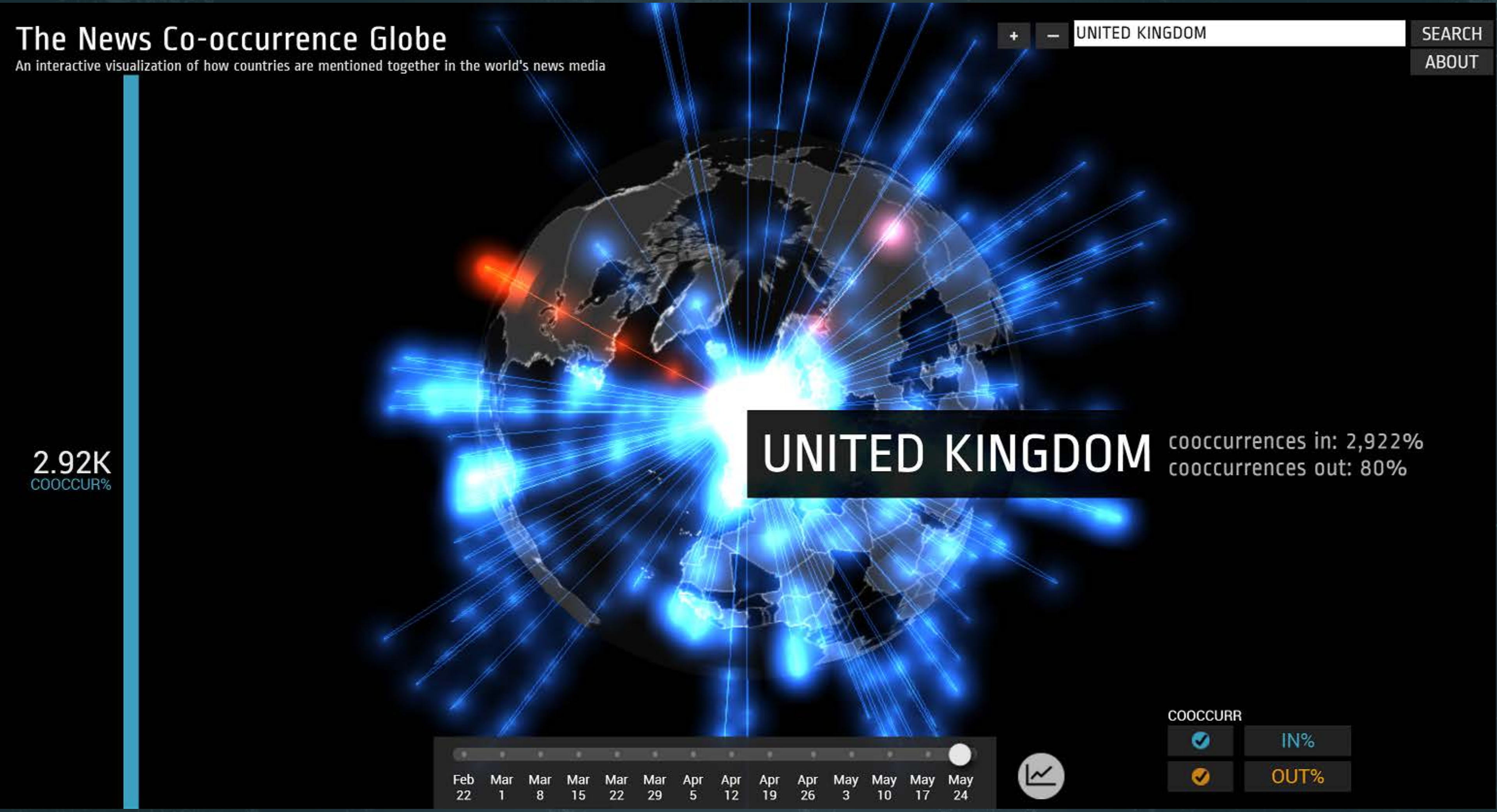
Visit scimaps.org and check out all our maps in stunning detail!



Earth – Cameron Beccario

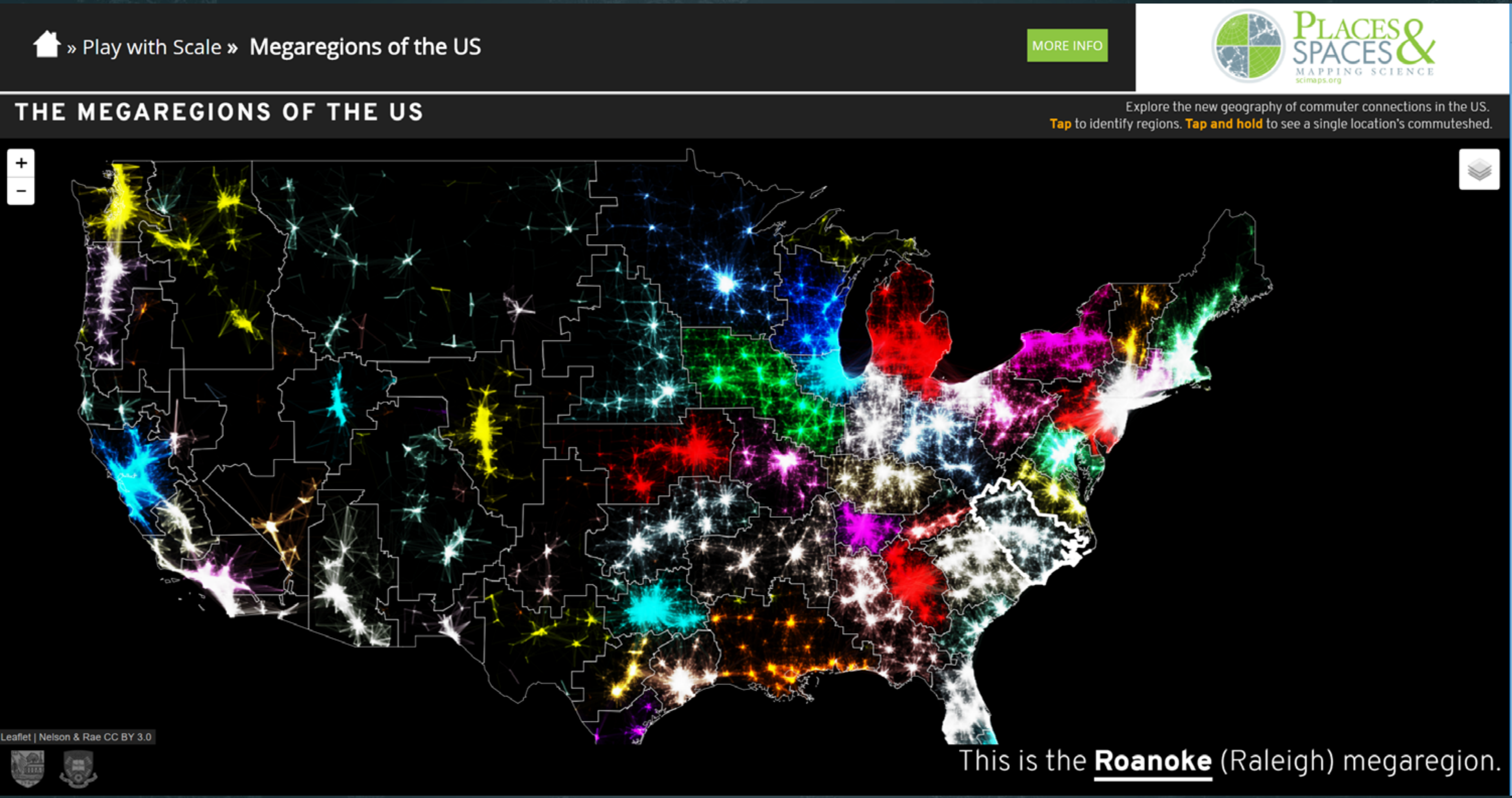


AcademyScope – National Academy of the Sciences & CNS



Mapping Global Society –Kalev Leetaru

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



Megaregions of the US –Garrett Dash Nelson and Alasdair Rae – 2016

Maps of Science & Technology

http://scimaps.org

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

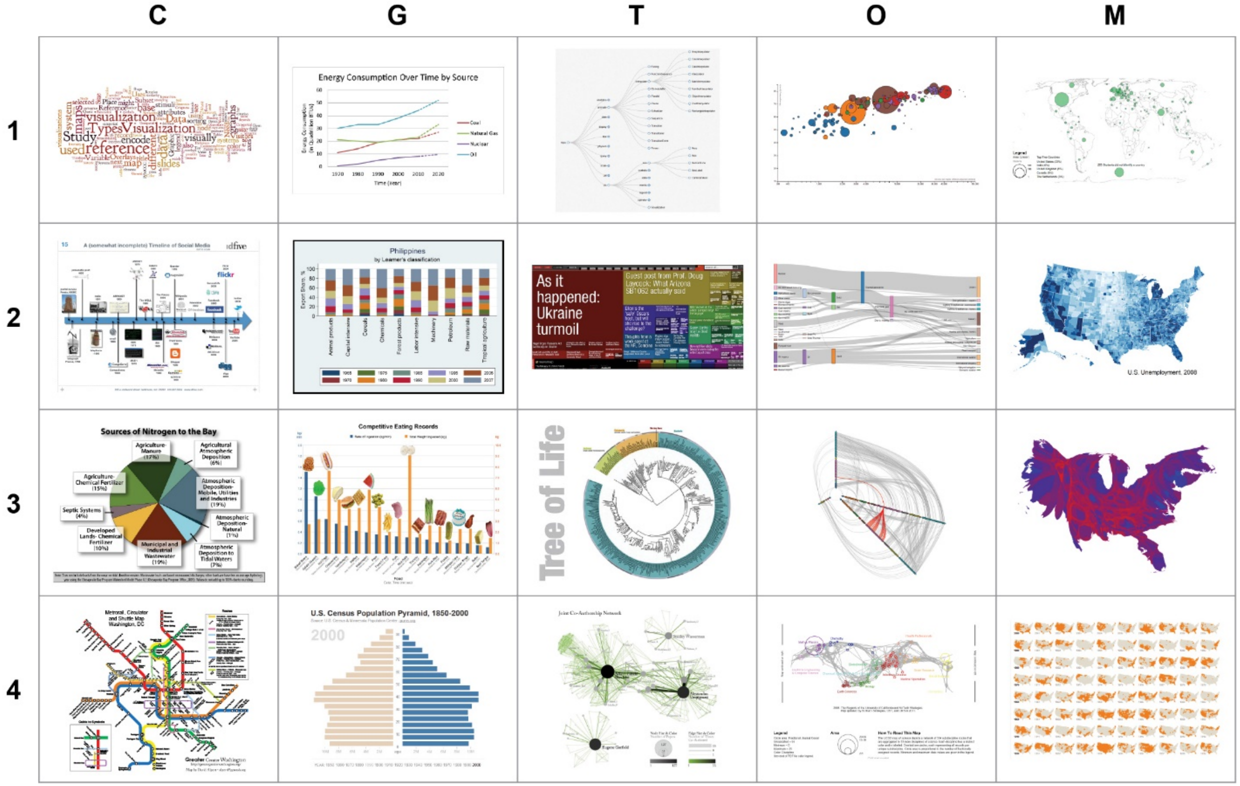
The David J. Sencer CDC Museum, Atlanta, GA.
January 25 - June 17, 2016.

100 maps and 12 macroscopes by 215 experts on display at 354 venues in 28 countries.

Data Visualization Literacy:
Research and Tools that Advance Public Understanding of Scientific Data

Problem: Data Visualization Literacy is Low

Most science museum visitors in the US cannot name, read, or interpret common data visualizations.



Börner, Katy, Joe E. Heimlich, Russell Balliet, and Adam V. Maltese. 2015. Investigating aspects of data visualization literacy using 20 information visualizations and 273 science museum visitors. *Information Visualization 1-16.* [*http://cns.iu.edu/docs/publications/2015-borner-investigating.pdf*](http://cns.iu.edu/docs/publications/2015-borner-investigating.pdf)

Data Visualization Literacy

Data visualization literacy (ability to read, make, and explain data visualizations) requires

- *literacy* (ability to read and write text, e.g., in titles, axis labels, legend),
- *visual literacy* (ability to find, interpret, evaluate, use, and create images and visual media), and
- *data literacy* (ability to read, create, and communicate data).

Being able to "read and write" data visualizations is becoming as important as being able to read and write text. Understanding, measuring, and improving data and visualization literacy is important for understanding STEAM developments and to strategically approach global issues.

How to Classify (Name & Make) Different Visualizations?

By

- User insight needs?
- User task types?

- Data to be visualized?
- Data transformation?

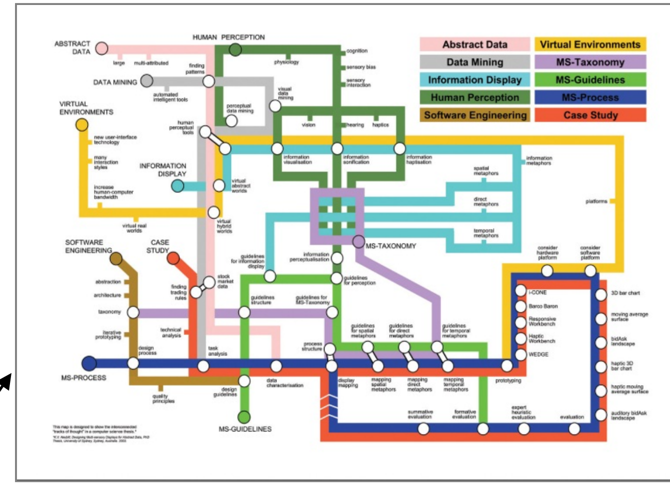
- Visualization technique?
- Visual mapping transformation?
- Interaction techniques?

- Or ?

Different Question Types

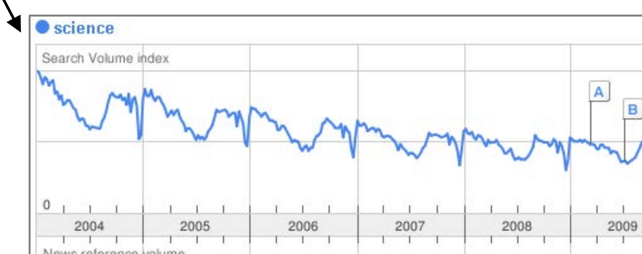
Terabytes of data

Descriptive & Predictive Models



Find your way

Find collaborators, friends

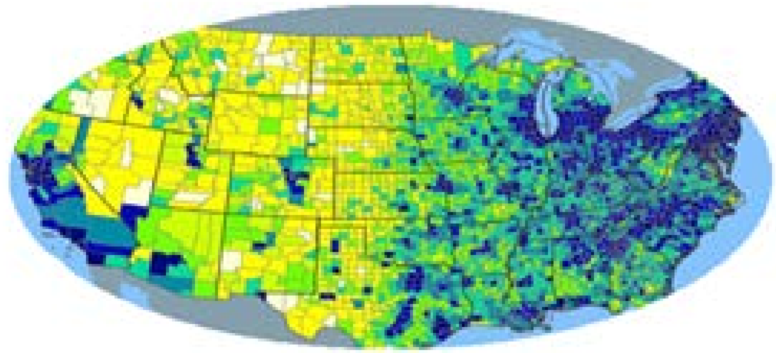


Identify trends

Different Levels of Abstraction/Analysis

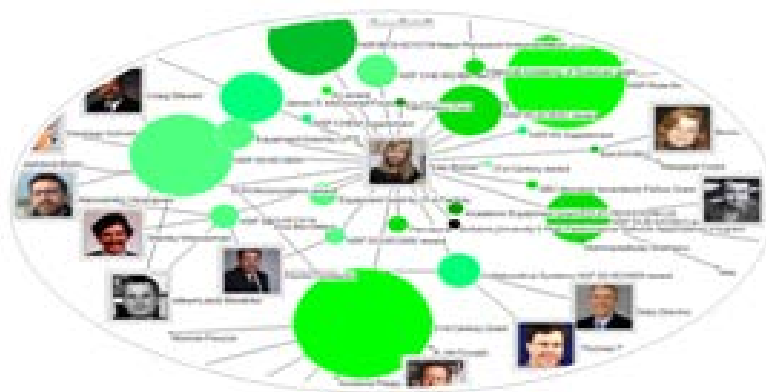
Macro/Global

Population Level



Meso/Local

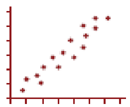
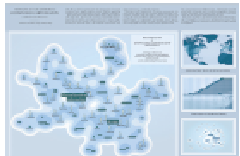
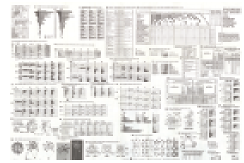
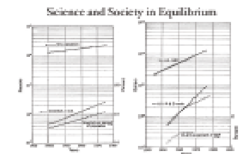
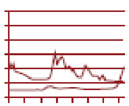
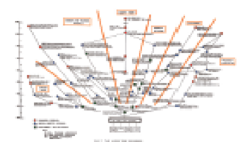
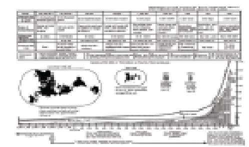
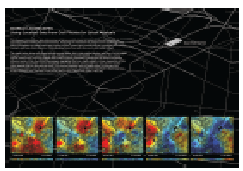
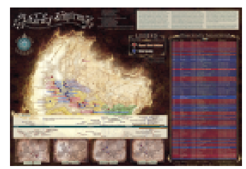
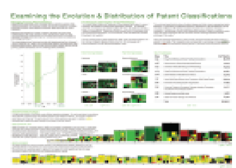
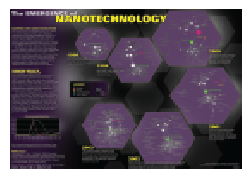
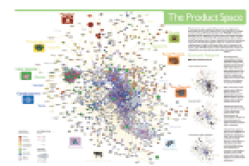
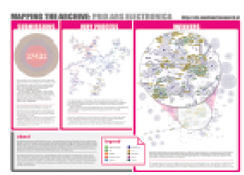
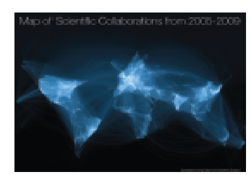
Group Level

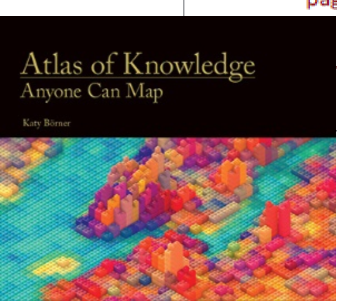


Micro

Individual Level

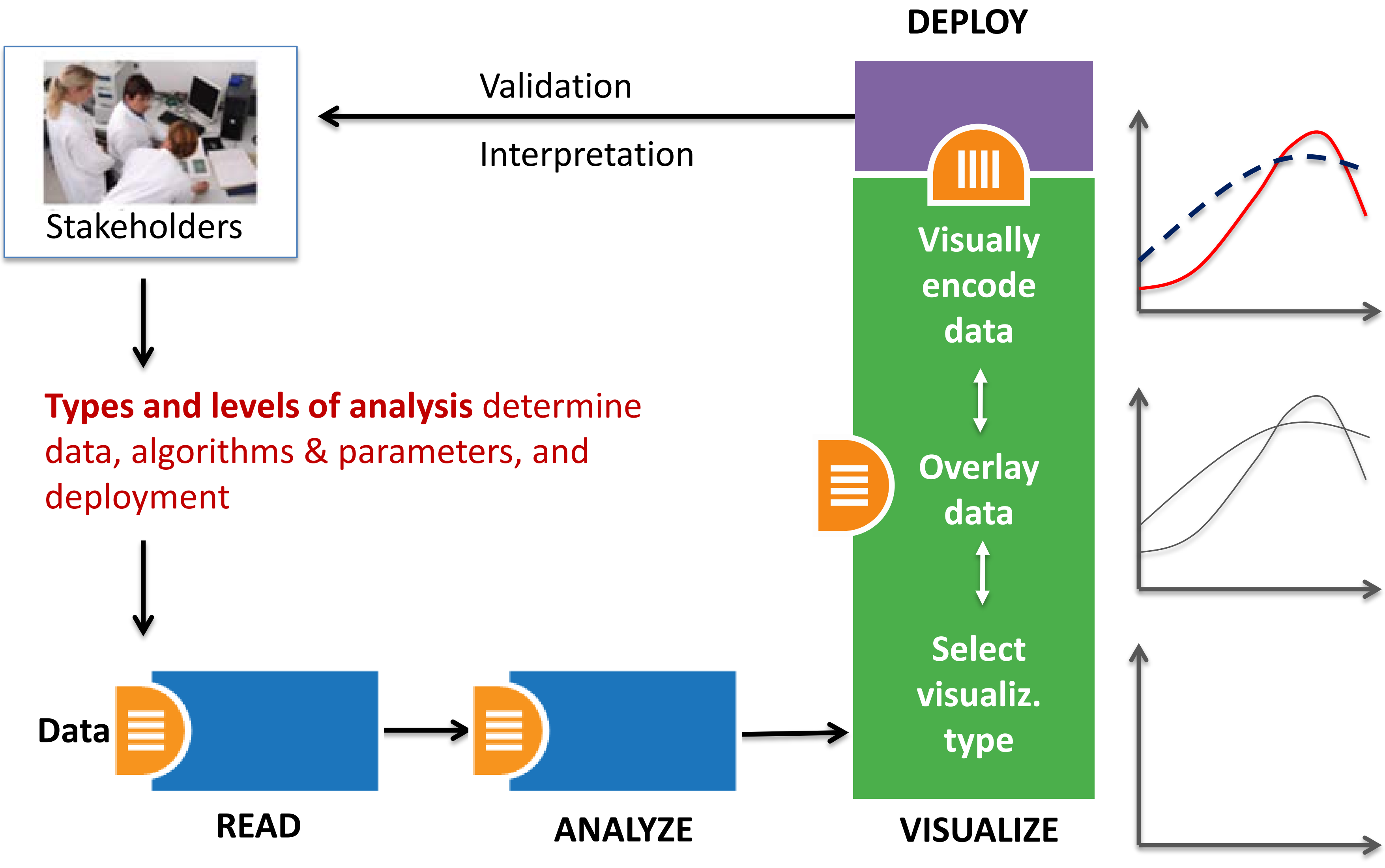
Tasks

TYPES \ 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 
Statistical Analysis 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
WHEN: Temporal Analysis 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
WHERE: Geospatial Analysis page 52 	 Cell phone usage in Milan, Italy page 109	 Victorian poetry in Europe page 137	 Ecological footprint of countries page 99
WHAT: Topical Analysis 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
WITH WHOM: Network Analysis page 60 	 World Finance Corporation network page 87	 Electronic and new media art networks page 133	 World-wide scholarly collaboration networks page 157

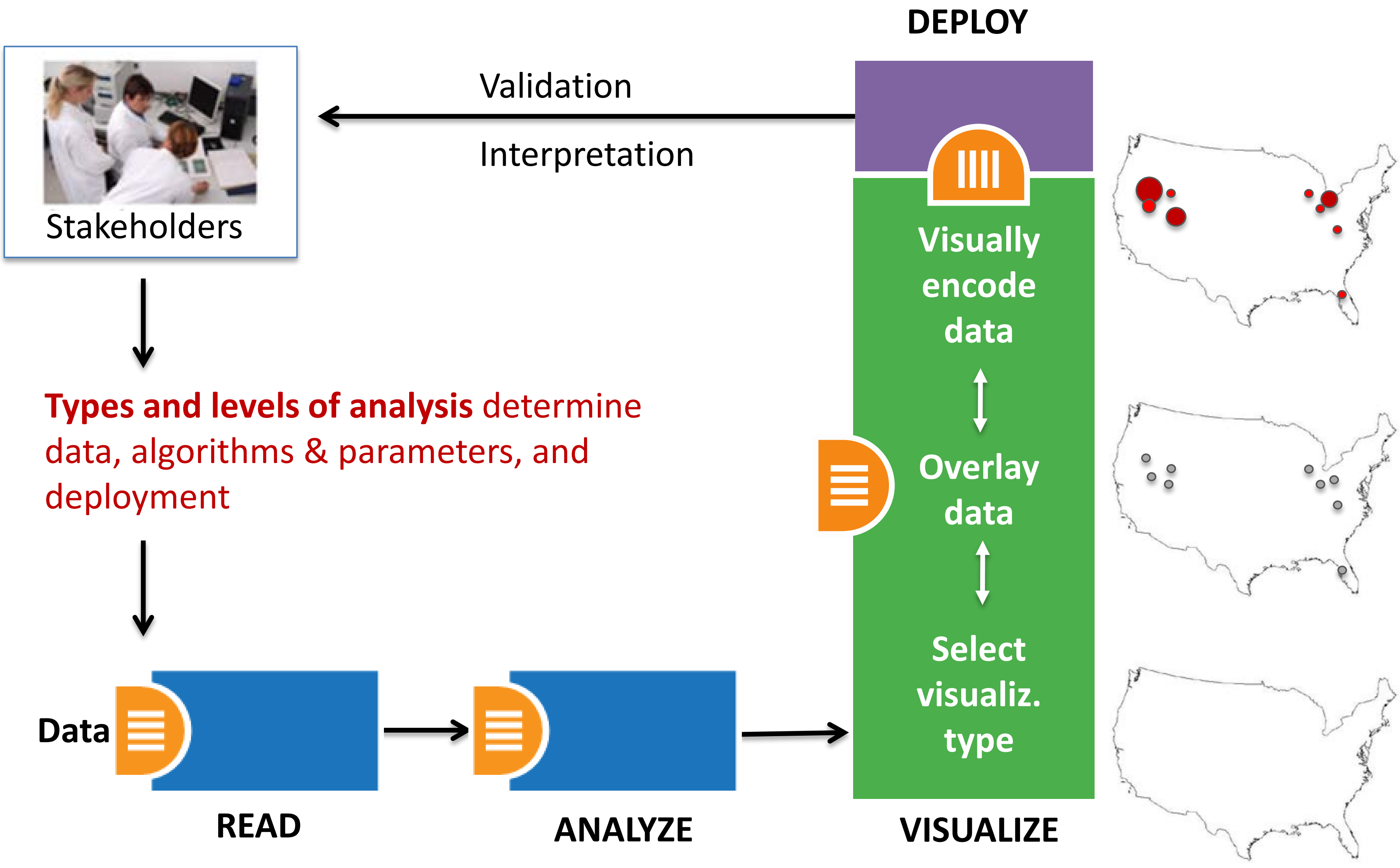


See *Atlas of Science: Anyone Can Map*, page 5

Needs-Driven Workflow Design

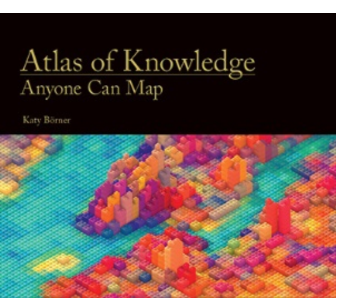


Needs-Driven Workflow Design



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
• categorize/cluster • order/rank/sort • distributions (also outliers, gaps) • comparisons • trends (process and time) • geospatial • compositions (also of text) • correlations/relationships	• nominal • ordinal • interval • ratio	• table • chart • graph • map • network layout	• geometric symbols point line area surface volume • linguistic symbols text numerals punctuation marks • pictorial symbols images icons statistical glyphs	• spatial position • retinal form color optics motion	• overview • zoom • search and locate • filter • details-on-demand • history • extract • link and brush • projection • distortion



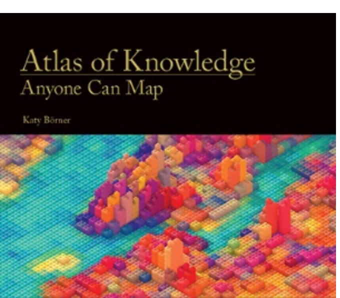
See *Atlas of Science: Anyone Can Map*, page 24

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

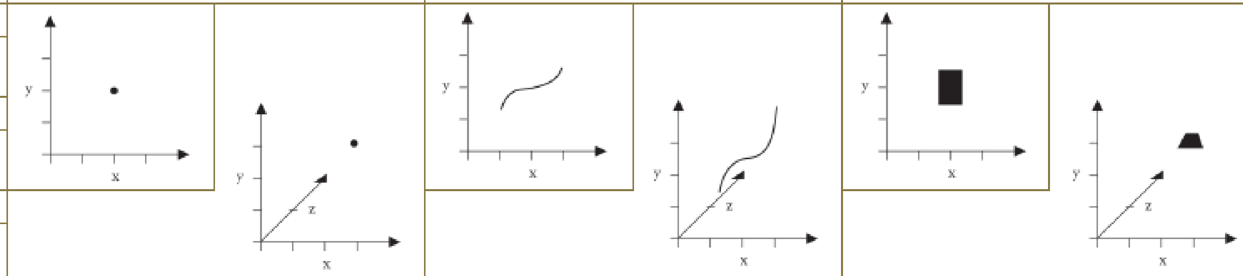
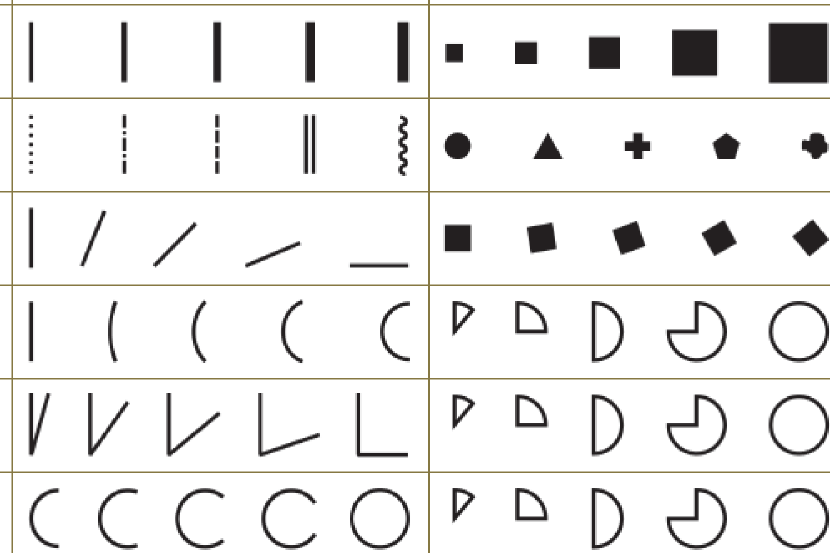
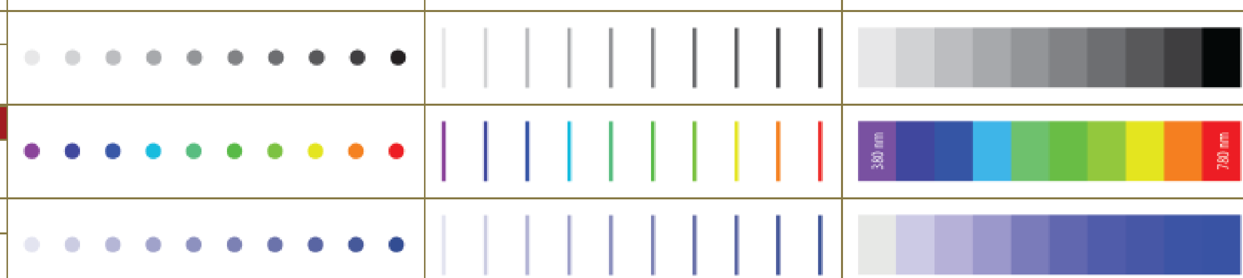
Visualization Framework

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
• categorize/cluster	• nominal	• table	• geometric symbols	• spatial	• overview
• order/rank/sort	• ordinal	• chart	point	position	• zoom
• distributions	• interval	• graph	line	• retinal	• search and locate
(also outliers, gaps)	• ratio	• map	area	form	• filter
• comparisons		• network layout	surface	color	• details-on-demand
• trends			volume	optics	• history
(process and time)			• linguistic symbols	motion	• extract
• geospatial			text		• link and brush
• compositions			numerals		• projection
(also of text)			punctuation marks		• distortion
• correlations/relationships			• pictorial symbols		
			images		
			icons		
			statistical glyphs		

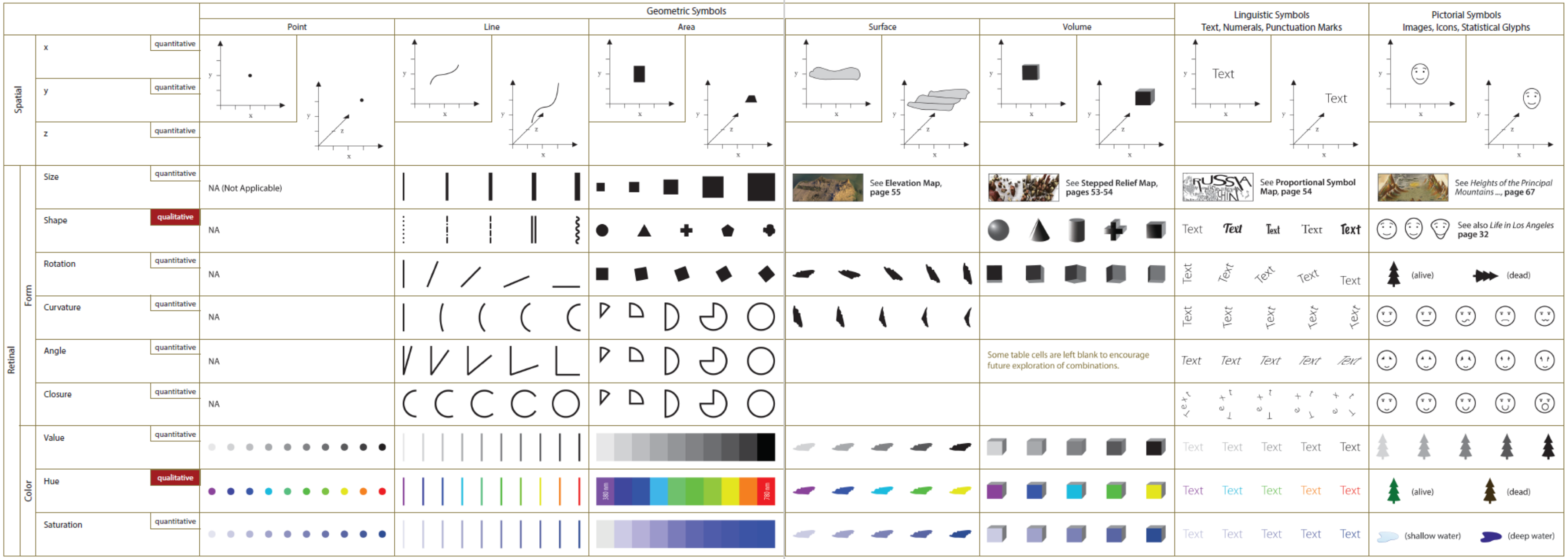


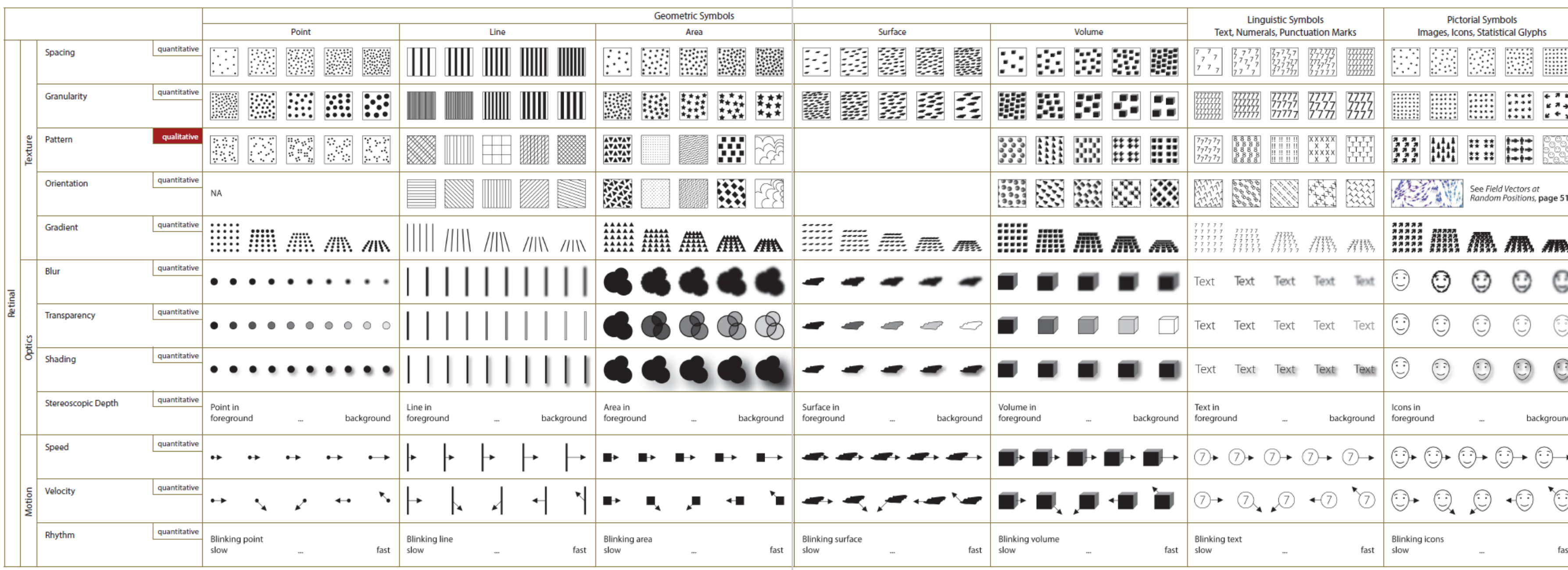
See *Atlas of Science: Anyone Can Map*, page 24

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





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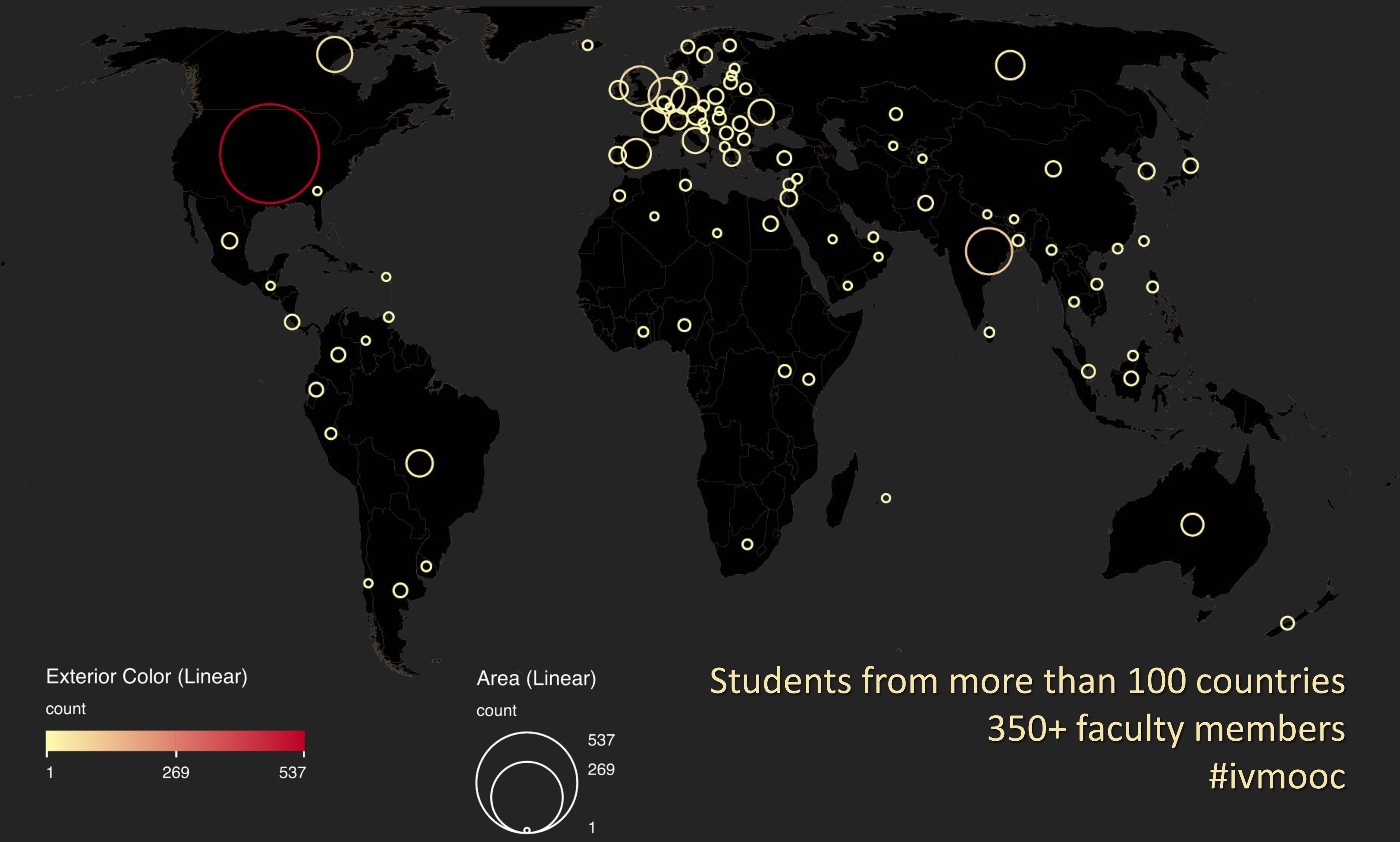

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Course Schedule

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

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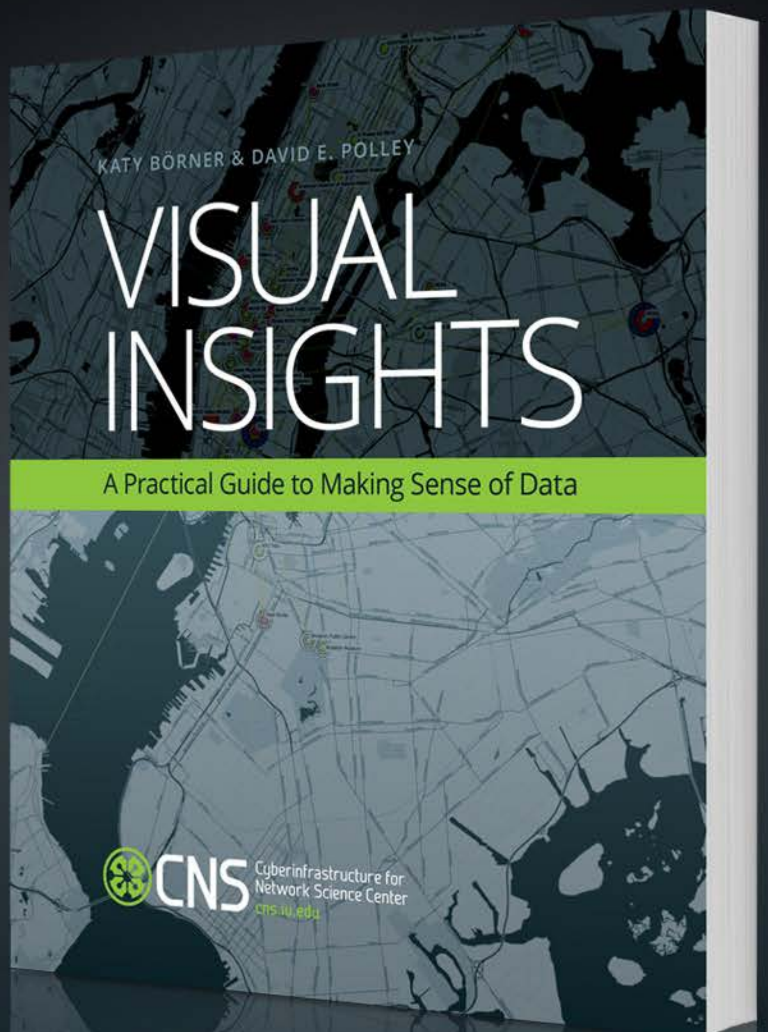
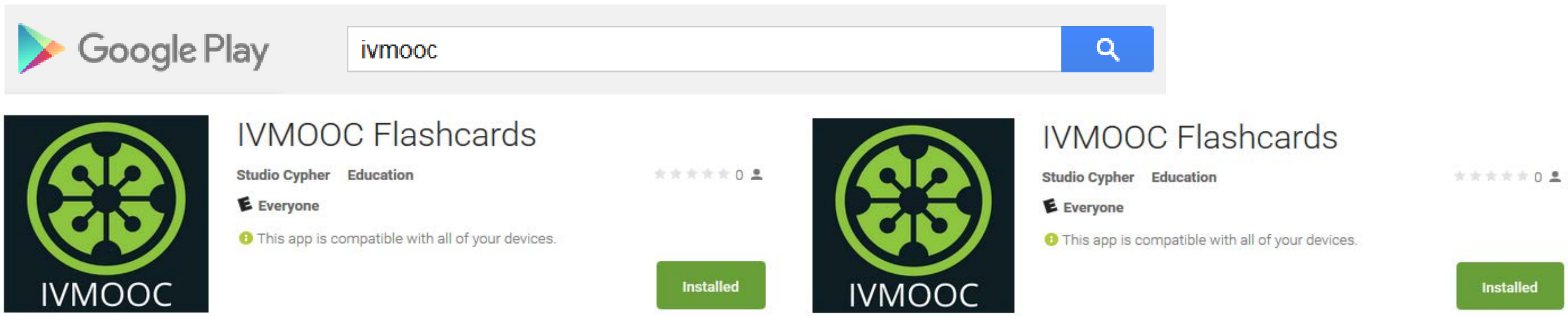
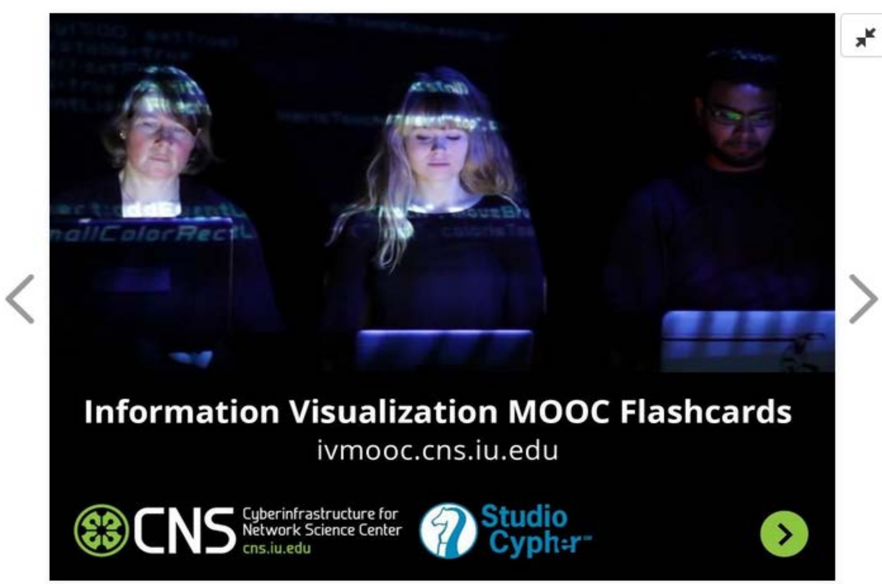


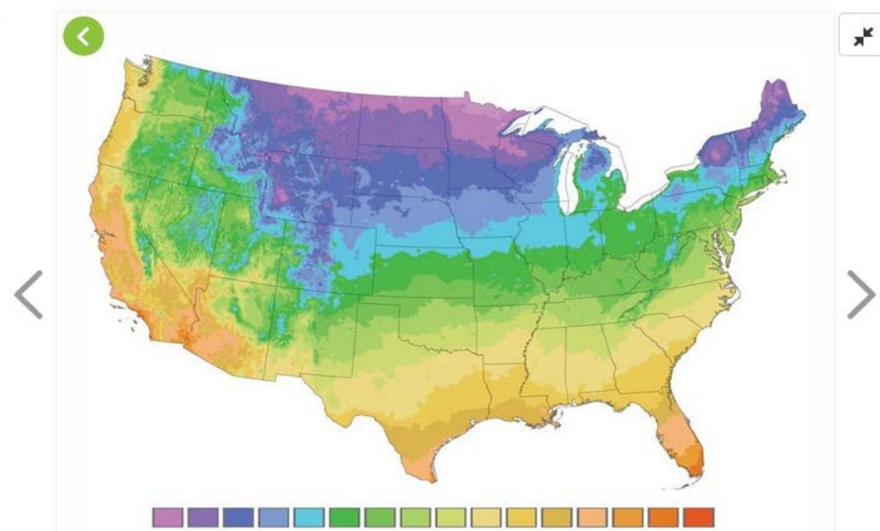
cns.iu.edu/ivmoocbook14.html

IVMOOC App

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







Sci2 Tool Interface Components Implement Vis Framework

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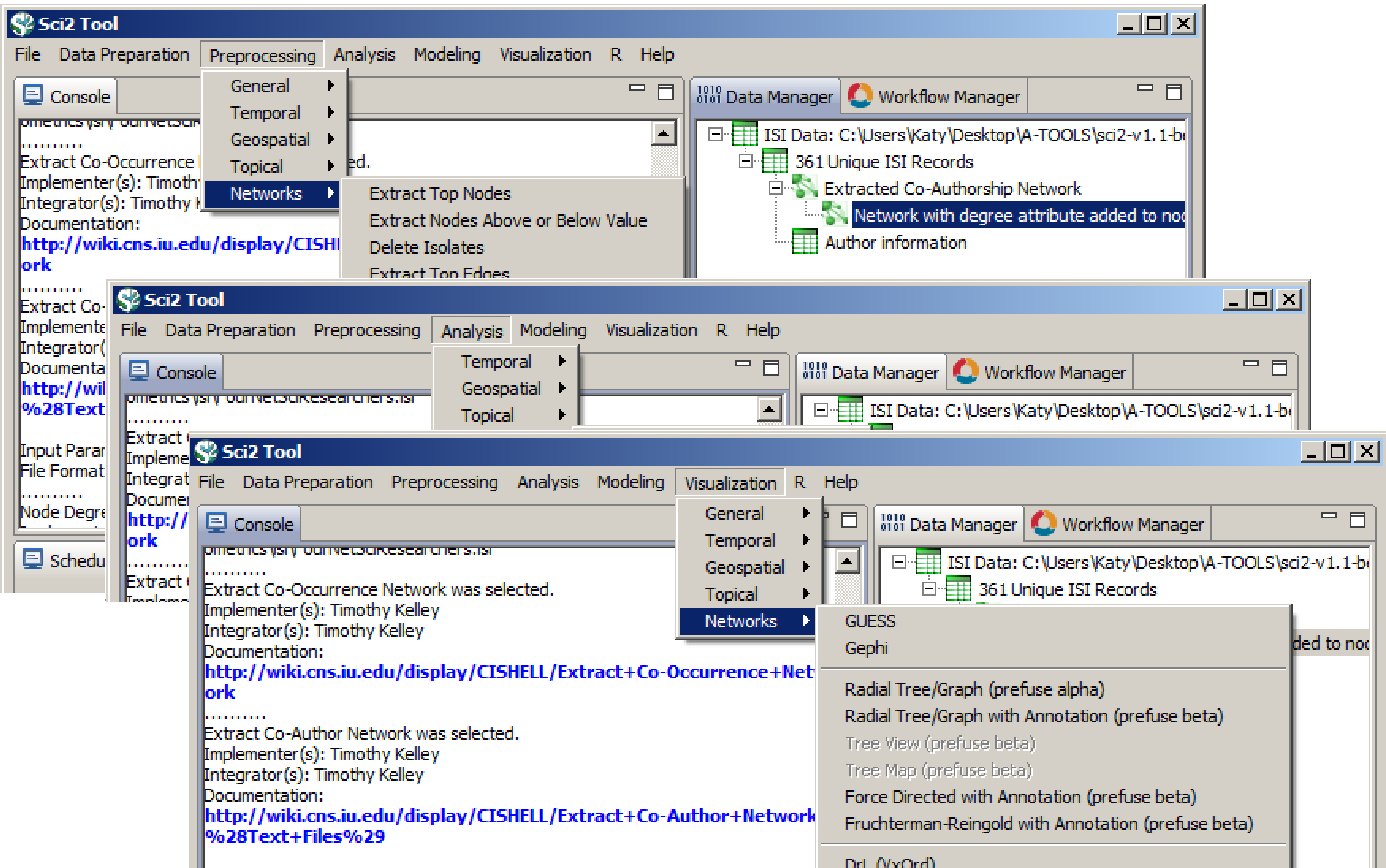


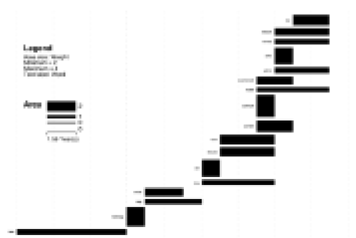
Load **One** File and Run **Many** Analyses and Visualizations

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, 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

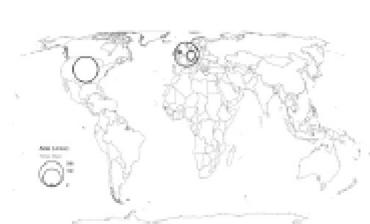
Statistical Analysis–p. 44

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

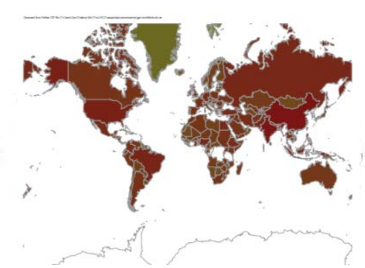
Temporal Burst Analysis–p. 48



Geospatial Analysis–p. 52



Geospatial Analysis–p. 52



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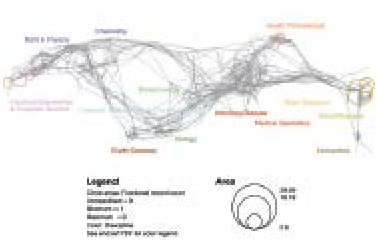
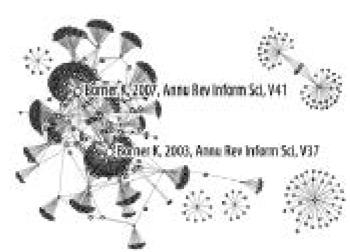
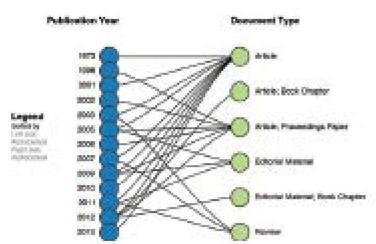
Topical Analysis—p. 56



Paper Citation Network—p. 60



Bi-Modal Network—p. 60



Co-author and
many other
bi-modal networks.

Model and Maps of Science:
Informing Data-Driven Decision Making

Models of Science, Technology, and Innovation

STI models use qualitative and quantitative data about scholars, papers, patents, grants, jobs, news, etc. to describe and predict the probable structure and/or dynamics of STI itself.

They are developed in economics, science policy, social science, scientometrics and bibliometrics, information science, physics, and other domains.

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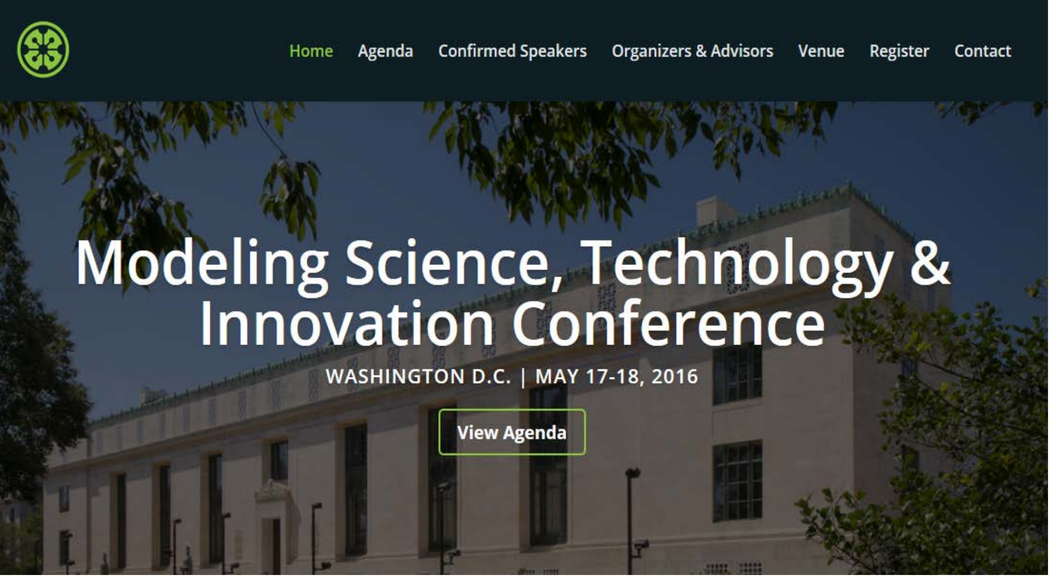

Government, academic, and industry leaders discussed challenges and opportunities associated with using big data, visual analytics, and computational models in STI decision-making.

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

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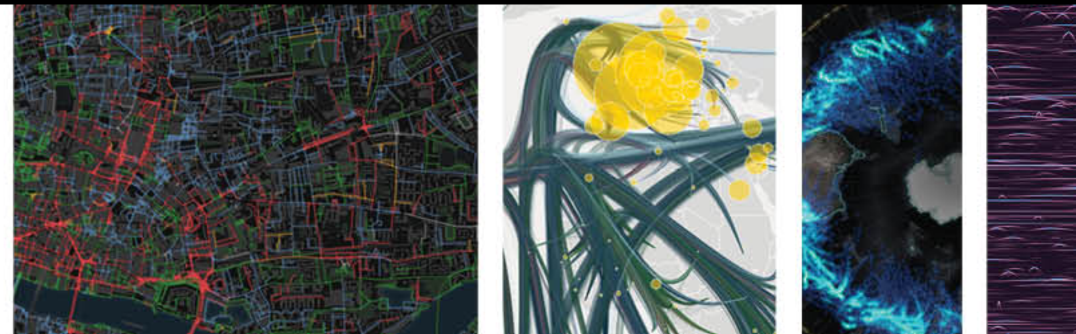

Modeling and Visualizing Science and Technology Developments

National Academy of Sciences Sackler Colloquium, December 4-5, 2017, Irvine, CA

Rankings and the Efficiency of Institutions

H. Eugene Stanley | Albert-László Barabási | Lada Adamic | Marta González | Kaye Husbands Fealing | Brian Uzzi | John V. Lombardi

Higher Education and the Science & Technology Job Market

Katy Börner | Wendy L. Martinez | Michael Richey | William Rouse | Stasa Milojevic | Rob Rubin | David Krakauer

Innovation Diffusion and Technology Adoption

William Rouse | Donna Cox | Jeff Alstott | Ben Shneiderman | Rahul C. Basole | Scott Stern | Cesar Hidalgo

Modeling Needs, Infrastructures, Standards

Paul Trunfio | Sallie Keller | Andrew L. Russell | Guru Madhavan | Azer Bestavros | Jason Owen-Smith

nasonline.org/Sackler-Visualizing-Science

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Modeling Advantage

Models are widely used in the construction of scientific theories as they help

- Make assumptions explicit
- Describe the structure and dynamics of systems
- Communicate and explain systems
- Suggest possible interventions
- Identify new questions

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Modeling Approaches

- Qualitative and quantitative models
- Deductive, abductive, and inductive models
- Analytic and predictive models
- Universal and domain specific models
- Multi-level (micro-macro) and multi-perspective models

Model Types

- Deterministic models
- Stochastic models
- Epidemic models
- Game-theoretic models
- Network models
- Agent-based models

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Science & Technology Outlook: 2005–2055

Technology Horizons Program
Institute for the Future
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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 (IFTF)** 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 IFTF 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 IFTF'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 technolgies, 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.

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 milieux that emphasize heterogeneity.

Intentional Biology

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 with 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

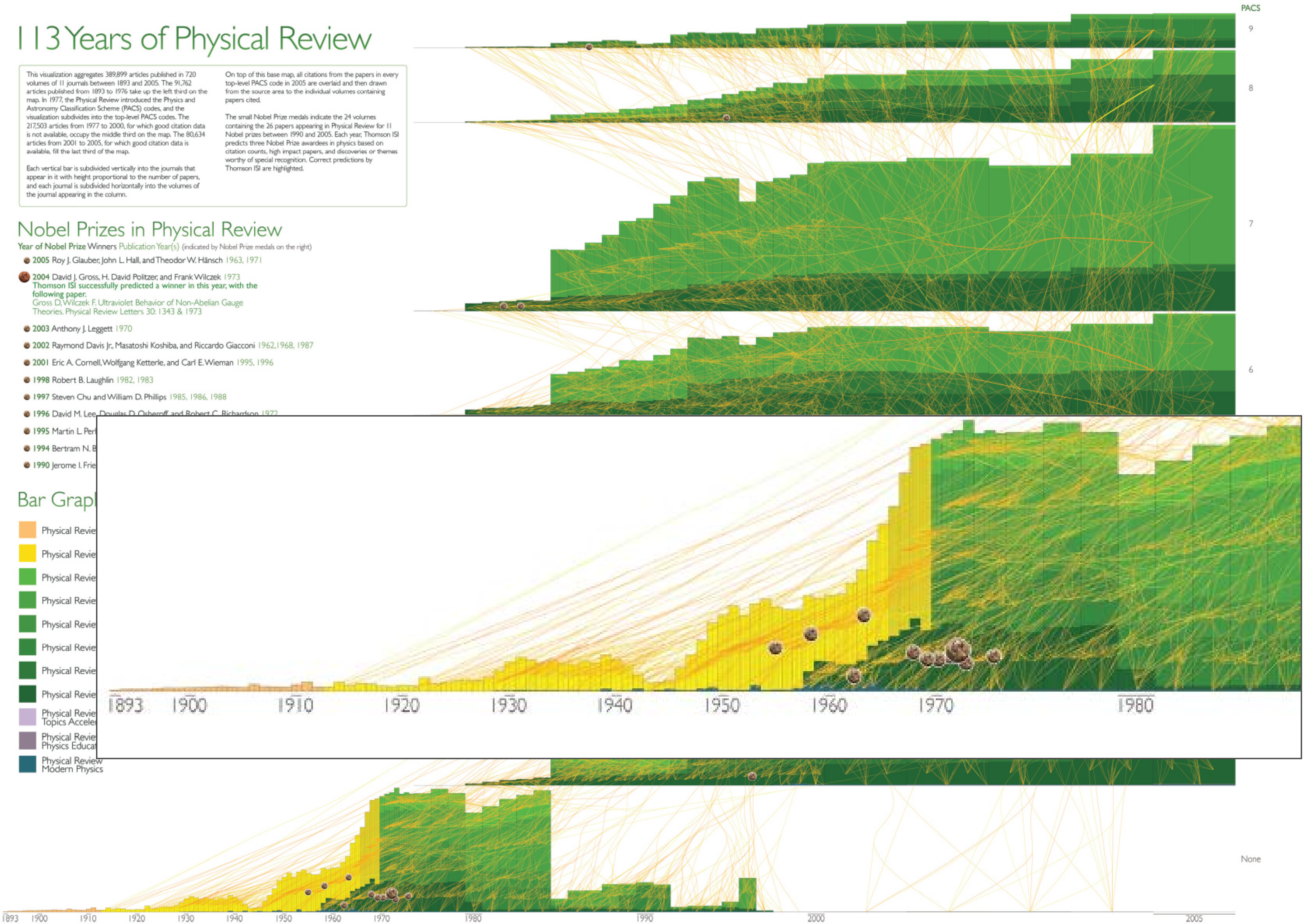
In the last two centuries, natural philosophy and natural history fractured into the now-familiar disciplines of physics, chemistry, biology, and so on. The sciences evolved into their current form in response to intellectual and professional opportunities, philanthropic priorities, and economic and 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 as a way of thinking about designing complex, robust technological systems. Finally, emergence is an accessible and vivid a 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.

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

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



III.6 *113 Years of Physical Review* - Bruce W. Herr II, Russell J. Duhon, Elisha F. Hardy, Shashikant Penumarthy, and Katy Börner - 2006

WEB OF SCIENCE™ 2016 CITATION LAUREATES

IMPACT OF SCIENTIFIC INNOVATIONS

CHEMISTRY

George Church and Feng Zhang developed application of CRISPR-cas9 gene editing in mouse and human cells.

Dennis Lo Yuk Ming detected cell-free fetal DNA in maternal plasma, a revolution in noninvasive prenatal testing.

Hiroshi Maeda and Yasuhiro Matsumura discovered the enhanced permeability and retention (EPR) effect of macromolecular drugs, a key finding for cancer therapeutics.

PHYSICS

Marvin L. Cohen for theoretical studies of solid materials, prediction of their properties, and especially for the empirical pseudopotential method.

Ronald W.P. Drever, Kip S. Thorne and Rainer Weiss developed the Laser Interferometer Gravitational-Wave Observatory (LIGO) that made possible the detection of gravitational waves.

Celso Grebogi, Edward Ott and James A. Yorke described a control theory of chaotic systems, the OGY method.

MEDICINE

James P. Allison, Jeffrey A. Bluestone and Craig B. Thompson explained how CD28 and CTLA-4 are regulators of T cell activation, modulating immune response.

Gordon J. Freeman, Tasuku Honjo and Arlene H. Sharpe elucidated programmed cell death-1 (PD-1) and its pathway, which has advanced cancer immunotherapy.

Michael N. Hall, David M. Sabatini and Stuart L. Schreiber discovered the growth regulator Target of Rapamycin (TOR) and the mechanistic Target of Rapamycin (mTOR).

ECONOMICS

Olivier J. Blanchard contributed to macroeconomics, including determinants of economic fluctuations and employment.

Edward P. Lazear developed the distinctive field of personnel economics.

Mark J. Melitz pioneered descriptions of firm heterogeneity and international trade.

Annually, Thomson Reuters analysts mine scientific literature citation data to identify the researchers whose work is worthy of Nobel recognition for induction into the Hall of Citation Laureates. They are the innovators responsible for the world's most influential scientific discoveries, with scholarly papers typically ranking in the top 0.1% by citations within their field. Many go on to win the Nobel Prize for their significant contributions toward the advancement of science.

To learn more visit: **stateofinnovation.com**

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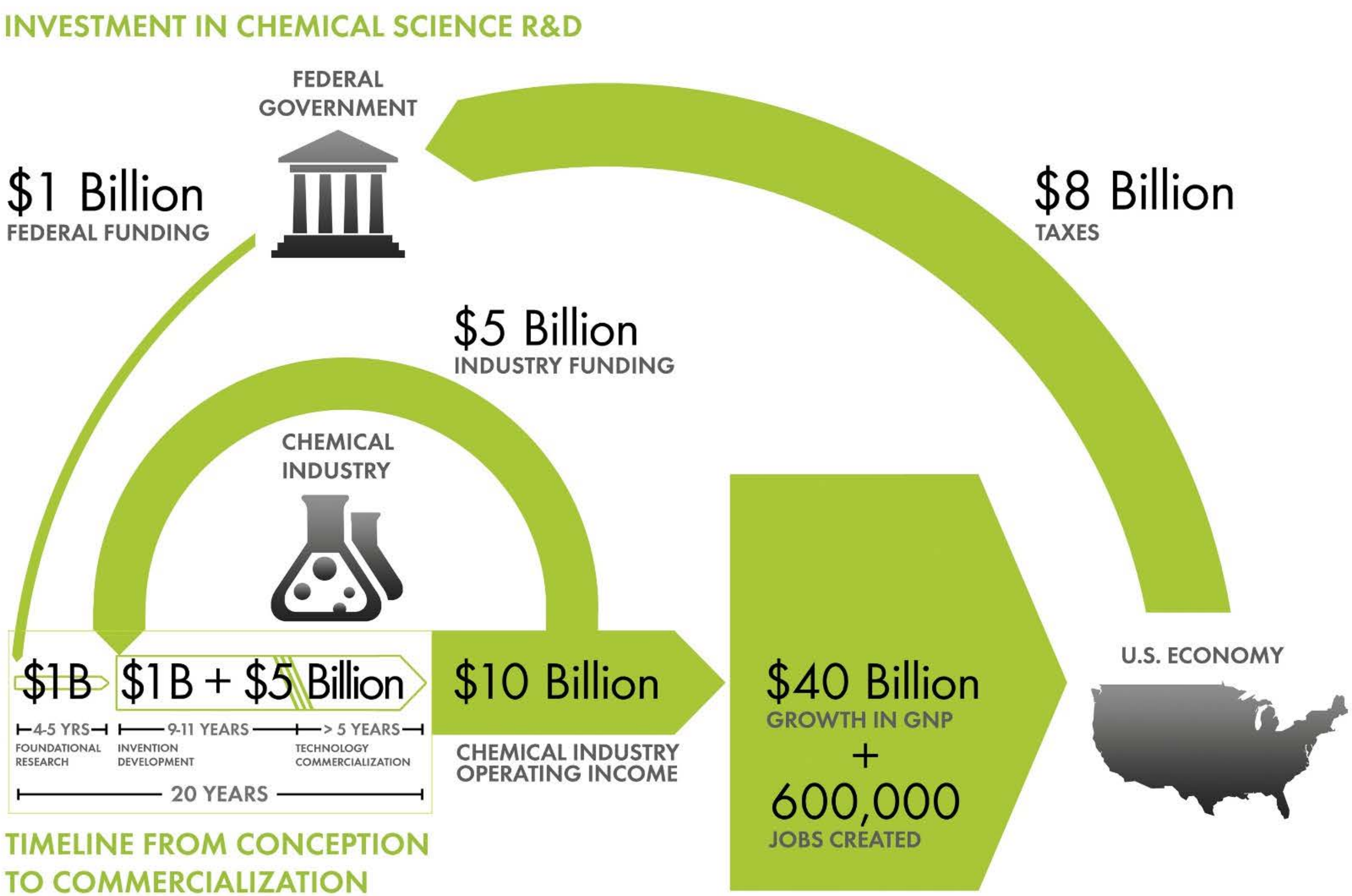
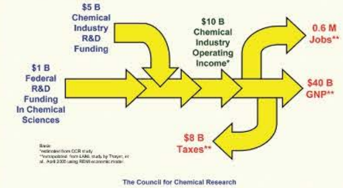
Chemical Research & Development

Powers the U.S. Innovation Engine

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



The Council for Chemical Research (CCR) 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.

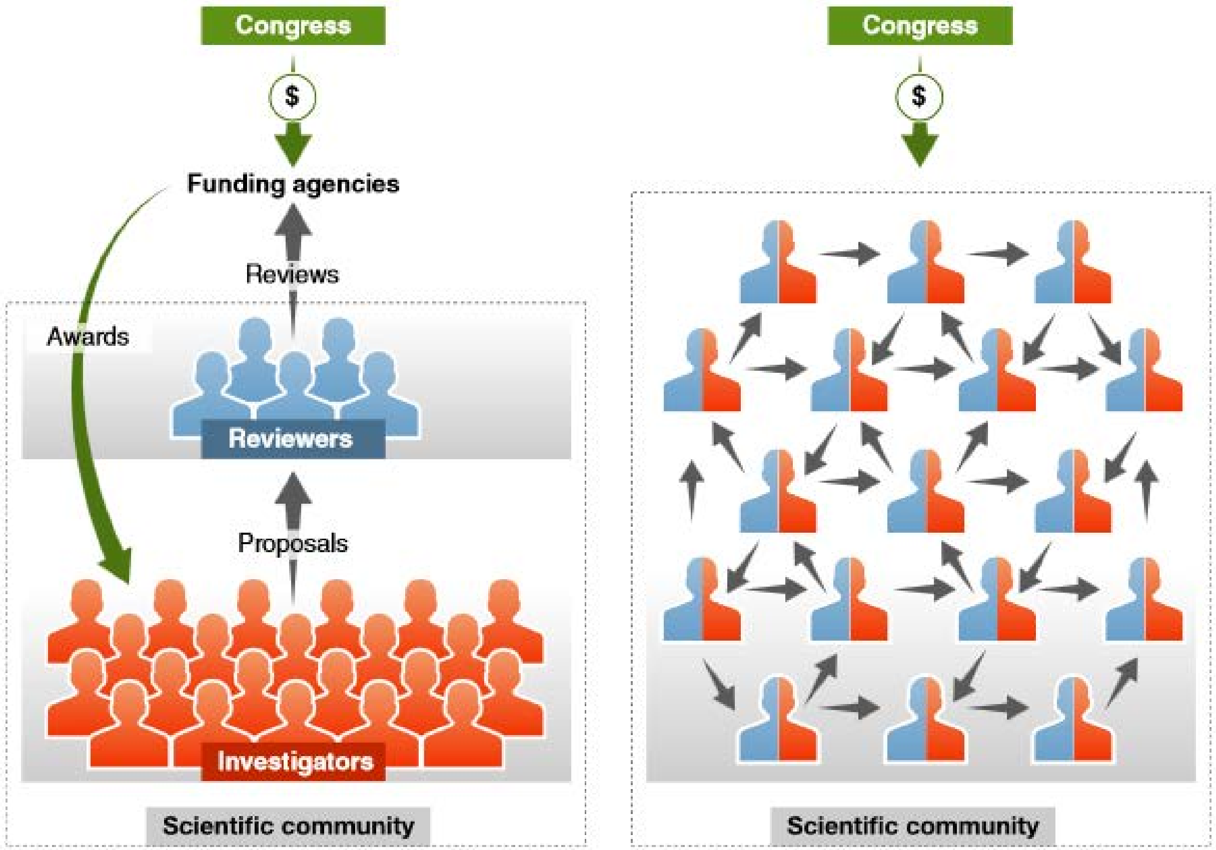


The design shows that an input of $1B in federal investment, leveraged by $5B in industry investment, brings new technologies to market and results in $10B of operating income for the chemical industry, $40B of growth in the Gross National Product (GNP) and further impacts the US economy by generating 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.

V.6 *Chemical R&D Powers the U.S. Innovation Engine* - The Council for Chemical Research - 2009

From funding agencies to scientific agency: Collective allocation of science funding as an alternative to peer review

Bollen, Johan, David Crandall, Damion Junk, Ying Ding, and Katy Börner. 2014. EMBO Reports 15 (1): 1-121.



Existing (left) and proposed (right) funding systems. Reviewers in blue; investigators in red.

In the proposed system, all scientists are both investigators and reviewers: every scientist receives a fixed amount of funding from the government and discretionary distributions from other scientists, but each is required in turn to redistribute some fraction of the total they received to other investigators.

Assume

Total funding budget in year y is t_y

Number of qualified scientists is n

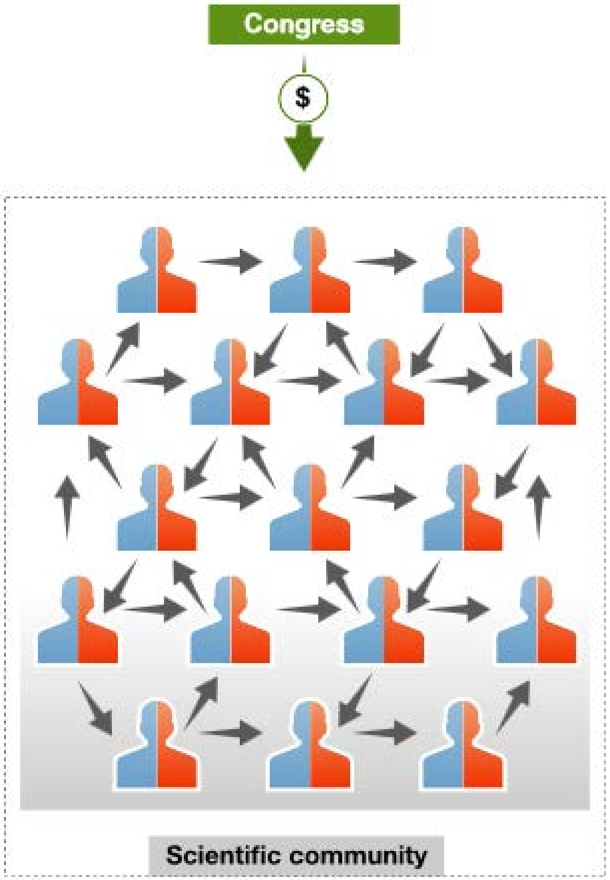
Each year,

the funding agency deposits a fixed amount into each account, equal to the total funding budget divided by the total number of scientists: t_y/n.

Each scientist must distribute a fixed fraction of received funding to other scientists (no self-funding, COIs respected).

Result

Scientists collectively assess each others' merit based on different criteria; they "fund-rank" scientists; highly ranked scientists have to distribute more money.



Example:

Total funding budget in year is 2012 NSF budget

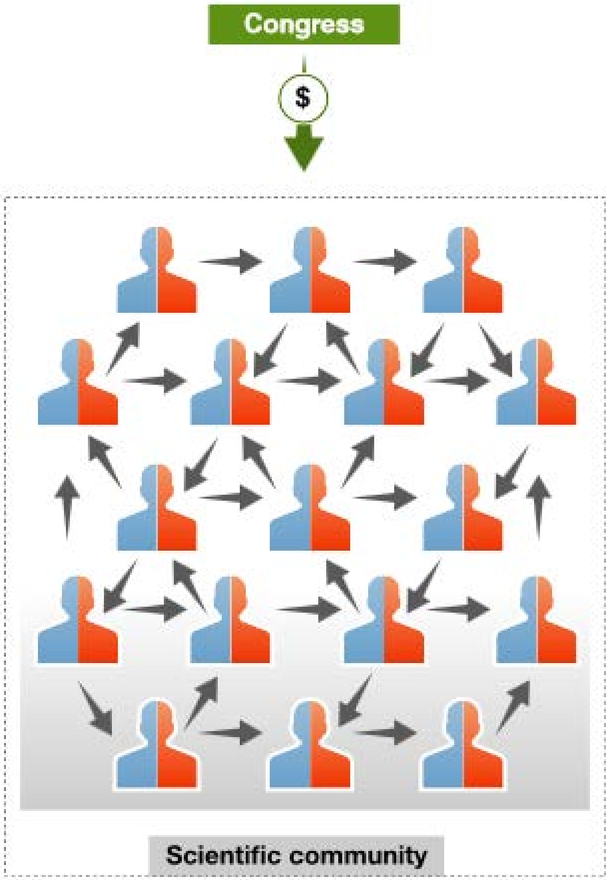
Given the number of NSF funded scientists, each receives a $100,000 basic grant.

Fraction is set to 50%

In 2013, scientist *S* receives a basic grant of $100,000 plus $200,000 from her peers, i.e., a total of $300,000.

In 2013, *S* can spend 50% of that total sum, $150,000, on her own research program, but must donate 50% to other scientists for their 2014 budget.

Rather than submitting and reviewing project proposals, *S* donates directly to other scientists by logging into a centralized website and entering the names of the scientists to donate to and how much each should receive.



Model Run and Validation:

Model is presented in http://arxiv.org/abs/1304.1067

It uses **citations as a proxy** for how each scientist might distribute funds in the proposed system.

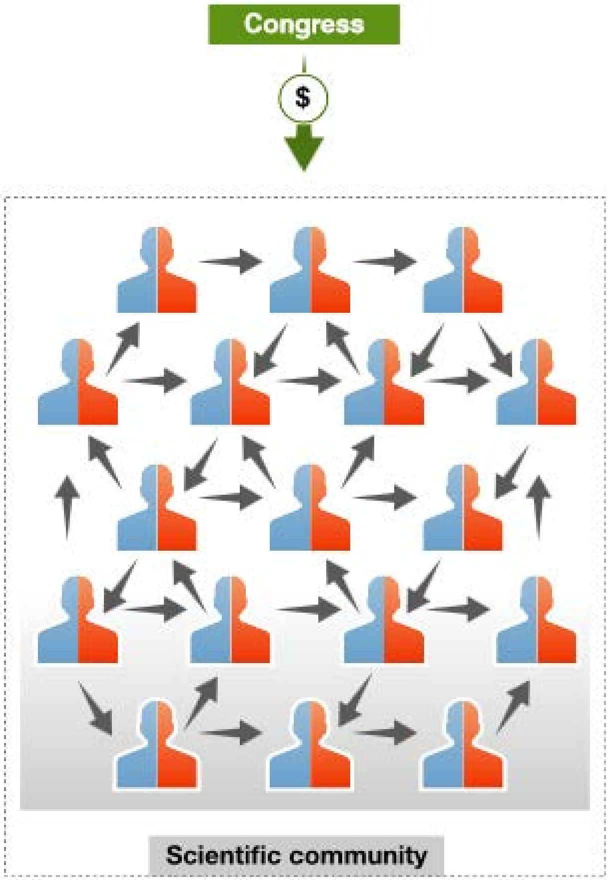
Using 37M articles from TR 1992 to 2010 Web of Science (WoS) database, we extracted **770M citations**. From the same WoS data, we also determined 4,195,734 unique author names and we took the **867,872 names** who had authored at least one paper per year in any five years of the period 2000–2010.

For each pair of authors we determined the number of times one had cited the other in each year of our citation data (1992–2010).

NIH and NSF funding records from IU's Scholarly Database provided 347,364 grant amounts for 109,919 unique scientists for that time period.

Simulation run begins in year 2000, in which every scientist was given a fixed budget of B = $100k. In subsequent years, scientists distribute their funding in proportion to their citations over the prior 5 years.

The model yields funding patterns similar to existing NIH and NSF distributions.



Model Efficiency:

Using data from the Taulbee Survey of Salaries Computer Science (http://cra.org/resources/taulbee) and the National Science Foundation (NSF) the following calculation is illuminating:

If four professors work four weeks full-time on a proposal submission, labor costs are about $35k. With success rates in CS around 20%, about five submission-review cycles might be needed resulting in a total expected labor cost of **$175k**.

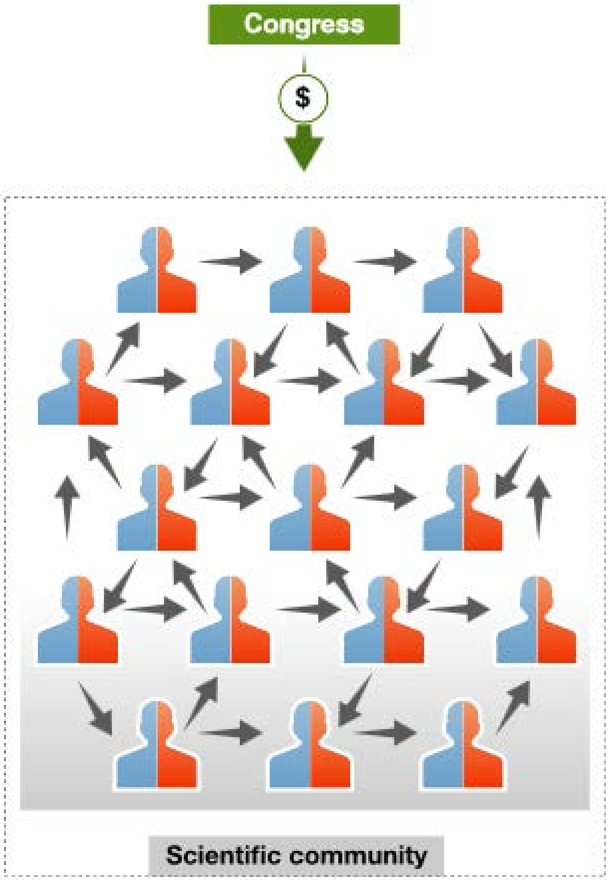
The average NSF grant is **$165k** per year.

U.S. universities charge about 50% overhead (ca. $55k), leaving about **$110k**.

In other words, average success results in a net loss for faculty in terms of paid research time.

That is, U.S. universities should forbid professors to apply for grants—if they can afford to forgo the indirect dollars.

To add: Time spent by researchers to review proposals. In 2015 alone, NSF commissioned more than 231,000 reviews to evaluate 49,600 proposals.



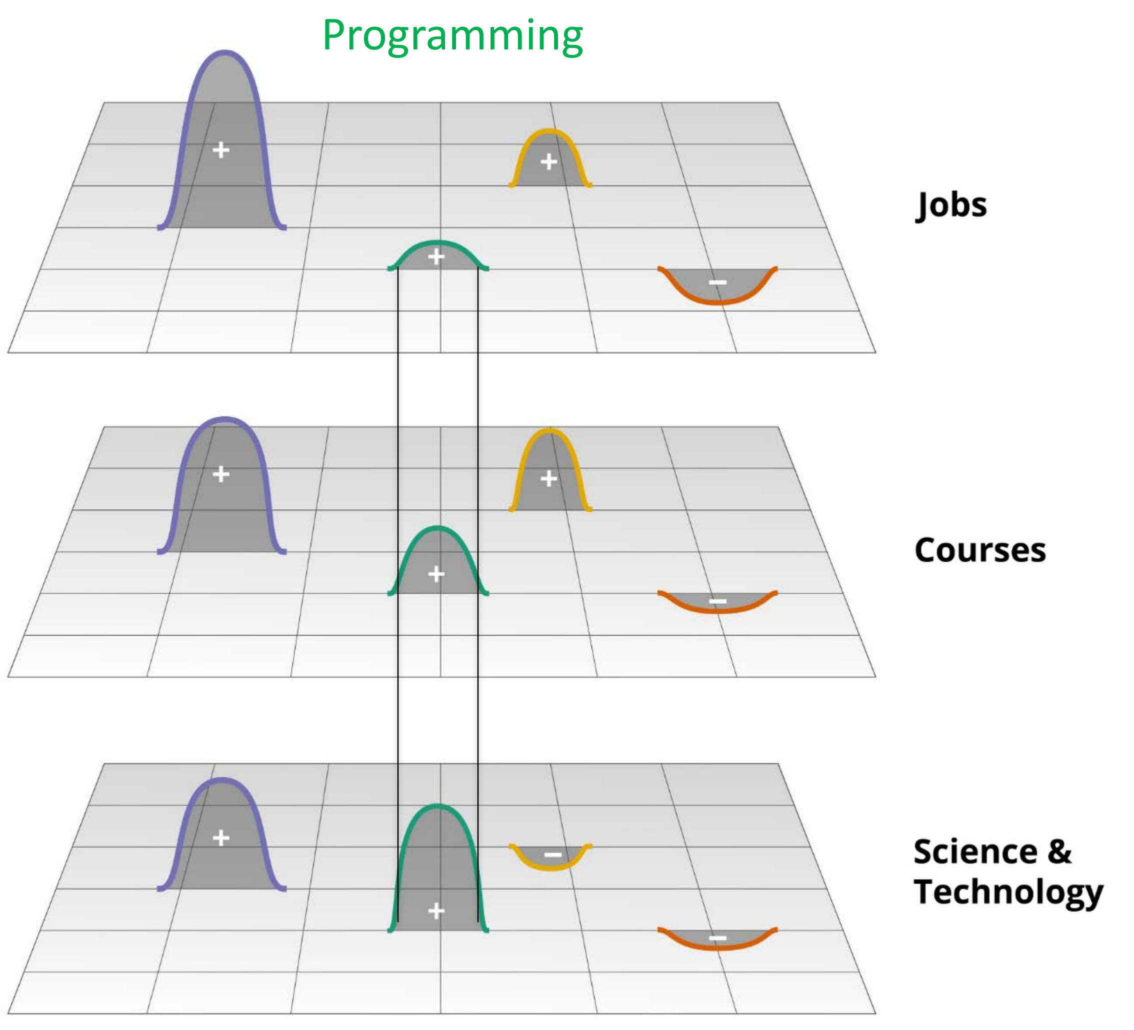
Science & Technology vs. Education/Training vs. Jobs

Katy Börnera, Olga Scrivner, Mike Gallant, Shutian Ma, Xiaozhong Liu, Keith Chewning, Lingfei Wu and James A. Evans

Need to study the **(mis)match** and **temporal dynamics** of S&T progress, education and workforce development options, and job requirements.

Challenges:

- Rapid change of STEM knowledge
- Increase in tools, AI
- Social skills (project management, team leadership)
- Increasing team size



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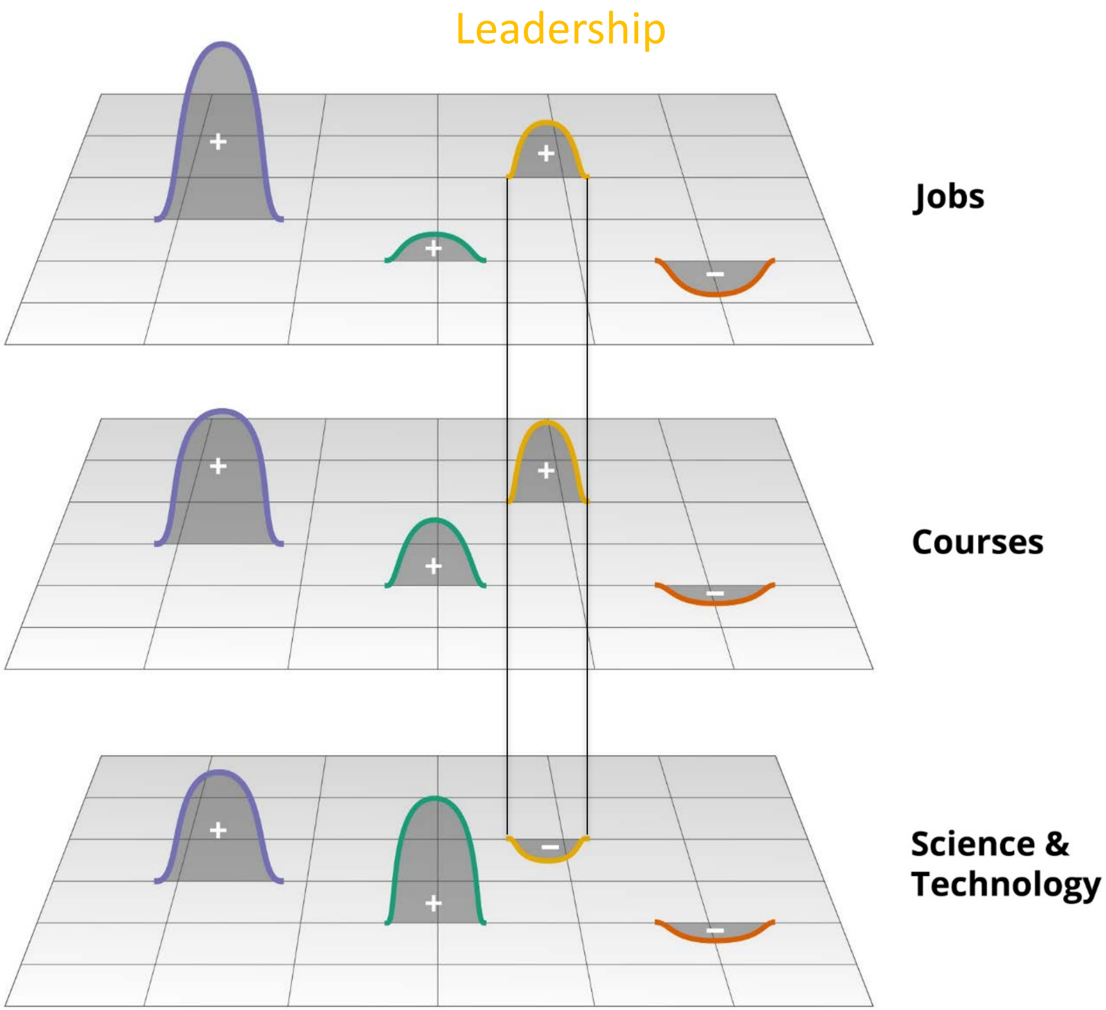

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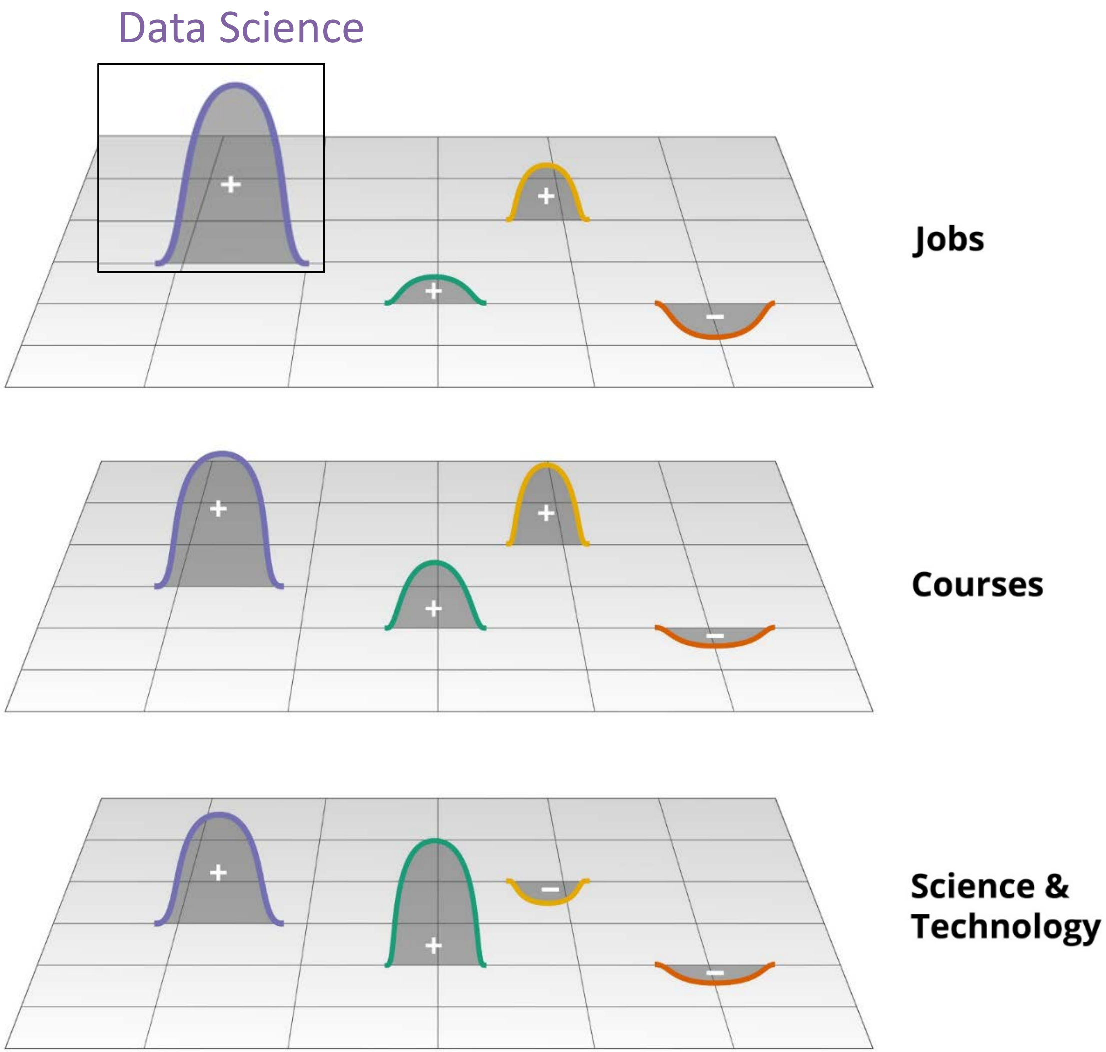

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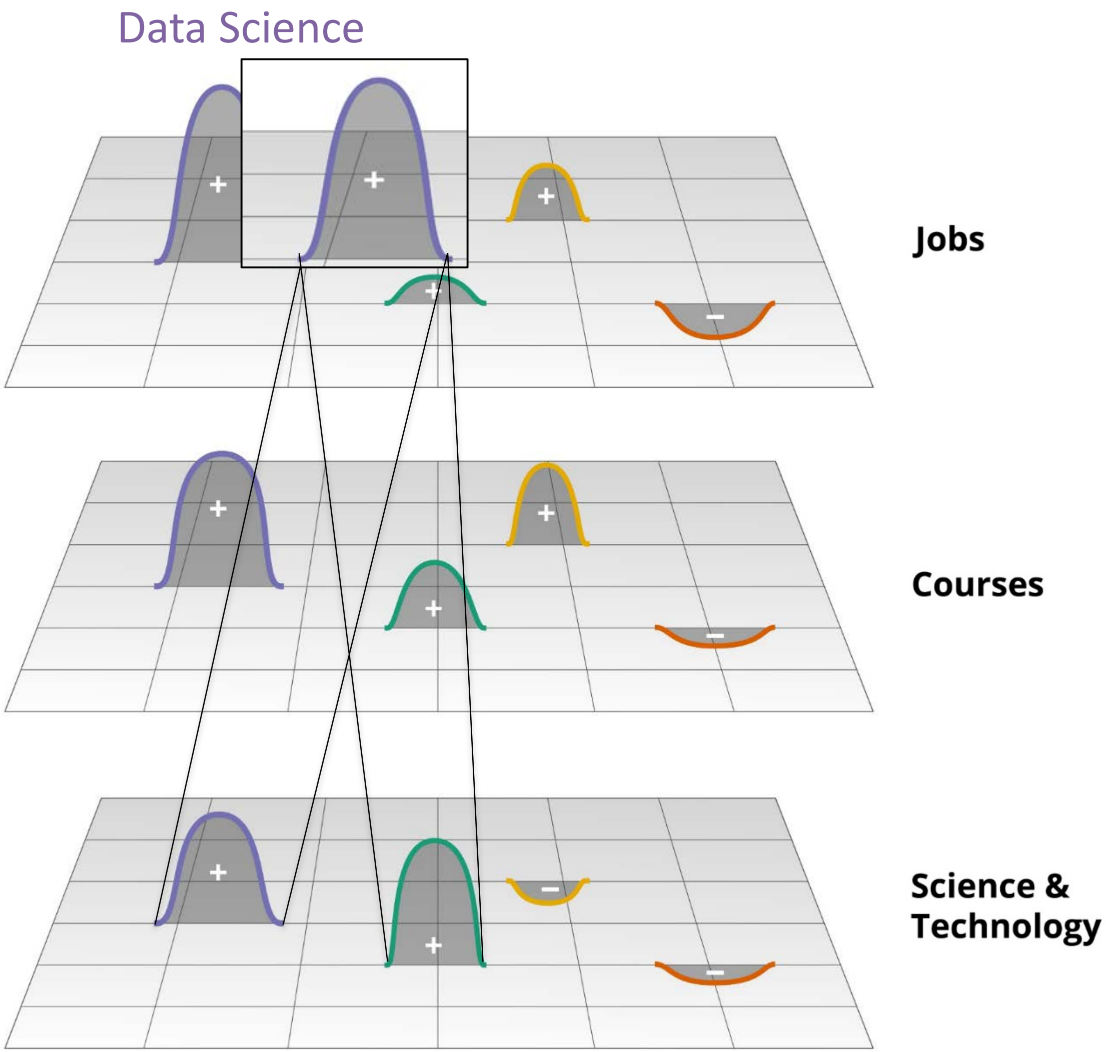

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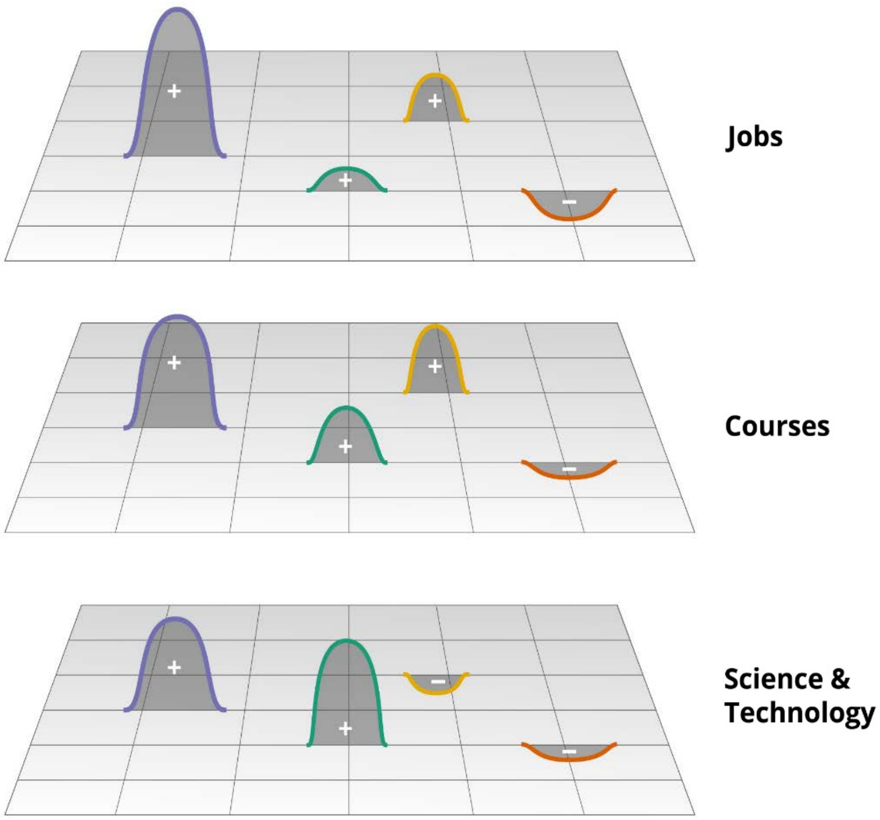
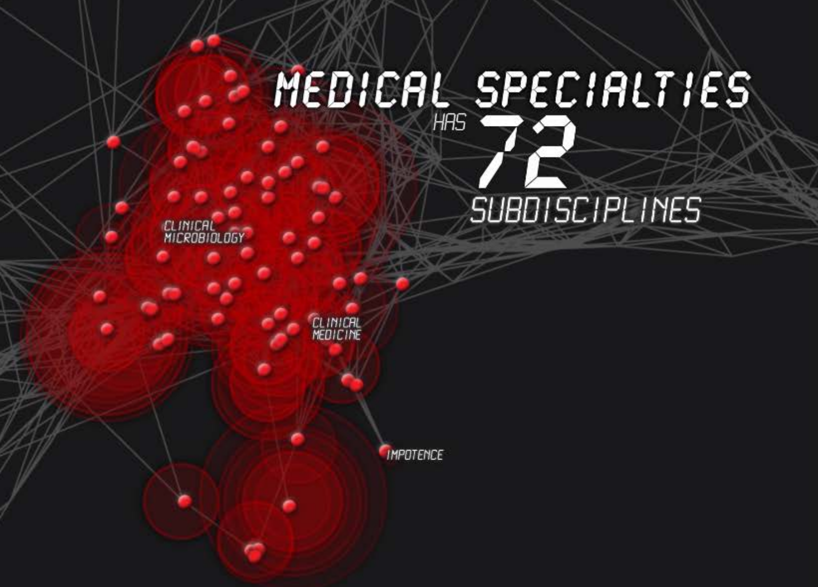
Study results are needed by:

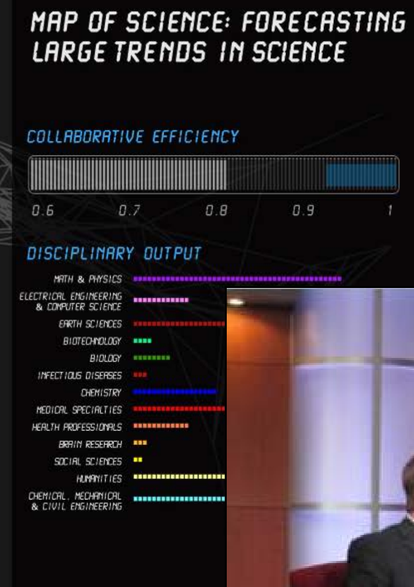
- **Students:** What jobs will exist in 1-4 years? What program/learning trajectory is best to get/keep my dream job?
- **Teachers:** What course updates are needed? What curriculum design is best? What is my competition doing? How much timely knowledge (to get a job) vs. forever knowledge (to be prepared for 80 productive years) should I teach? How to innovate in teaching and get tenure?
- **Employers:** What skills are needed next year, in 5 years? Who trains the best? What skills does my competition list in job advertisements? How to hire/train productive teams?



What is ROI of my time, money, compassion?

Science Forecast S1:E1





Science Forecast S1:E1

https://www.youtube.com/watch?v=lByX2_eb_QQ

Modelling Challenges

Comprise among others:

- Model utility and usability
- Model credibility and validation
- Model extendibility and reproducibility
- Model sharing and retrieval

Computed Using Data from Elsevier's Scopus

Modelling Opportunities

Now available:

- High-quality, high coverage, interlinked data
- Cost-effective storage and computation
- Validated, scalable algorithms
- Visualization and animations capabilities

Computed Using Data from Elsevier's Scopus

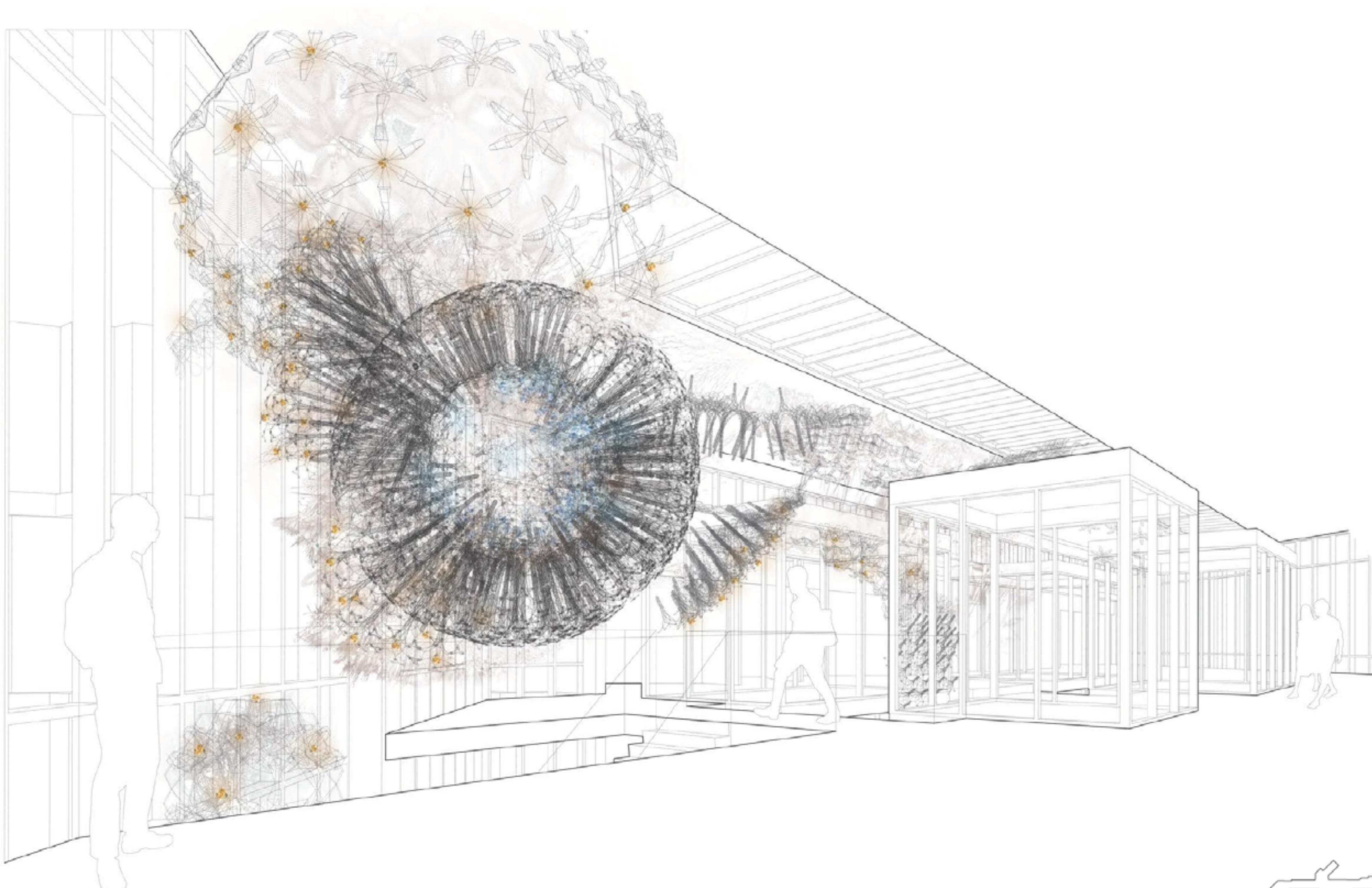
Inventing and Implementing Desirable Futures:
Embracing Human and Machine Intelligence Synergies

Visualizing the Internet of Things (IoT)

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

Work by Philip Beesley | www.philipbeesley.ca | www.lasg.ca

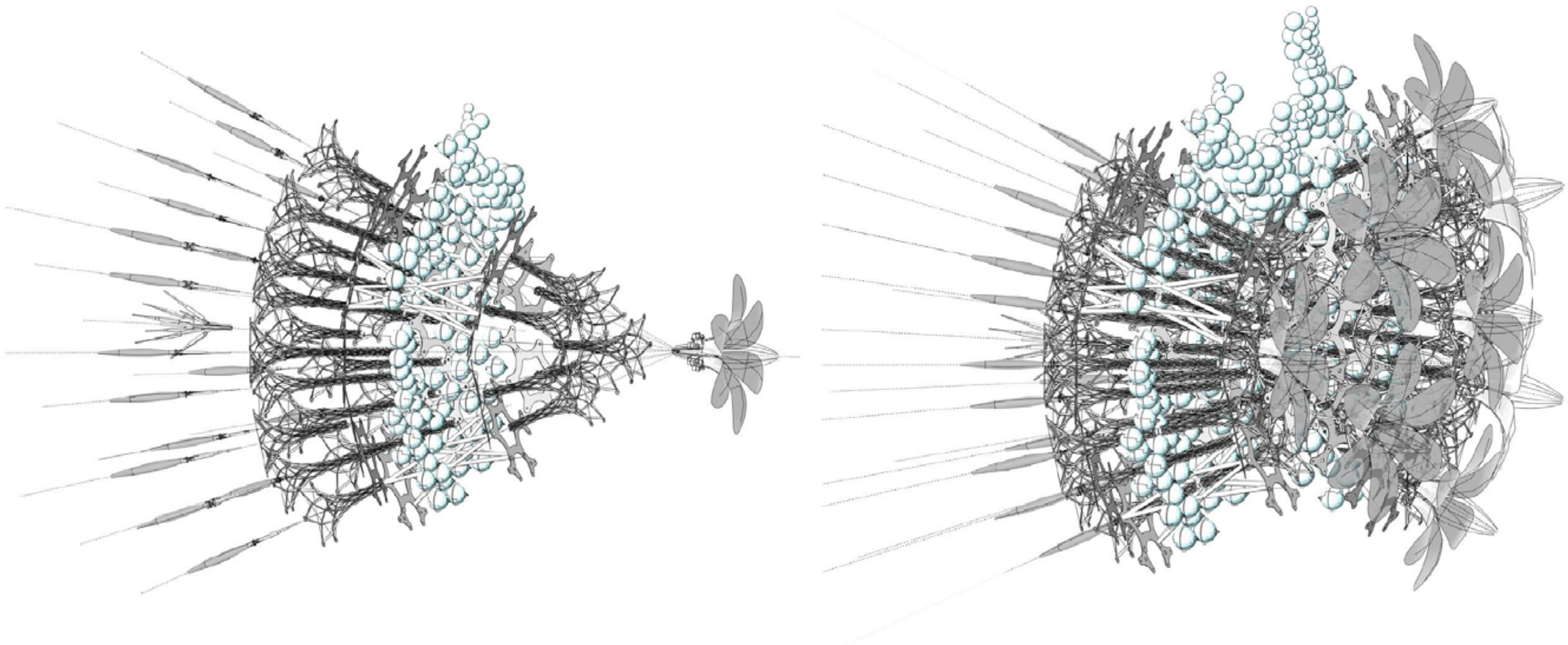
Sentient Chamber, National Academy of Sciences, Washington, D.C. (2016)



Luddy Hall Installation
Indiana University Bloomington
April 29 2017

UPPER ATRIUM

Philip Beesley • Living Architecture Systems



Luddy Hall Installation
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ASSEMBLY SAMPLE

Philip Beesley • Living Architecture Systems

Amatria Unveiled by Andreas Bueckle et al. Data visualizations of sensor/actuator positions and types, energy and communication flows, and emergent behavior of smart environments.

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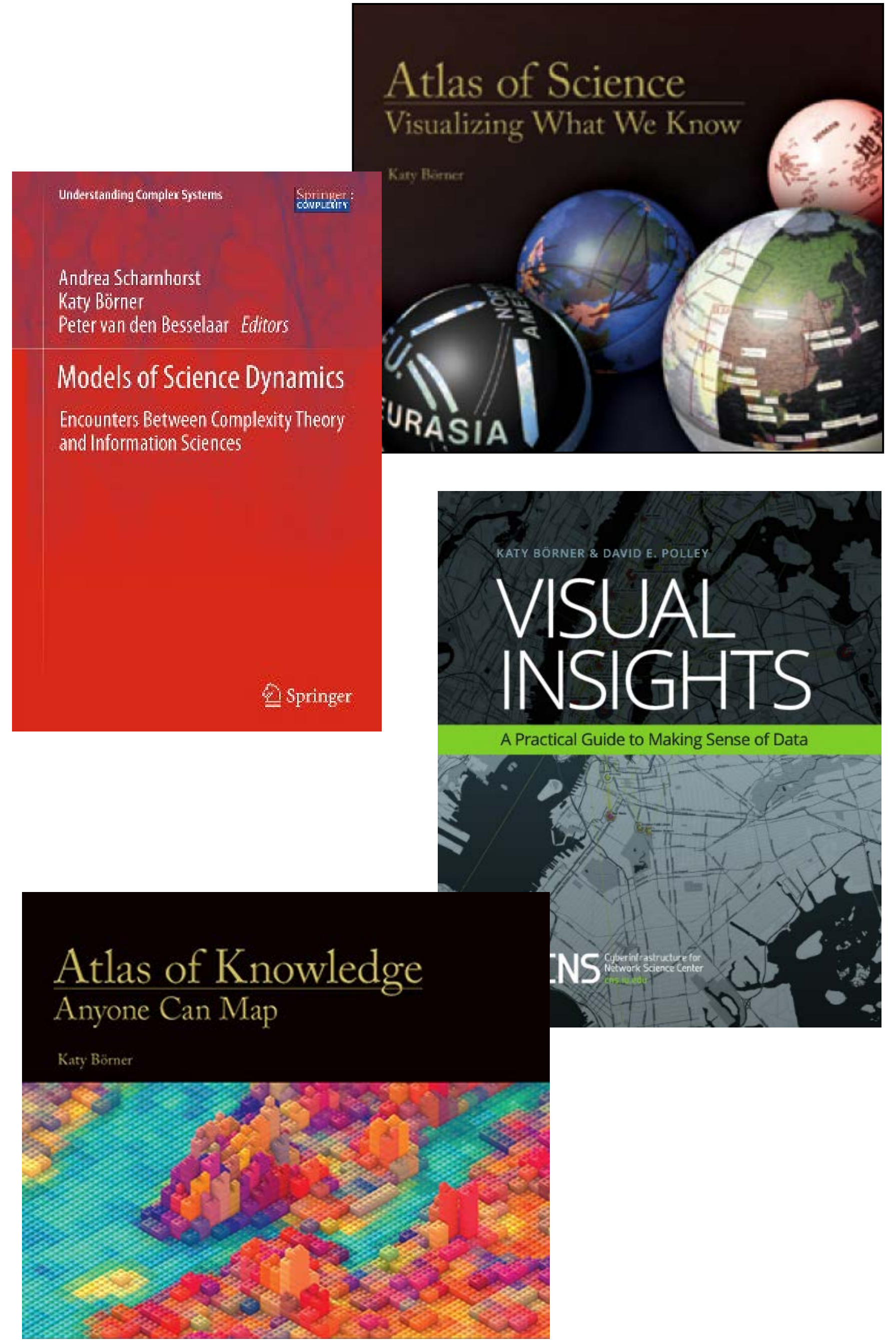

All papers, maps, tools, talks, press are linked from http://cns.iu.edu
These slides are at http://cns.iu.edu/presentations.html

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