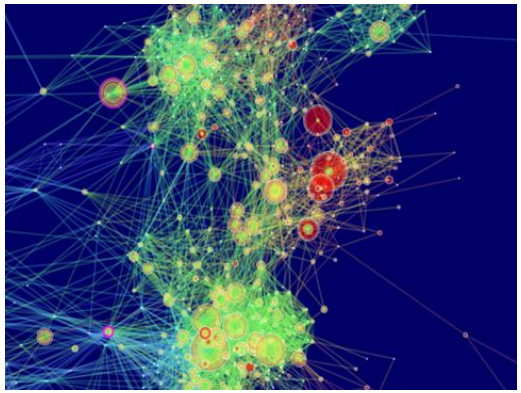
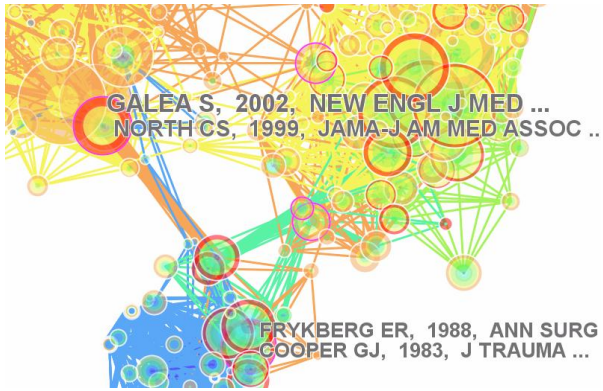
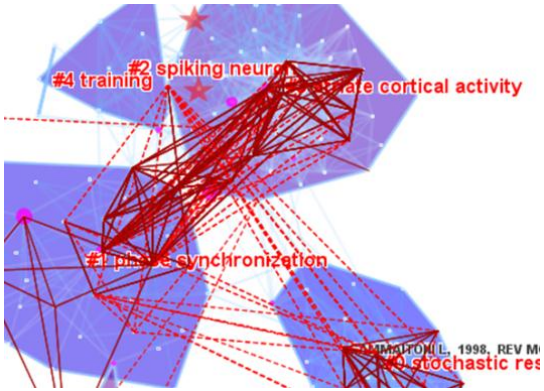
Visualizing Science

Hindsight, Insight, and Foresight







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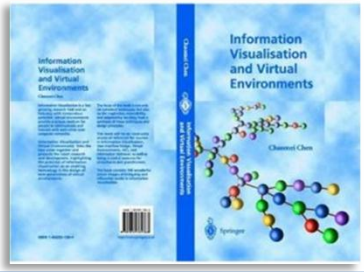
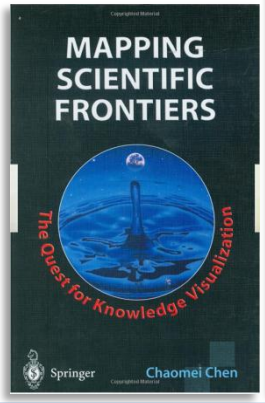
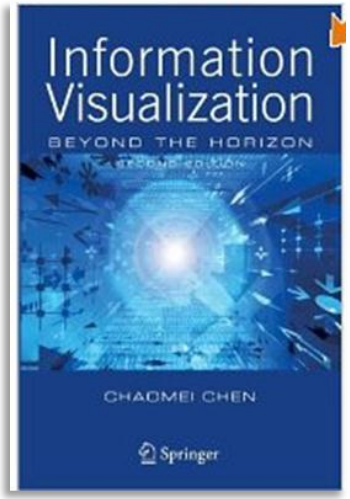
Visualizing Science
Annual Conference of the Special Libraries Association
Philadelphia
June 13, 2011

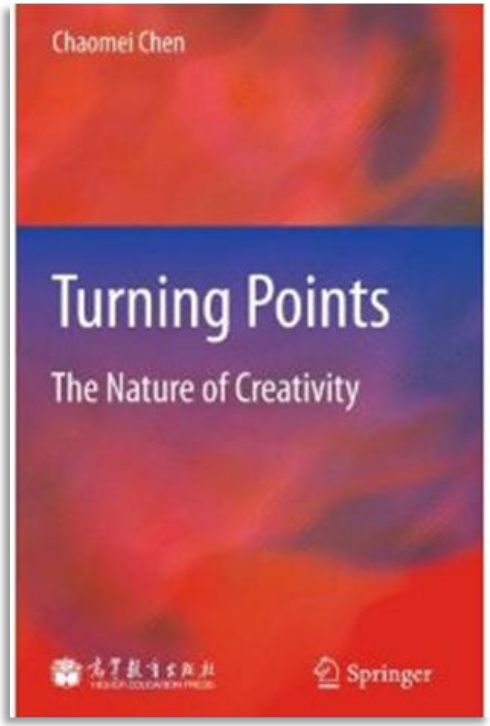
CiteSpace

Visualizing Patterns and Trends in Scientific Literature



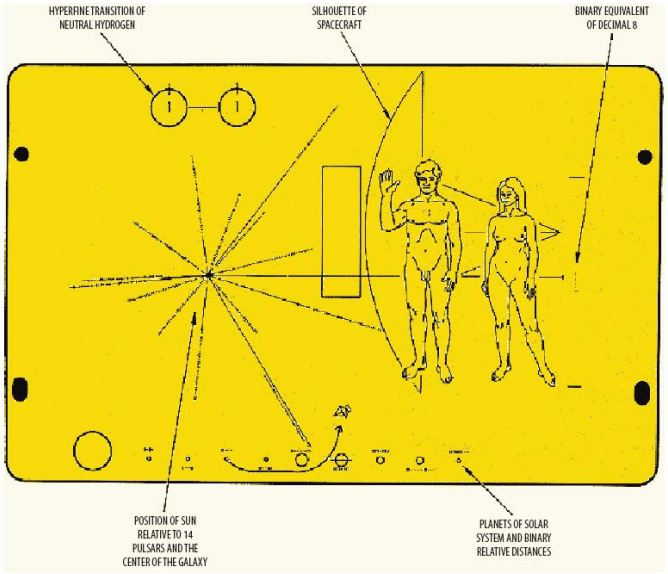




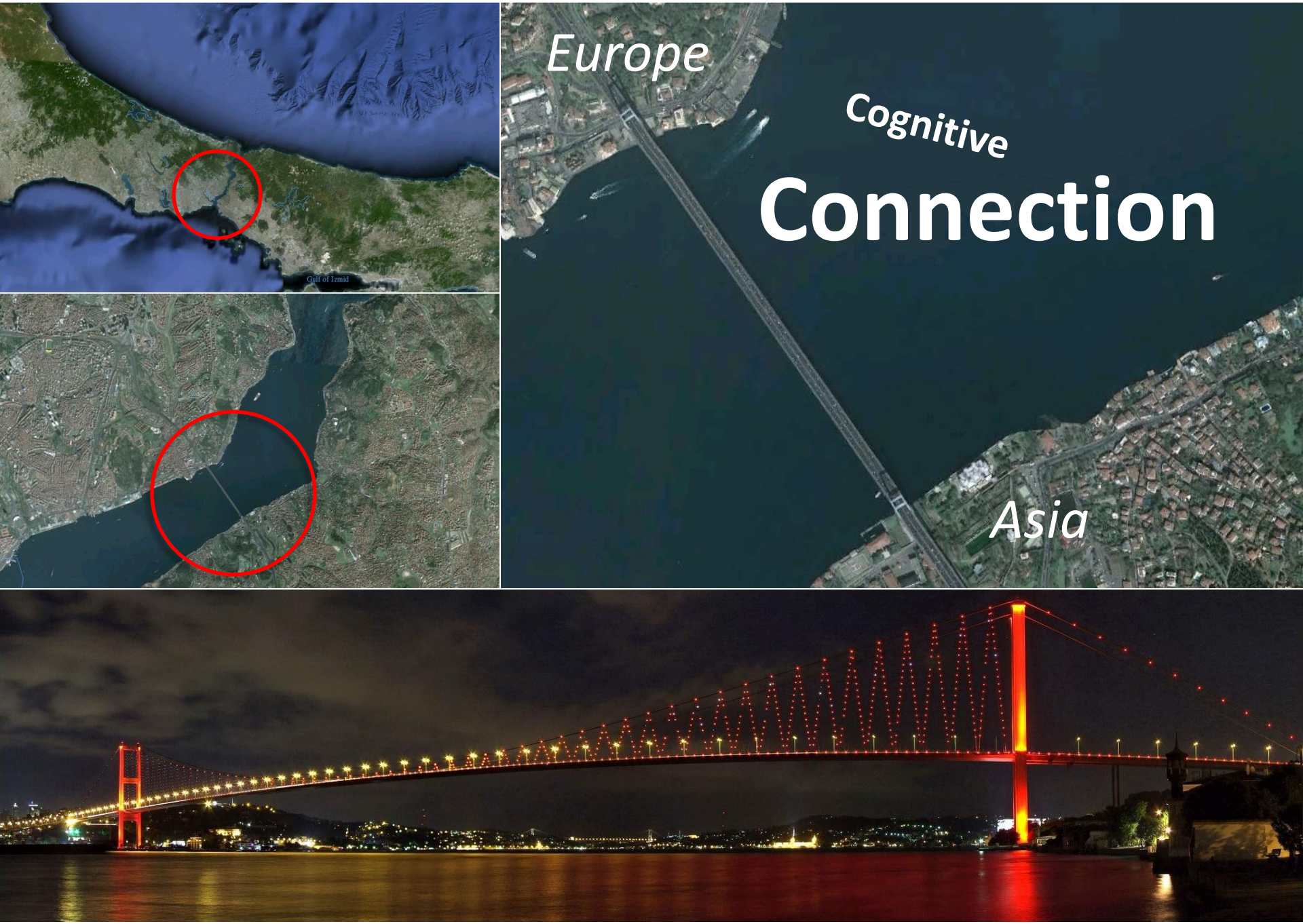


1999 2003 2004 2011

The eyes are not responsible when the mind does the seeing.
Publilius Syrus (c. 85–43 BC)




Information
Foraging

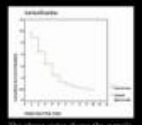

Gulf of Izmid
Europe
Cognitive
Connection
Asia

Mapping the Universe

Space, Time, Discovery!

Fan et al. (2003). A survey of z>5.7 quasars in the Sloan Digital Sky Survey II: Discovery of three additional quasars at z>6. *The Astronomical Journal*, 125, 1649-1659.

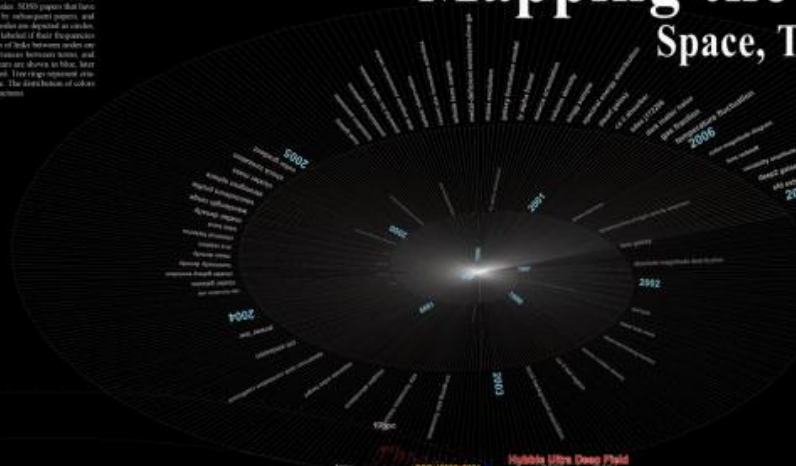
Citation burst detects an abrupt increase of citations received by a scientific paper so that potential high-impact papers as a research field can be identified. Papers with long periods of citation burst tend to have a profound impact. The two papers by Hennawi et al. and Fan et al. highlighted here have the highest citation burst rates. They represent two citation burst examples of two different isotopes. Fan et al. was possible because of the new telescope and technology that allowed identification of these few new high-redshift quasars. Hennawi et al. was possible because of the huge volume of space surveyed by SDSS.



The above curve shows the cumulative probability of survival of a citation burst. The X-axis is the time span of a citation burst, and Y-axis is the probability of the end of a citation burst, based on our data. The average citation burst in the SDSS literature lasts 3.5 years.

Network of Scientific Literature

The SDSS literature network gives an example of a collective and dynamic intellectual structure of a scientific community. The network consists of 1,832 nodes and 8,291 links. It contains two types of nodes: SDSS papers that have received four or more citations, i.e. referenced by subsequent papers, and terms extracted from a citing SDSS paper. Paper nodes are depicted as circles; refereed terms are shown as triangles. They are labeled if their frequencies exceed user-defined threshold values. Three types of links between nodes are defined: co-citations between papers, co-occurrences between terms, and term-to-paper citations. Links added in earlier years are shown in blue, later years in light green, and the most recent ones in red. Tree rings represent citations received by a corresponding paper over time. The distribution of colors reveals the dynamic nature of such intellectual structures.



Time Spiral

The time spiral depicts new topics that emerged each year in the SDSS literature. These topics are selected based on statistical tests of association between terms found in SDSS papers. Terms are included in the time spiral only if they appear for the first time. Subsequent appearances of the same term are not included in the time spiral. Terms in the time spiral are expected to indicate emerging areas of future growth of the SDSS literature.

Map of the Universe

The map of the universe depicts more than 800,000 astronomical objects. The majority is identified by the Sloan Digital Sky Survey (SDSS). Commonly known galaxies, stars, and planets are also included in the map. Each object in the map is positioned based on its right ascension and a logarithmic transformation of its distance from the Earth. The right ascension is projected counter clockwise. Multiple scales of distance are used, namely kiloparsec, astronomical unit, parsec, kiloparsec, megaparsec, and gigaparsec. The logarithmic scales of megaparsec and gigaparsec are specifically enlarged to make the details in these areas more readable. Colors and shapes of objects are arbitrarily assigned. The only consideration is to make it easy to differentiate distinct objects and their original data sources.

373,781	SDSS quasars, galaxies, and stars
218,479	Asteroids
8,690	CfA2 galaxies
8,420	Satellites
8,277	Hipparcos objects
234	Large-scale structures
118	Landmark discoveries
94	Extrasolar planets
66	Objects with citation bursts
45	Local group galaxies
24	Messier galaxies
11	Stars
11	The Sun, the Moon, and the planets in our Solar system
4	Space probes
618,223	**Objects shown in the map of the Universe**

LEGEND

- Asteroids
- CfA2 Galaxies
- Extrasolar Planets
- Hipparcos Stars
- Local Group Galaxies
- Messier Galaxies
- Planets in the Solar System
- Satellites
- SDSS Galaxies
- SDSS High Redshift Quasars
- Space Probes
- Stars

Orion Nebula
1610 ← Date of Discovery
Objects with Citation Bursts

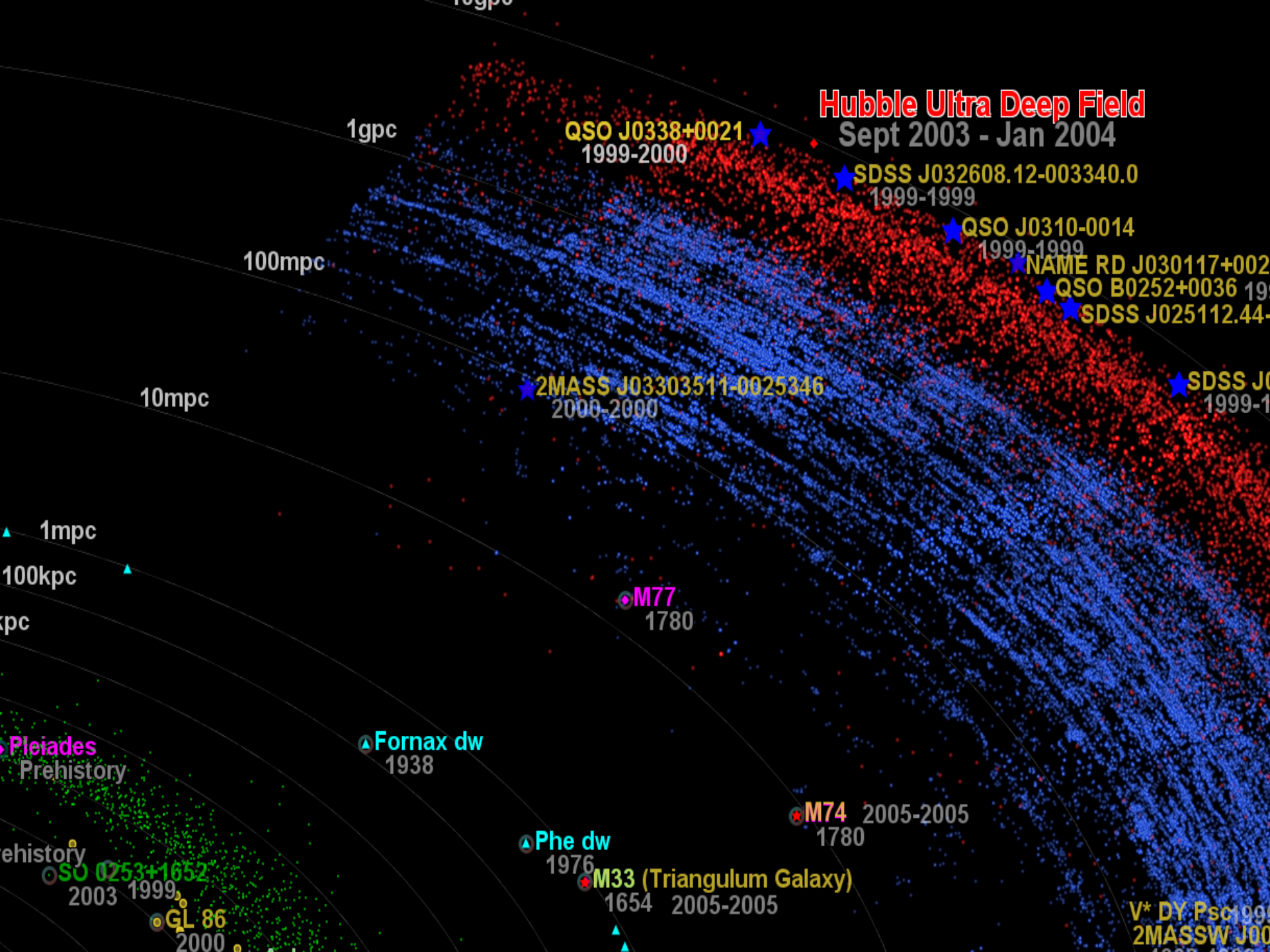
Ancient

1610

2003

2005

Observations of 13 million galaxies and 200,000 quasars from the SDSS allow data from all cosmic magnification caused by the gravitational effect of dark matter throughout the universe. Using this technique, telescopes now map not only the visible galaxies, but also the invisible dark matter.


Hubble Ultra Deep Field
Sept 2003 - Jan 2004
1gpc
QSO J0338+0021
1999-2000
SDSS J032608.12-003340.0
1999-1999
QSO J0310-0014
1999-1999
100mpc
NAME RD J030117+002
QSO B0252+0036
SDSS J025112.44-
10mpc
2MASS J03303511-0025346
2000-2000
SDSS J
1999-1
1mpc
100kpc
M77
1780
Pleiades
Prehistory
Fornax dw
1938
M74
2005-2005
1780
Phe dw
1976
M33 (Triangulum Galaxy)
1654
2005-2005
SO 0253+1652
2003
1999
GL 86
2000
V* DY Psc
2MASSW J00

114,996 influenza virus protein sequences

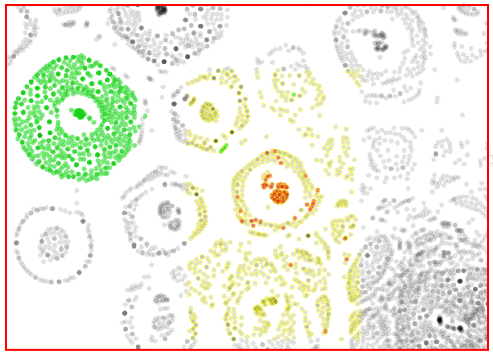
What are the ways that A and B may be connected?

Pellegrino, D. A., Chen, C. (2011) Data repository mapping for influenza protein sequence analysis. *Visualization and Data Analysis (VDA) 2011*. January 23-27, 2011. Hyatt Regency San Francisco Airport Hotel, San Francisco, California United States.

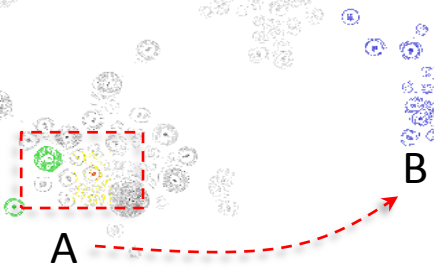
Sequences from the 2009 H1N1 Swine Flu pandemic

Sequences from the 1918 H1N1, 1957 H2N2 and 1968 H3N2 deadly human pandemics

Sequences that code for the PB1-F2 protein known to cause virulence in humans



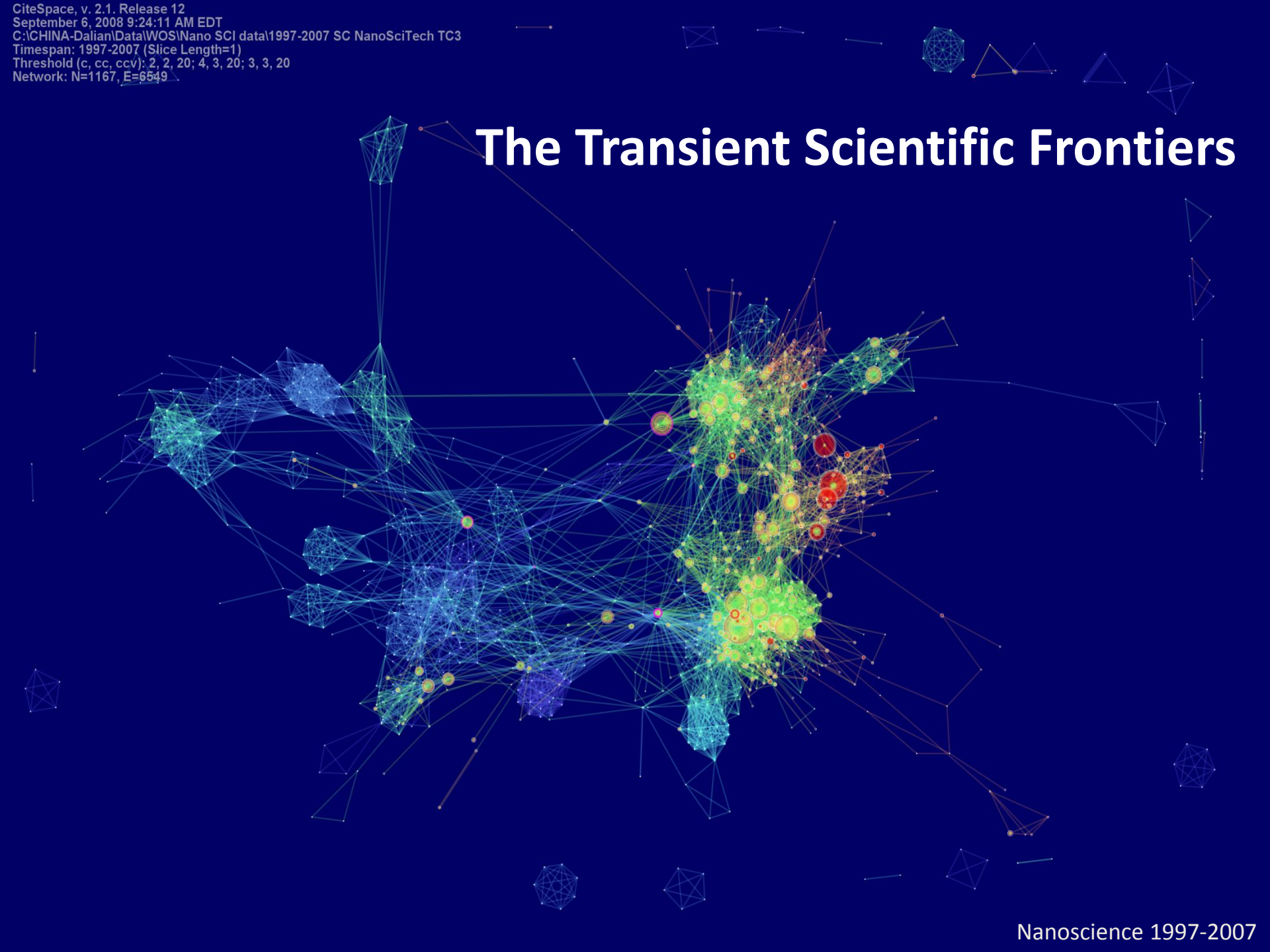
1001 sequences selected



Hindsight

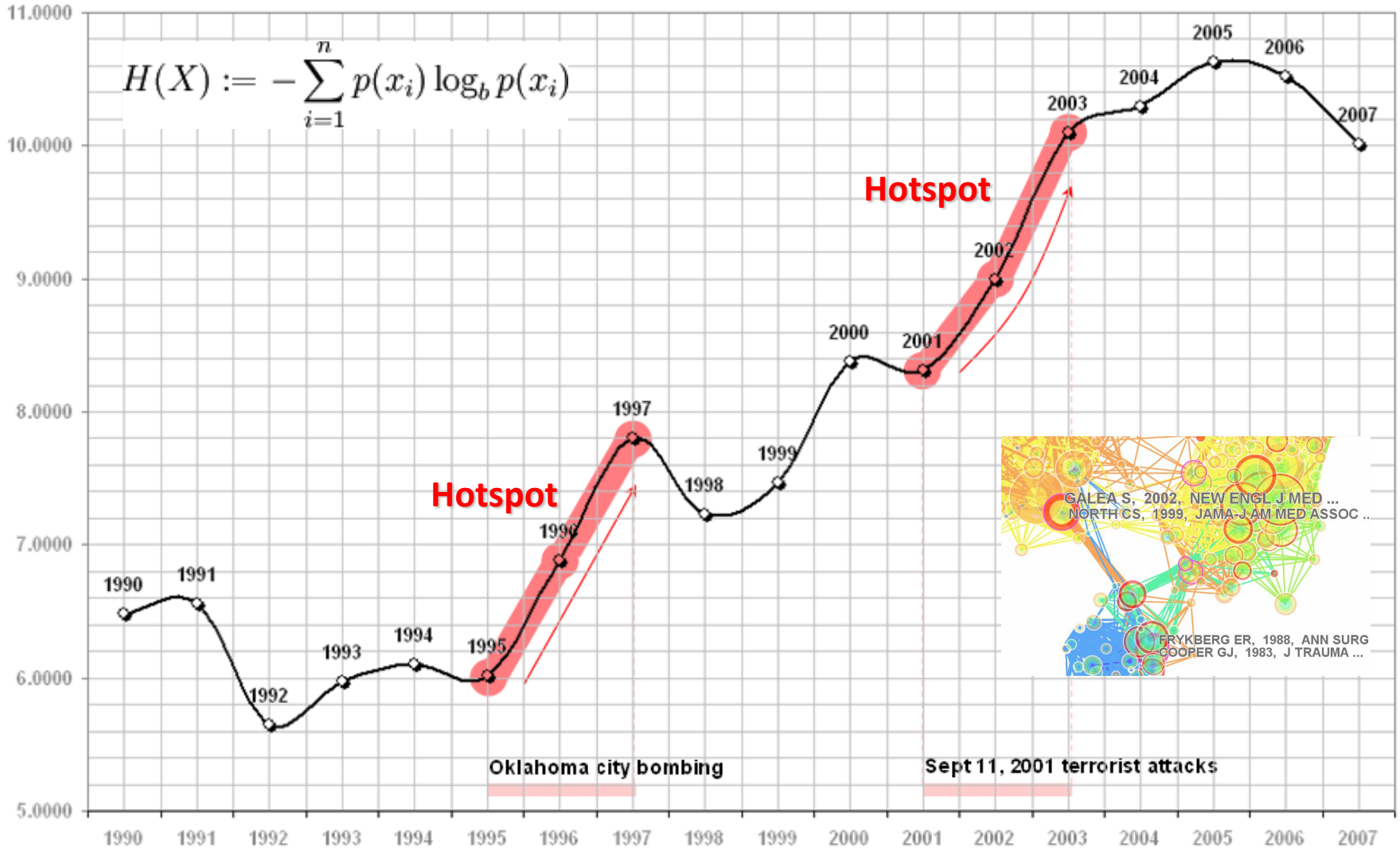
CiteSpace, v. 2.1. Release 12
September 6, 2008 9:24:11 AM EDT
C:\CHINA-Dalian\Data\WOS\Nano SCI data\1997-2007 SC NanoSciTech TC3
Timespan: 1997-2007 (Slice Length=1)
Threshold (c, cc, ccv): 2, 2, 20; 4, 3, 20; 3, 3, 20
Network: N=1167, E=6549

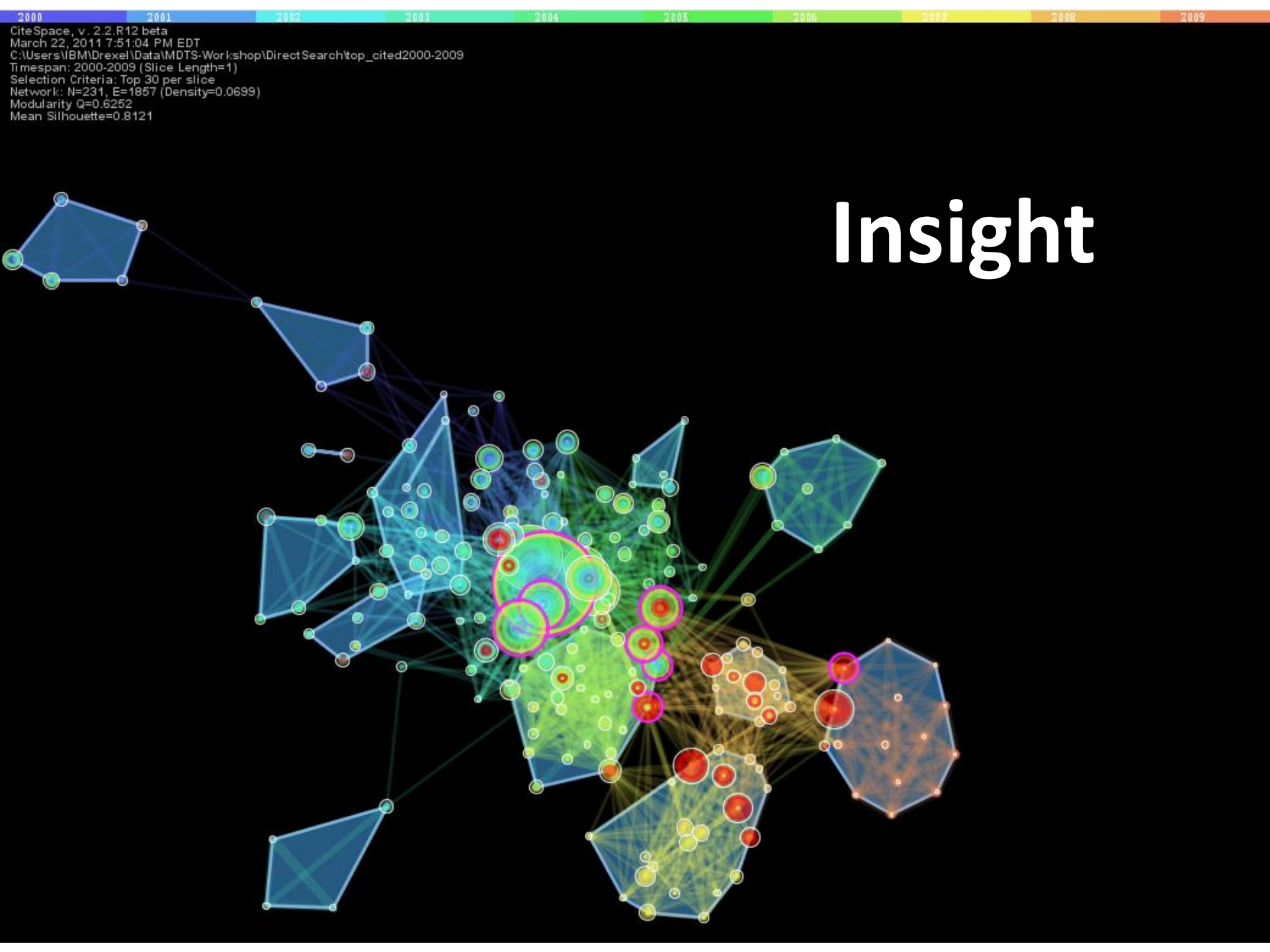
The Transient Scientific Frontiers



Nanoscience 1997-2007

Signs and Indicators




2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
CiteSpace, v. 2.2.R12 beta
March 22, 2011 7:51:04 PM EDT
C:\Users\IBM\Drexel\Data\MDTS-Workshop\DirectSearch\top_cited2000-2009
Timespan: 2000-2009 (Slice Length=1)
Selection Criteria: Top 30 per slice
Network: N=231, E=1857 (Density=0.0699)
Modularity Q=0.6252
Mean Silhouette=0.8121
Insight

Intellectual Turning Points and Paradigm Shifts

CiteSpace © 2003-2010 Chaomei Chen

Visualizing Patterns and Trends in Scientific Literature

WebStart **Archive**
User Guide **Tutorial** **Screenshots** **Publications** **Videos**
News **User Map**
Questions **Wiki**

Chen, C. et al. (2010) The structure and dynamics of co-citation clusters: A multiple-perspective co-citation analysis. *Journal of the American Society for Information Science and Technology*. (10.1002/asi.21309)

Chen, C. (2006) CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. *Journal of the American Society for Information Science and Technology*, **57**(3), 359-377. 《中译本》

Chen, C. (2004) Searching for intellectual turning points: Progressive Knowledge Domain Visualization. *Proceedings of the National Academy of Sciences of the United States of America* (PNAS), **101** (Suppl. 1), 5303-5310.

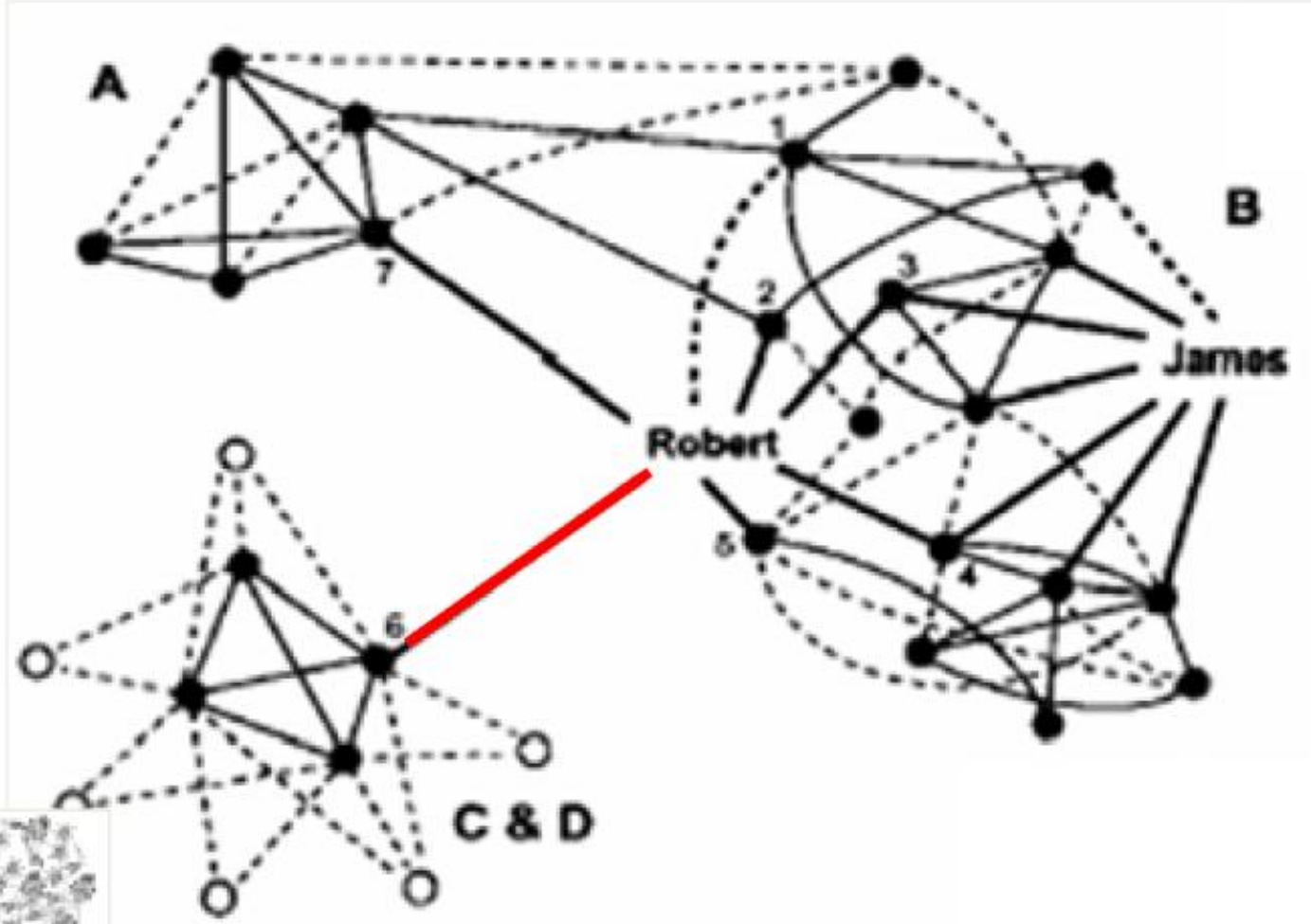
March 13, 2004: Science News Online. Mapping Scientific Frontiers by Ivars Peterson. (Local Copy)

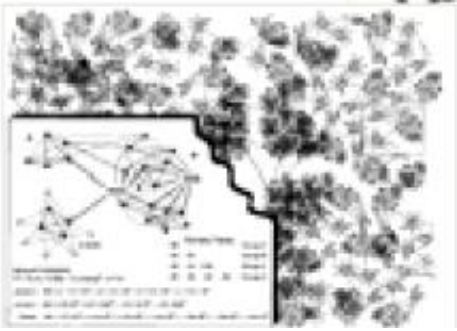
SCIENCE NEWS Online

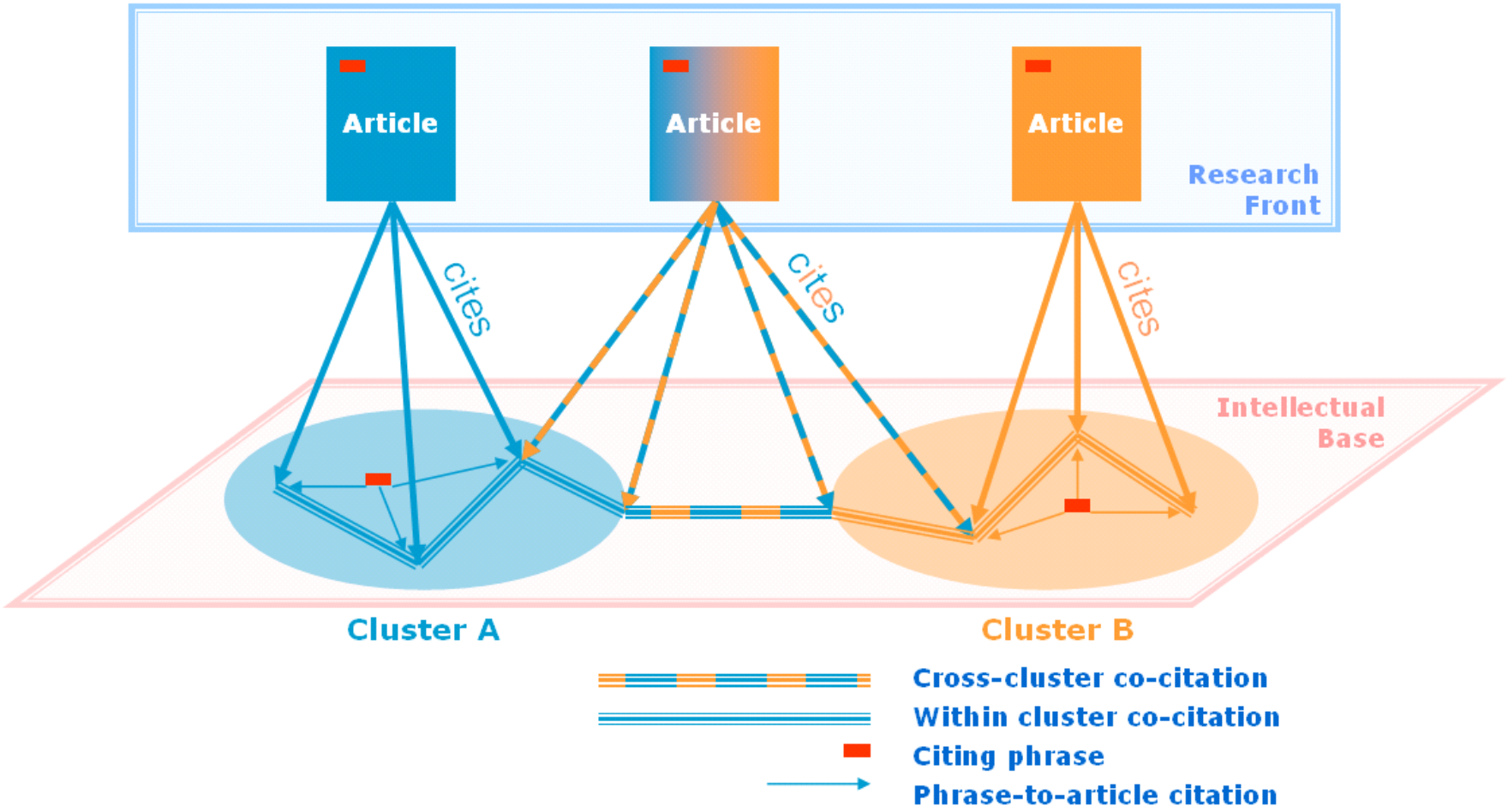
January 21, 2004: BioMedNet. Special Report: Mapping intellectual milestones by Helen Dell. (Local Copy)

BioMedNet bmn.com

Structural Holes in Social Networks

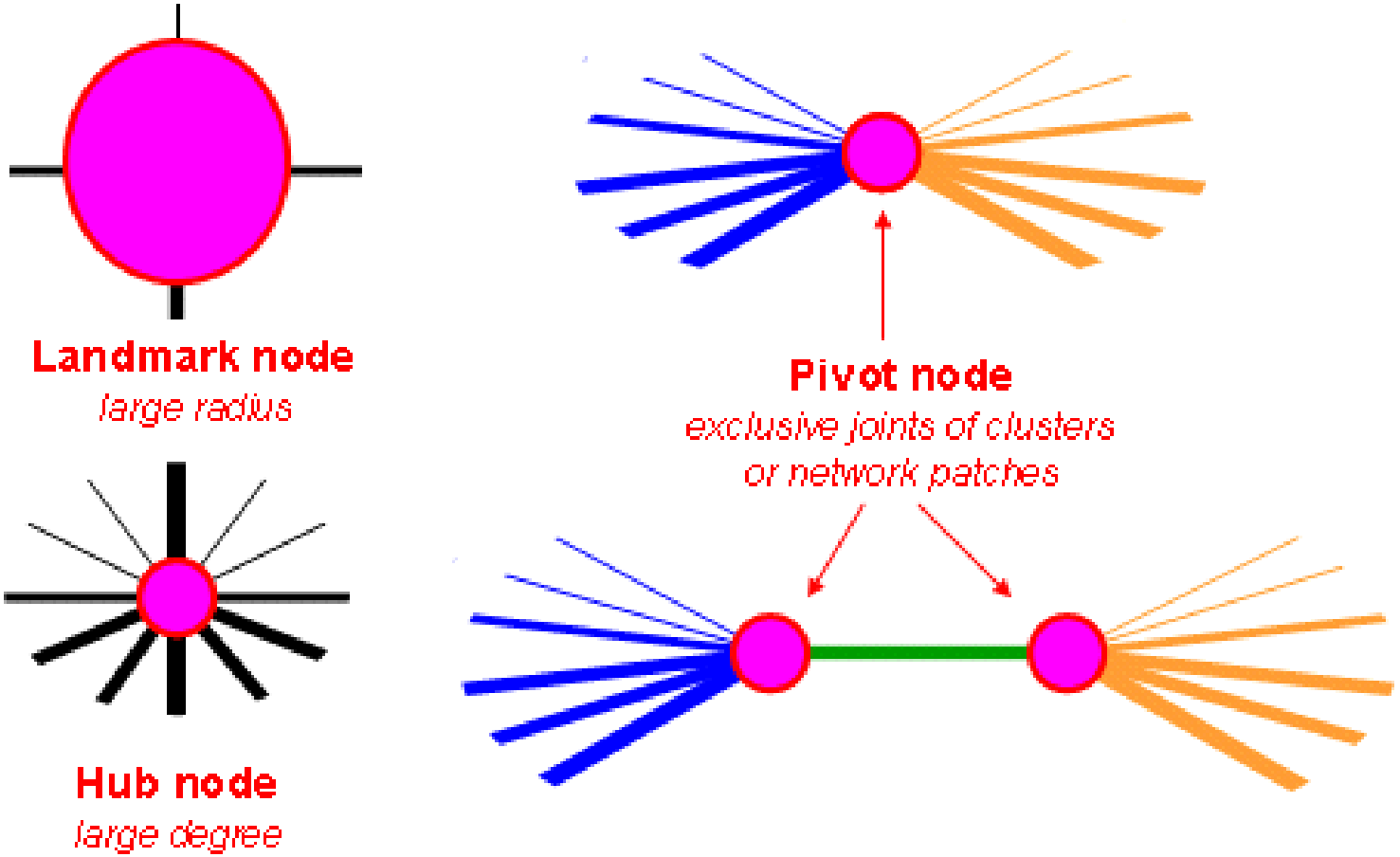


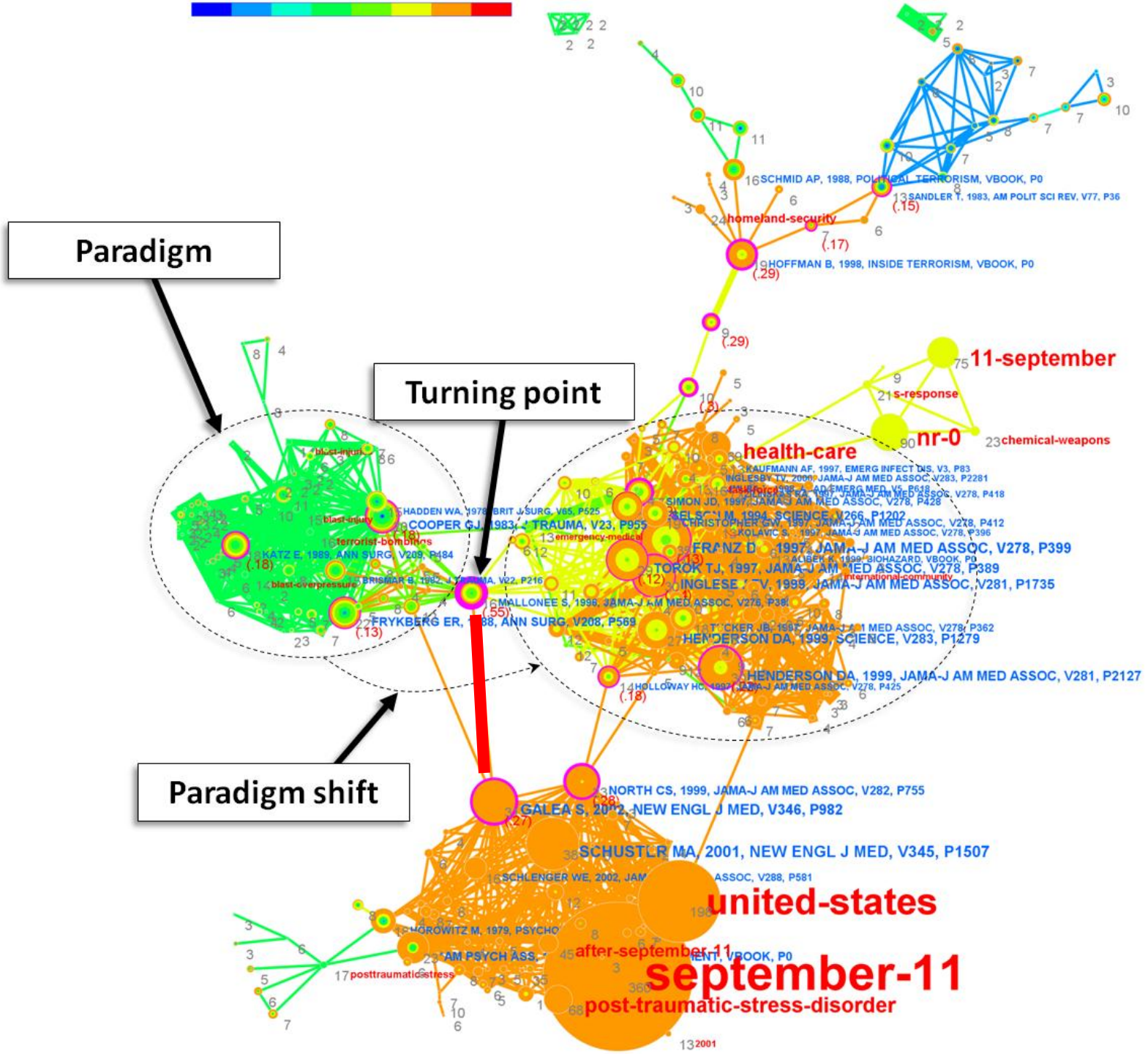



Article
Article
Article
Research Front
cites
cites
cites
Intellectual Base
Cluster A
Cluster B
Cross-cluster co-citation
Within cluster co-citation
Citing phrase
Phrase-to-article citation

CiteSpace

Chen, C. (2004) Searching for intellectual turning points. *PNAS*, 101 (Suppl. 1), 5303-5310




Paradigm
Turning point
Paradigm shift
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11-september
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nr-0
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health-care
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INGLESBY TV, 2000, JAMA-J AM MED ASSOC, V283, P2281
SIMON JD, 1997, JAMA-J AM MED ASSOC, V278, P428
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international-community
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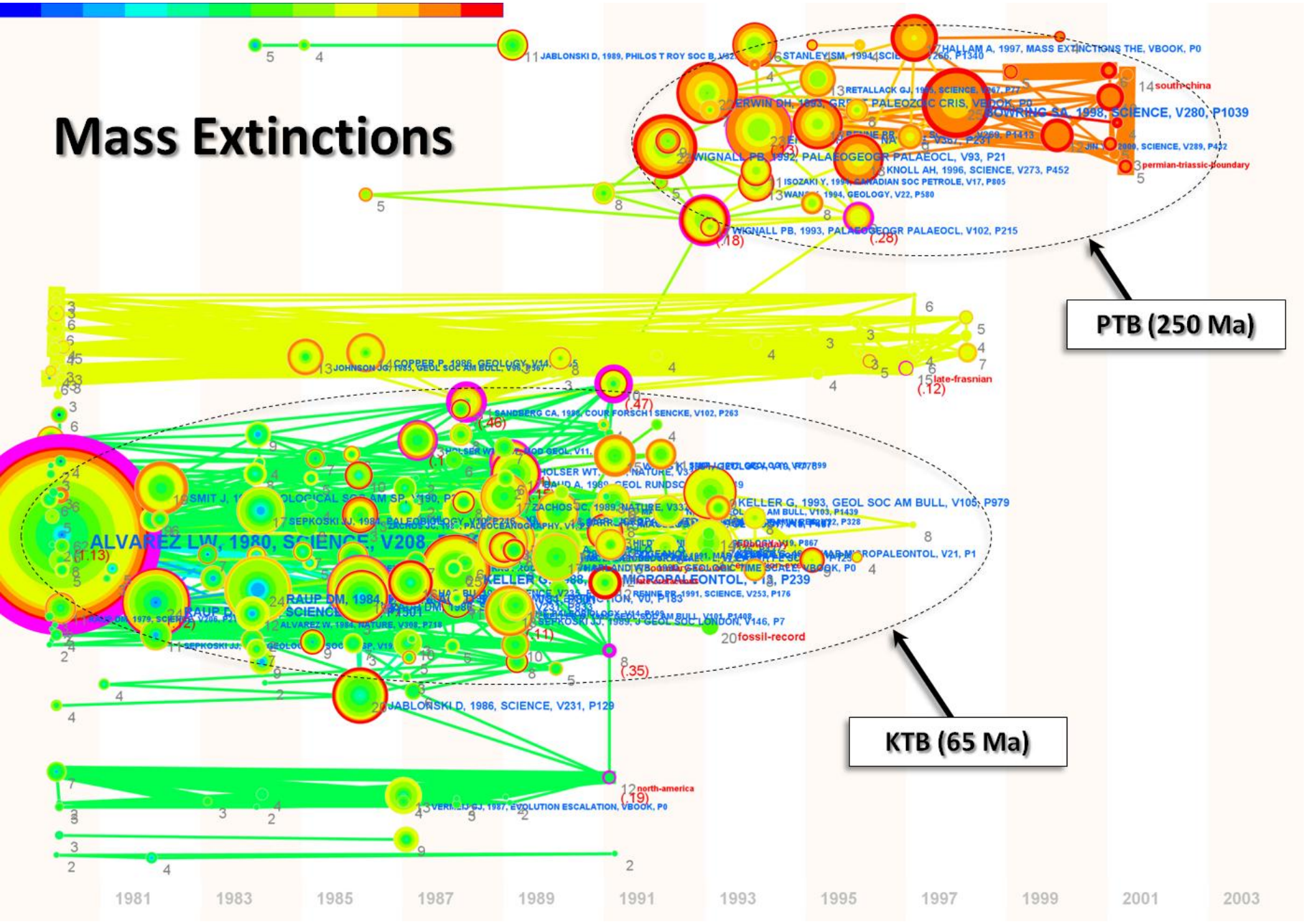
posttraumatic-stress
after-september-11
september-11
post-traumatic-stress-disorder
united-states
2001

2. *What was the major impact or implication of your article on subsequent research?*

   There have been a number of articles that have been published after the September 11 attacks, all discussing in some respect the psychological consequences of those attacks/potential implications of terrorism. I think our article (a) established the importance of terrorist events for population mental health (b) clearly laid out the fact that persons in the general population (not just victims) can have psychological disorders after a mass disaster.

Mass Extinctions



InterScience

CiteSpace II: Detecting and Visualizing Emerging Trends and Transient Patterns in Scientific Literature

Chaomei Chen
College of Information Science and Technology, Drexel University, 3141 Chestnut Street, Philadelphia, PA 19104-2875. E-mail: chaomei.chen@cis.drexel.edu

This article describes the latest development of a generic approach to detecting and visualizing emerging trends and transient patterns in scientific literature. The work makes substantial theoretical and methodological contributions to progressive knowledge domain visualization. A specialty is conceptualized and visualized as a time-variant duality between two fundamental concepts in information science: research fronts and intellectual bases. A research front is defined as an emergent and transient grouping of concepts and underlying research issues. The intellectual base of a research front is its citation and co-citation footprint in scientific literature—an evolving network of scientific publications cited by research-front concepts. Kleinberg's (2002) burst-detection algorithm is adapted to identify emergent research-front concepts. Freeman's (1979) betweenness centrality metric is used to highlight potential pivotal points of paradigm shift over time. Two complementary visualization views are designed and implemented: cluster views and time-zone views. The contributions of the approach are that (a) the nature of an intellectual base is algorithmically and temporally identified by emergent research-front terms, (b) the value of a co-citation cluster is explicitly interpreted in terms of research-front concepts, and (c) visually prominent and algorithmically detected pivotal points substantially reduce the complexity of a visualized network. The modeling and visualization [illegible] CiteSpace II, a Java application [illegible] research fields: [illegible] works were [illegible] who are the authors of [illegible] plications of the work are discussed. [illegible] lenges and opportunities for future studies are identified.

Introduction

Scientific literature is characterized by two distinct citation half-lives of articles: classic articles with persistently high citations and transient ones with their citations peaked within a short period of time (Price, 1965). Transient ones are much more common than classics (van Raan, 2000). The average length of time that a research article continues to be cited in the scientific literature is closely connected to the growth speed of the underlying research area (Abt, 1998). Understanding the dynamics of how transient articles transform the intellectual landscape of a scientific field has significant practical implications for scientists in a wide variety of disciplines.

Emergent trends and abrupt changes in the scientific literature can be associated with internal as well as external causes. Typical internal causes include new discoveries and scientific breakthroughs such as the discovery of an impact crater in mass-extinction research or the discovery of a supermassive black hole in astronomy. External ones may provoke scientists to study a subject matter from new perspectives. For example, the September 11, 2001, terrorist attacks have raised a variety of new issues to be addressed by researchers in national security, health care, posttraumatic stress disorder (PTSD) research, and many other areas. Detecting and understanding emerging trends and abrupt changes caused by such events in scientific disciplines can significantly improve the ability of scientists to deal with the changes in a timely manner. It is worth noting [illegible] large-scale changes in complex systems characterized [illegible] self-organized criticality may take place without apparent [illegible] triggering events (Bak & Chen, 1991). There is limited evidence to suggest that the growth of scientific literature may be connected to self-organized criticality (van Raan, 2000). In this article, we concentrate on changes associated with significant events.

The concept of a *research front* was originally introduced by Price (1965) to characterize the transient nature of a research field. Price observed what he called the immediacy factor: There seems to be a tendency for scientists to cite the most recently published articles. In a given field, a research front refers to the body of articles that scientists actively cite. According to Price, a research front may consist of 40 to 50 recent articles. A research front has been studied in at least

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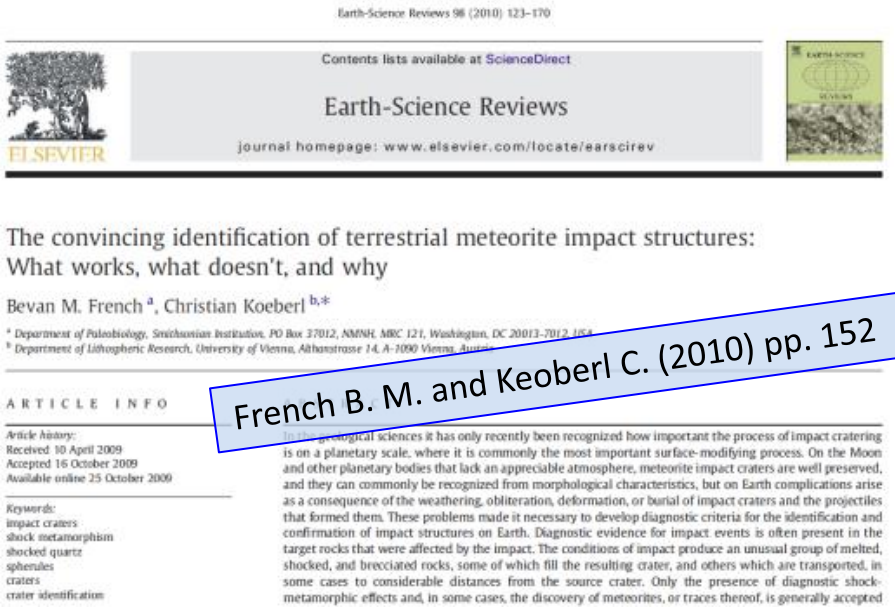
Chen, C. (2006) pp. 369



Earth-Science Reviews 98 (2010) 123–170

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journal homepage: www.elsevier.com/locate/earscirev

The convincing identification of terrestrial meteorite impact structures: What works, what doesn't, and why

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impact craters
shock metamorphism
shocked quartz
spherules
craters
crater identification

[illegible] geological sciences it has only recently been recognized how important the process of impact cratering is on a planetary scale, where it is commonly the most important surface-modifying process. On the Moon and other planetary bodies that lack an appreciable atmosphere, meteorite impact craters are well preserved, and they can commonly be recognized from morphological characteristics, but on Earth complications arise as a consequence of the weathering, obliteration, deformation, or burial of impact craters and the projectiles that formed them. These problems made it necessary to develop diagnostic criteria for the identification and confirmation of impact structures on Earth. Diagnostic evidence for impact events is often present in the target rocks that were affected by the impact. The conditions of impact produce an unusual group of melted, shocked, and brecciated rocks, some of which fill the resulting crater, and others which are transported, in some cases to considerable distances from the source crater. Only the presence of diagnostic shock-metamorphic effects and, in some cases, the discovery of meteorites, or traces thereof, is generally accepted

French B. M. and Keoberl C. (2010) pp. 152

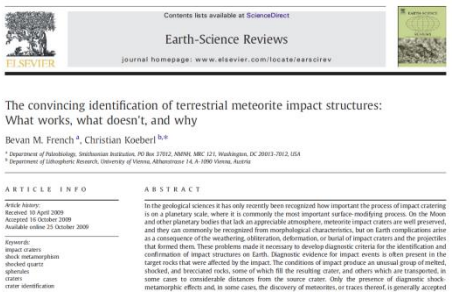
2006

2010

7.1.1. Background

The end of the Permian period, about 250 Ma ago, is marked by the largest known mass extinction in geological history. At this time, in two closely-separated events, more than the 90% of known marine species disappeared, accompanied by a major portion of terrestrial species as well (Erwin, 1993, 2006). Since the establishment of a firm connection between the later K–T extinction and a major impact event (Alvarez et al., 1980), numerous workers have searched for evidence of a similar connection between another large impact event and the Permian extinctions. Most efforts have concentrated on the younger and larger of the two extinction events, which marks the actual Permian–Triassic (P–Tr) boundary at 251 Ma.

French B. M. and Keoberl C. (2010) pp. 152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The convincing identification of terrestrial meteorite impact structures: What works, what doesn't, and why

Bevan M. French [a], Christian Koeberl [b,*]

[a] Department of Paleobiology, Smithsonian Institution, PO Box 37012, MRNH, MRC 121, Washington, DC 20013-7012, USA
[b] Department of Lithospheric Research, University of Vienna, Althanstrasse 14, A-1090 Vienna, Austria

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Keywords:
impact craters
shock metamorphism
shocked quartz
spherules
craters
crater identification

ABSTRACT

In the geological sciences it has only recently been recognized how important the process of impact cratering is on a planetary scale, where it is commonly the most important surface-modifying process. On the Moon and other planetary bodies that lack an appreciable atmosphere, meteorite impact craters are well preserved, and they can commonly be recognized from morphological characteristics, but on Earth complications arise as a consequence of the weathering, obliteration, deformation, or burial of impact craters and the projectiles that formed them. These problems made it necessary to develop diagnostic criteria for the identification and confirmation of impact structures on Earth. Diagnostic evidence for impact events is often present in the target rocks that were affected by the impact. The conditions of impact produce an unusual group of melted, shocked, and brecciated rocks, some of which fill the resulting crater, and others which are transported, in some cases to considerable distances from the source crater. Only the presence of diagnostic shock-metamorphic effects and, in some cases, the discovery of meteorites, or traces thereof, is generally accepted

Chen, C. (2006) pp. 369


CiteSpace II: Detecting and Visualizing Emerging Trends and Transient Patterns in Scientific Literature

Chaomei Chen

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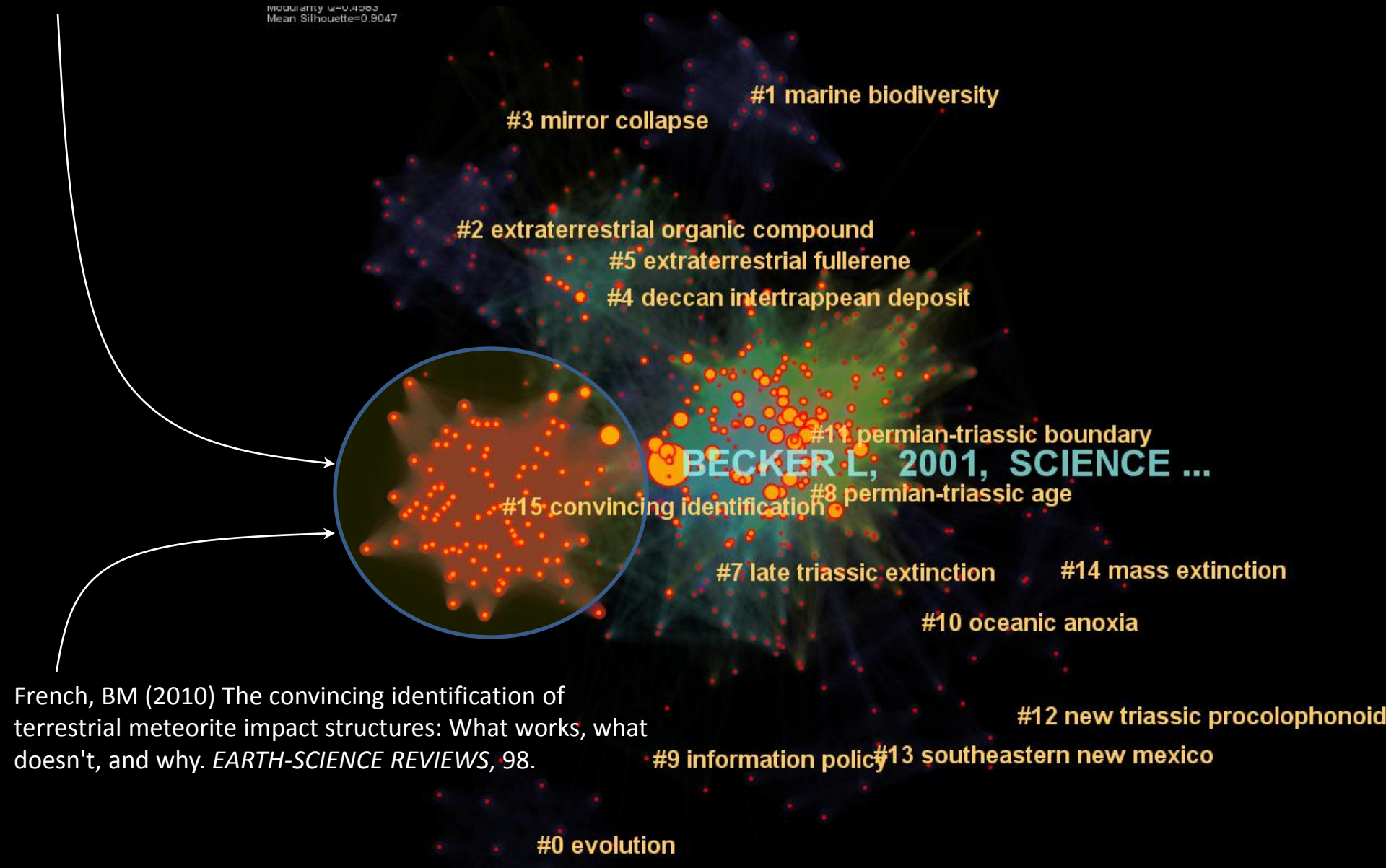
comparable to that of the Chicxulub crater to the K-T impact theory. The discovery of the Chicxulub crater dramatically boosted the credibility of the K-T impact theory. Encouraged by the successful puzzle-solving experience, many scientists appear to have adapted the same approach to solve a different puzzle—by applying the impact theory to an earlier mass extinction. Finding the impact crater is the next logical step. Identifying a Permian-Triassic boundary impact crater has attracted the attention of many researchers. It was in this context that the current research front has emerged.

Farley, KA (2001) An extraterrestrial impact at the Permian-Triassic boundary? *SCIENCE*, 293.

Without confirmation of fullerene-hosted ^{3}He in Bed 25, both the occurrence of an extraterrestrial impact and the cause of the mass extinction at the PTB must remain open questions.



French, BM (2010) The convincing identification of terrestrial meteorite impact structures: What works, what doesn't, and why. *EARTH-SCIENCE REVIEWS*, 98.

A Roadmap Drawn by a Leading Expert in the Field

Geobiology (2007), 5, 303–309 DOI: 10.1111/j.1472-4669.2007.00130.x

Editorial

The End-Permian mass extinction – how bad did it get?

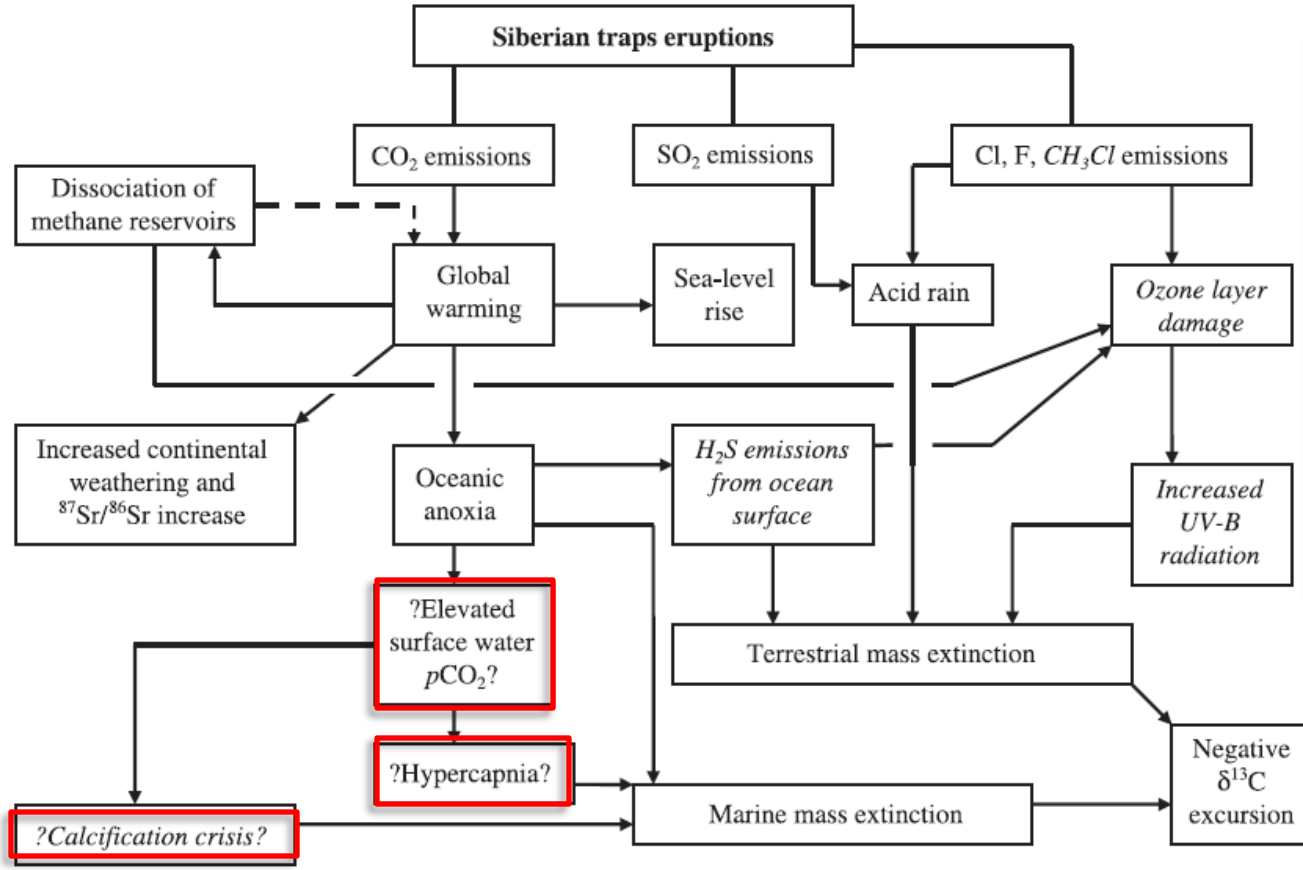


Fig. 2 Flow chart, modified from Fig. 1, summarizing the cascade of environmental consequences caused by the eruption of the Siberian Traps and the latest additions, since 2001, to current thought (shown in italics). The increase in viable terrestrial extinction mechanisms is especially notable. Although this diagram attempts to show a current consensus, all aspects of the chart are actively debated. Boxes with a '?' denote proposed causes and effects that, for this author at least, should be treated with skepticism.

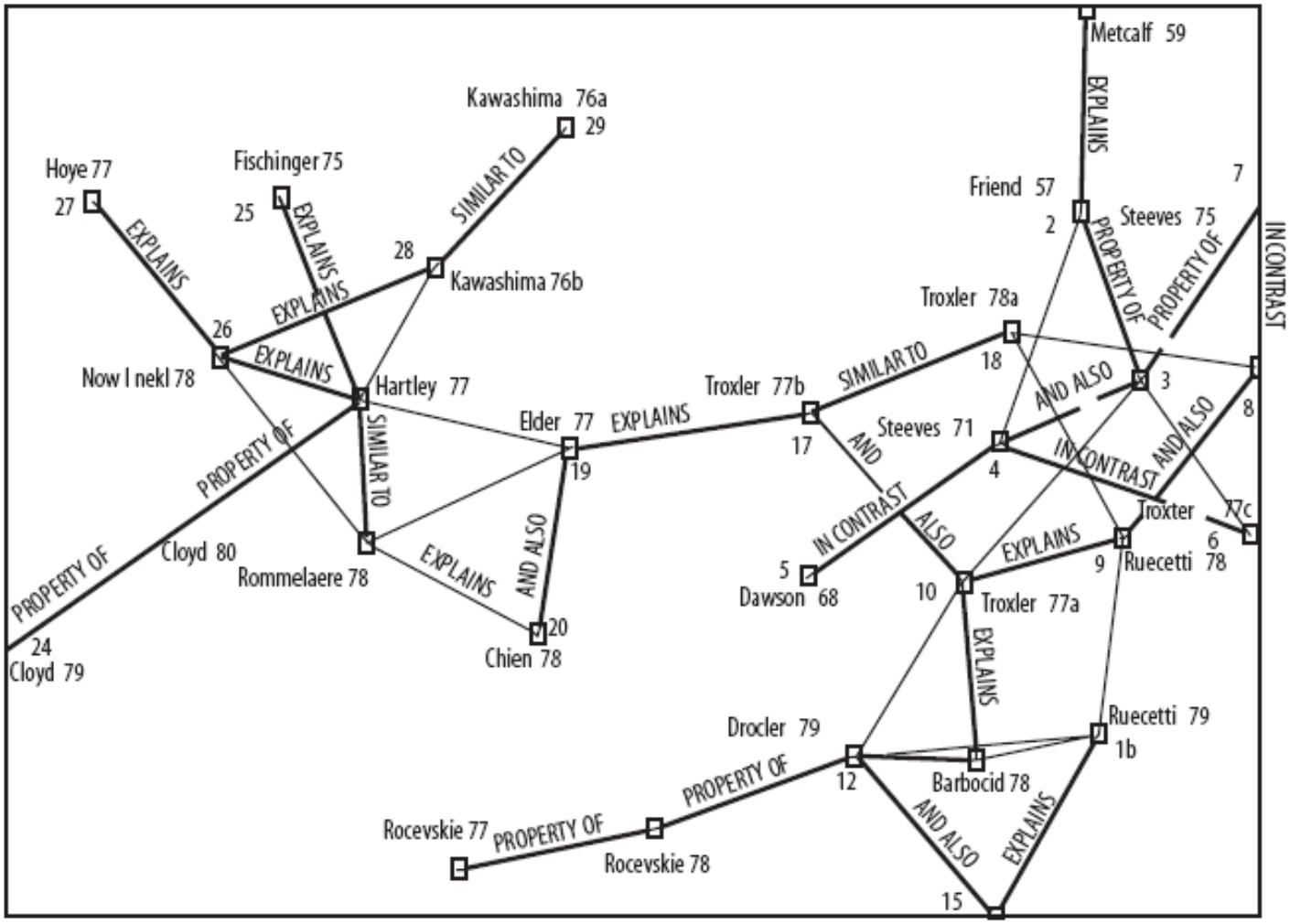
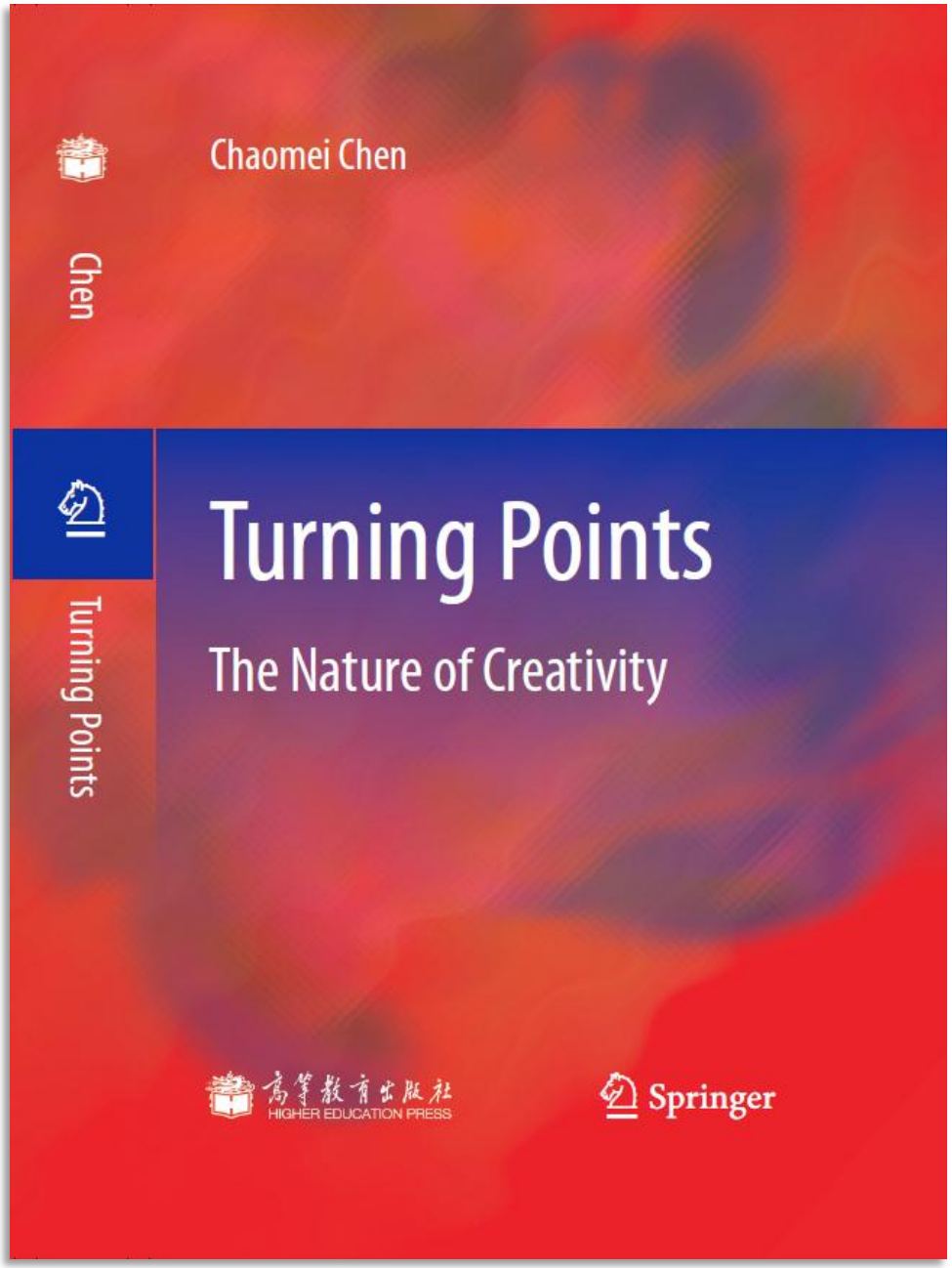


Figure 5.9 Specialty narrative of leukemia viruses. Specialty narrative links are labeled by citation-context categories (Small, 1986). Reproduced by permission of Henry Small.

Foresight



- What is the nature of creativity?
- What will attract our attention?
- Are there generic mechanisms of creative thinking?
- Where is a creative idea likely to appear?

How Do We Find Our Way?

- Donald T. Campbell (Psychology)
  - Blind variation and selective retention
- Albert Rothenberg (Psychology)
  - The Janusian Process
  - To be AND not to be
- Hongzhou Zhao(Physics):
  - Elements of knowledge
  - Binding of 'free' elements of knowledge
  - The Yuasa Phenomenon
- Ronald S. Burt (Sociology)
  - Brokerage as a social capital and a source of good ideas
- Our own theory (Information Science)
  - Explanatory and computational
  - Structural + temporal properties
  - Early signs of transformative research

Some of these theories are instructional – they provide guidance that we can follow. Others provide no such guidance.

Searching for Growth Points of Creativity

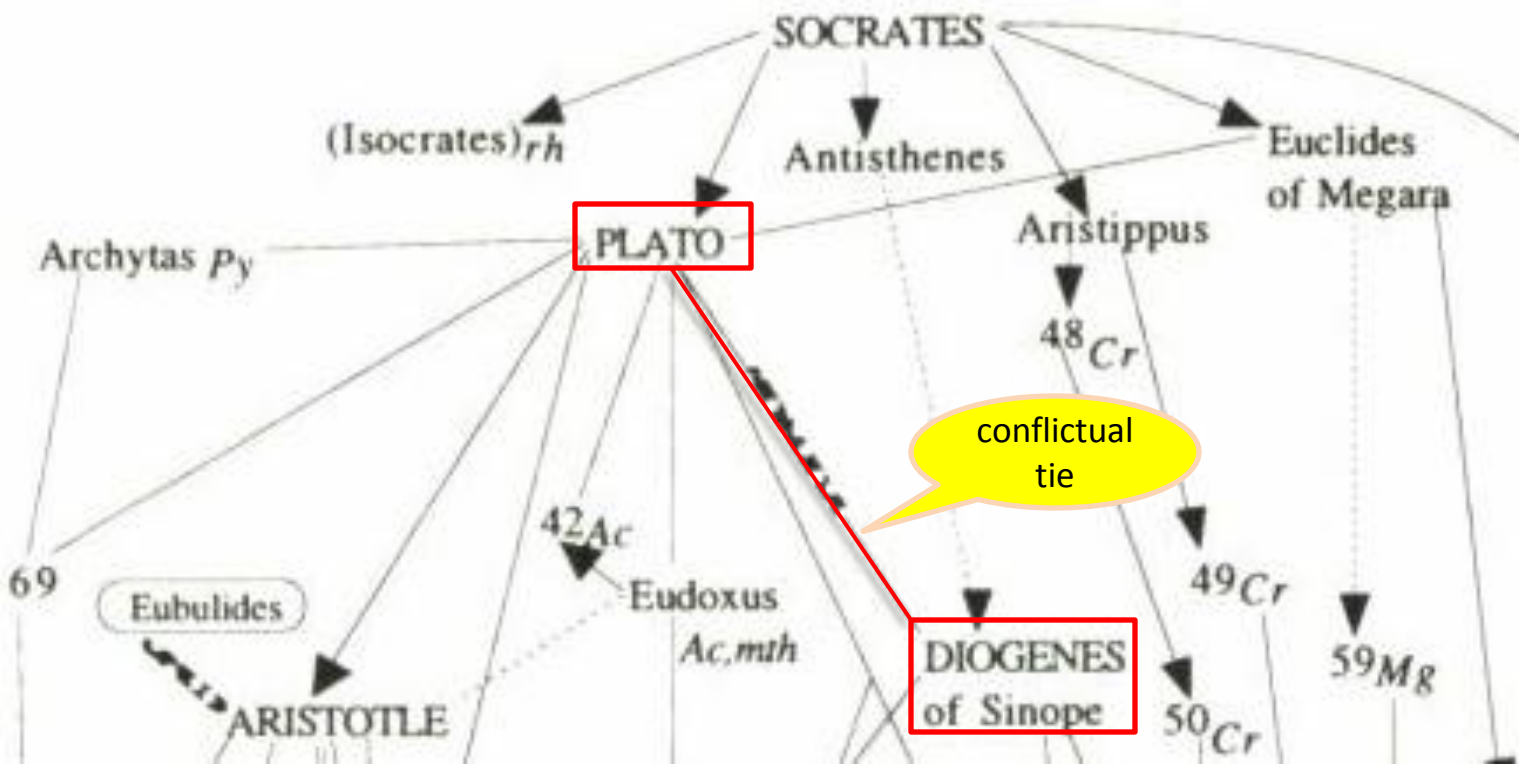
- *Creativity is the friction of the attention space at the moments when the structural blocks are grinding against one another the hardest.*

Collins (1998, p.76)

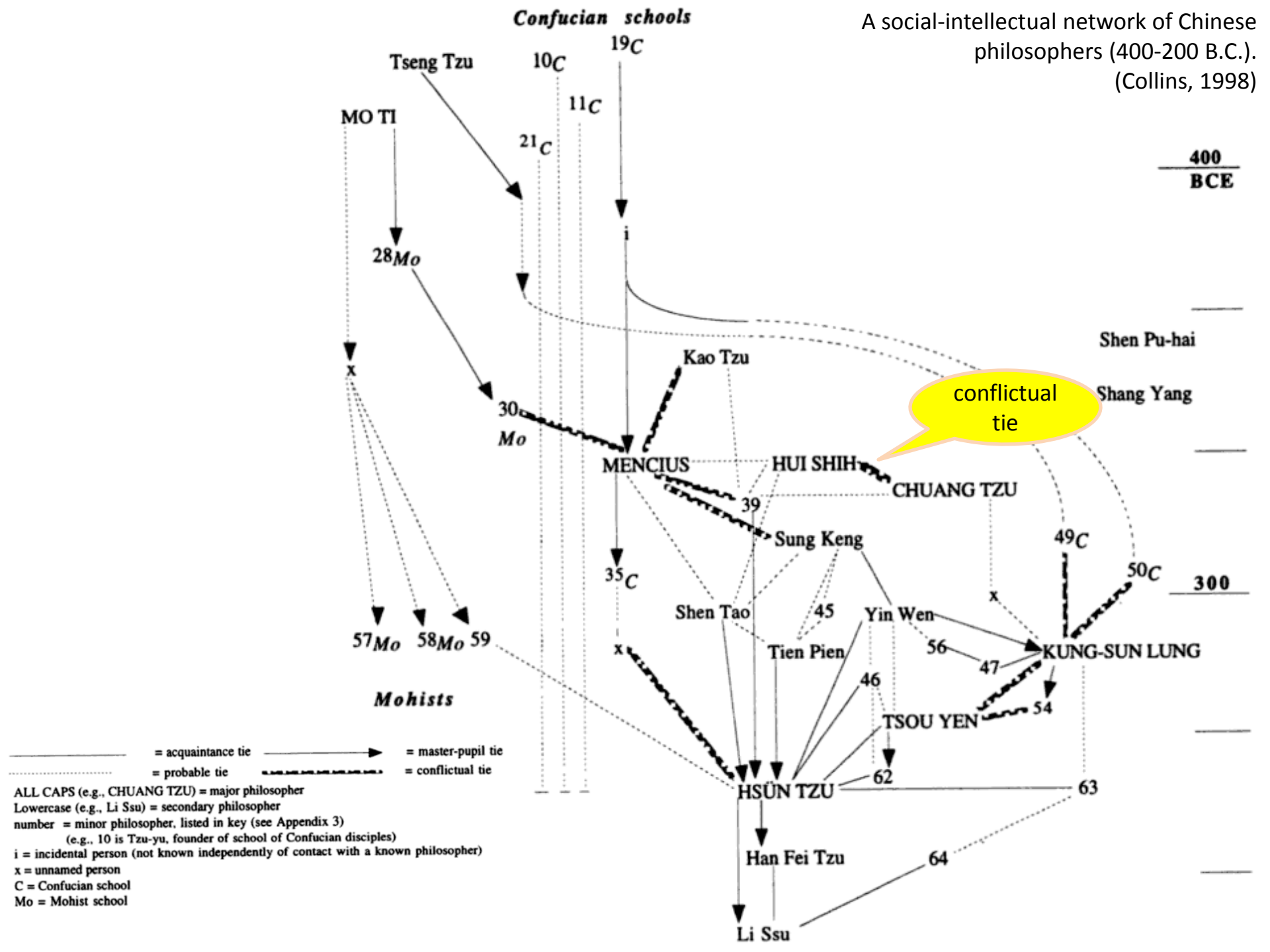
Conflicting Thoughts Make Great Philosophers

Collins, Randall (1998) The sociology of philosophers. Cambridge, MA: Harvard University Press

The philosophers of greatest repute tend to be personal rivals representing conflicting schools of thought for their generation. p. 76.



A social-intellectual network of Chinese philosophers (400-200 B.C.). (Collins, 1998)



Making the Right Connections

The Video Tape Recorder

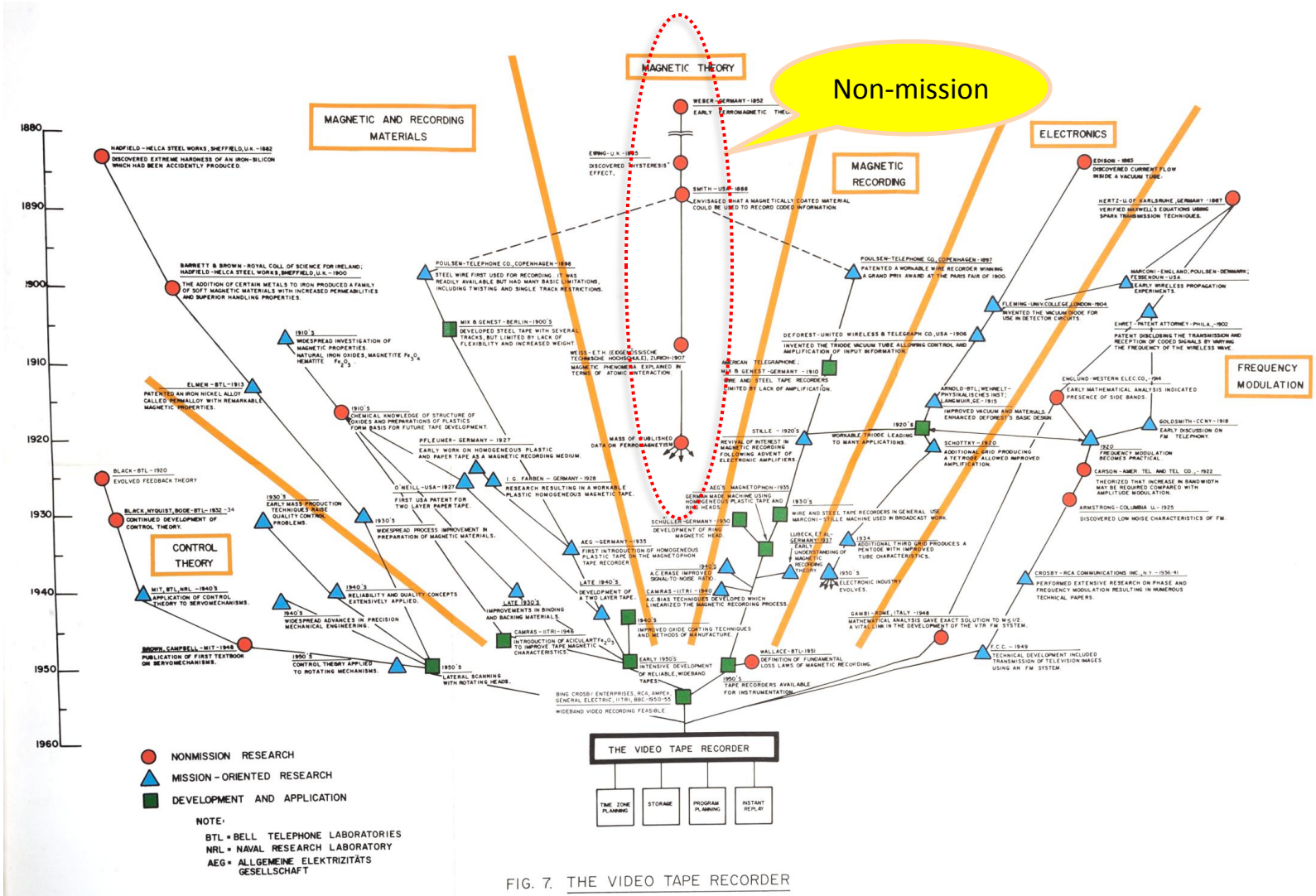


FIG. 7. THE VIDEO TAPE RECORDER

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Journal of INFORMETRICS

Towards an explanatory and computational theory of scientific discovery☆

Chaomei Chen[a,b,*], Yue Chen[b], Mark Horowitz[a], Haiyan Hou[b], Zeyuan Liu[b], Donald Pellegrino[a]

[a] College of Information Science and Technology, Drexel University, USA
[b] The WISE Lab, Dalian University of Technology, China

1. Structural properties: *brokerage as a discovery mechanism*
2. Temporal properties: *good ideas are in general easy to recognize*

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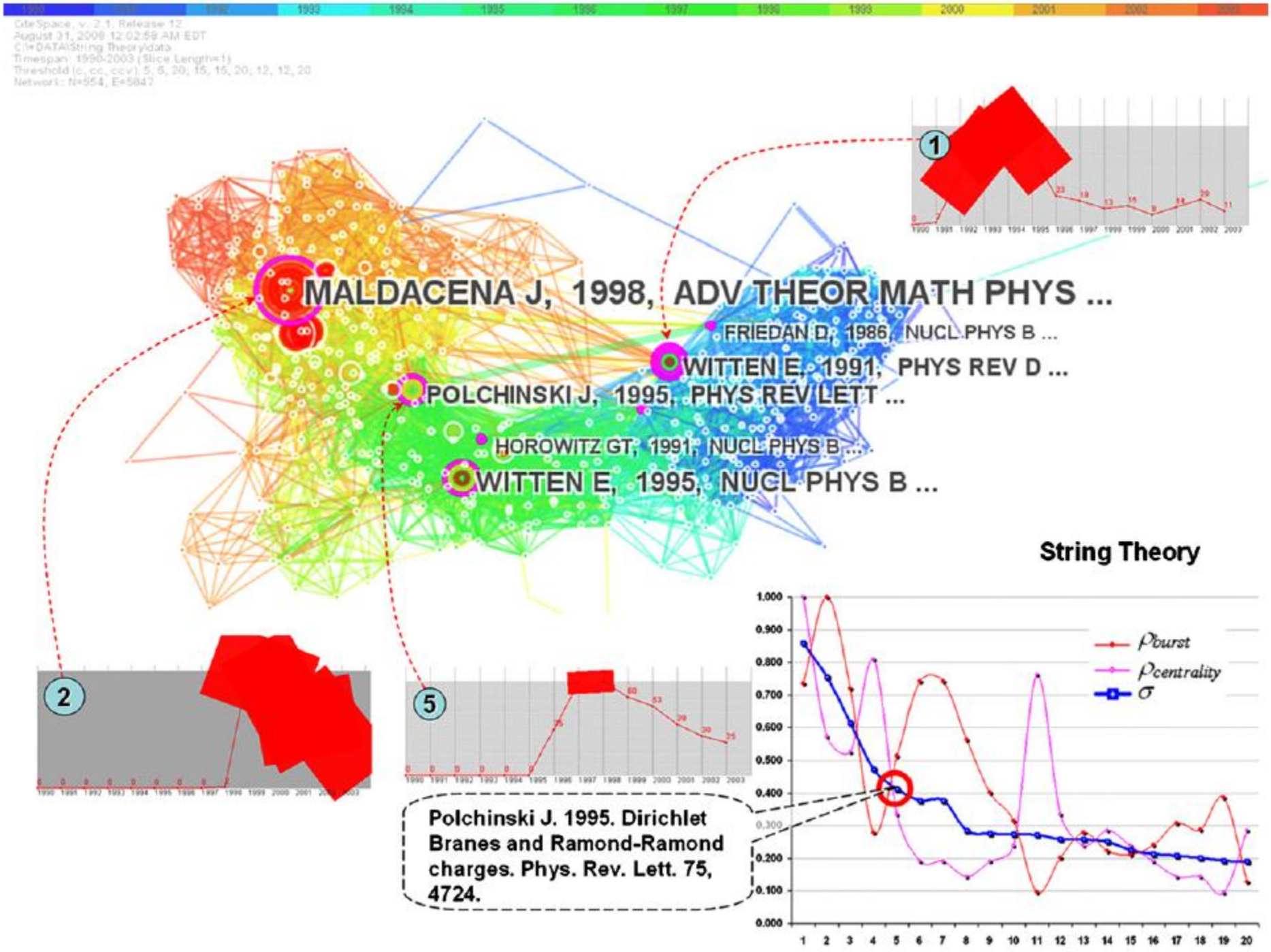
Transformative scientific discoveries
Theory of structural holes
Intellectual brokerage
Knowledge diffusion
Information foraging

ABSTRACT

We propose an expla eries in sci-
ence. The theory is of scientific
change, scientific dis ience, soci-
ology of science, soc extends the
concept of structural e networks
found in science studies, especially including networks that reflect underlying intellectual structures such as co-citation networks and collaboration networks. The central premise is that connecting otherwise disparate patches of knowledge is a valuable mechanism of creative thinking in general and transformative scientific discovery in particular. In addition, the premise consistently explains the value of connecting people from different disciplinary specialties. The theory not only explains the nature of transformative discoveries in terms of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August 31, 2008 12:02:59 AM EDT
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Threshold (c, cc, ccv): 5, 5, 20; 15, 15, 20; 12, 12, 20
Network: N=554, E=5847
1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003
1
MALDACENA J, 1998, ADV THEOR MATH PHYS ...
FRIEDAN D, 1986, NUCL PHYS B ...
WITTEN E, 1991, PHYS REV D ...
POLCHINSKI J, 1995, PHYS REV LETT ...
HOROWITZ GT, 1991, NUCL PHYS B ...
WITTEN E, 1995, NUCL PHYS B ...
String Theory
2
5
Polchinski J. 1995. Dirichlet Branes and Ramond-Ramond charges. Phys. Rev. Lett. 75, 4724.
ρburst
ρcentrality
σ
1.000
0.900
0.800
0.700
0.600
0.500
0.400
0.300
0.200
0.100
0.000
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

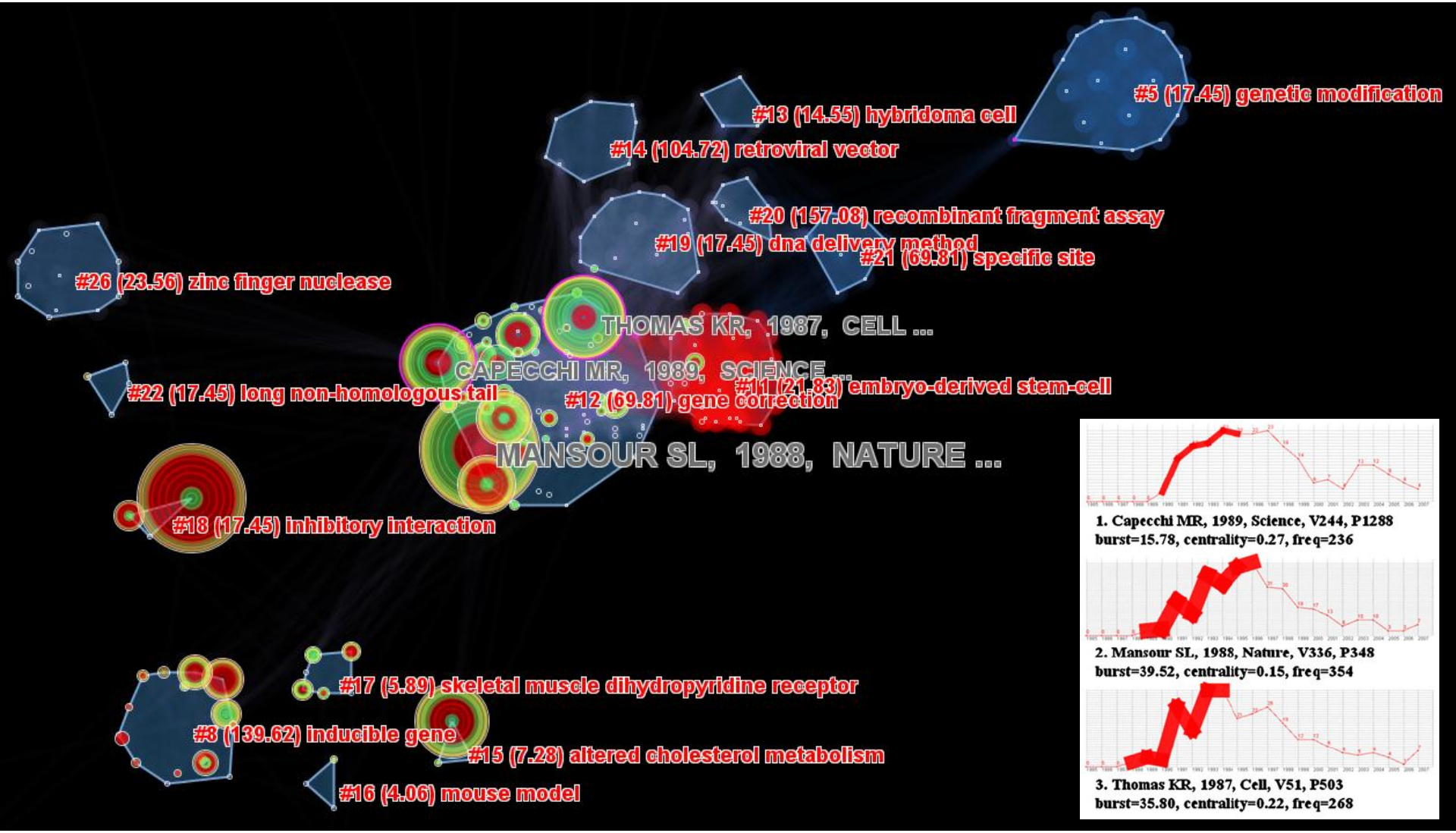
The Nature of Maldacena-1998

- We aked Juan Maldacena to identify the nature of his major contributions in this article to String Theory.
- His reply: "It ***connected*** two different kinds of theories: 1) particle theories or gauge theories and 2) string theory. Many of the papers on string dualities (and this is one of them) connect different theories. ***This one connects string theory to more conventional particle theories***."
- TIME 100 Innovator website
  - "he forged a ***connection*** between the esoteric formulas of string theory and the rest of mainstream physics."
  - "he has been able to suggest a way to knit together ***two theories previously thought to be incompatible***: quantum mechanics, which deals with the universe at its smallest scales; and Einstein's general theory of relativity, which deals with the very largest."
- He is the recipient of the 2007 Dannie Heineman Prize for Mathematical Physics
  - "for profound developments in Mathematical Physics that have illuminated ***interconnections*** and launched major research areas in Quantum Field Theory, String Theory, and Gravity."

…… made an unexpected connection

Nobel Prize Winning Gene Targeting

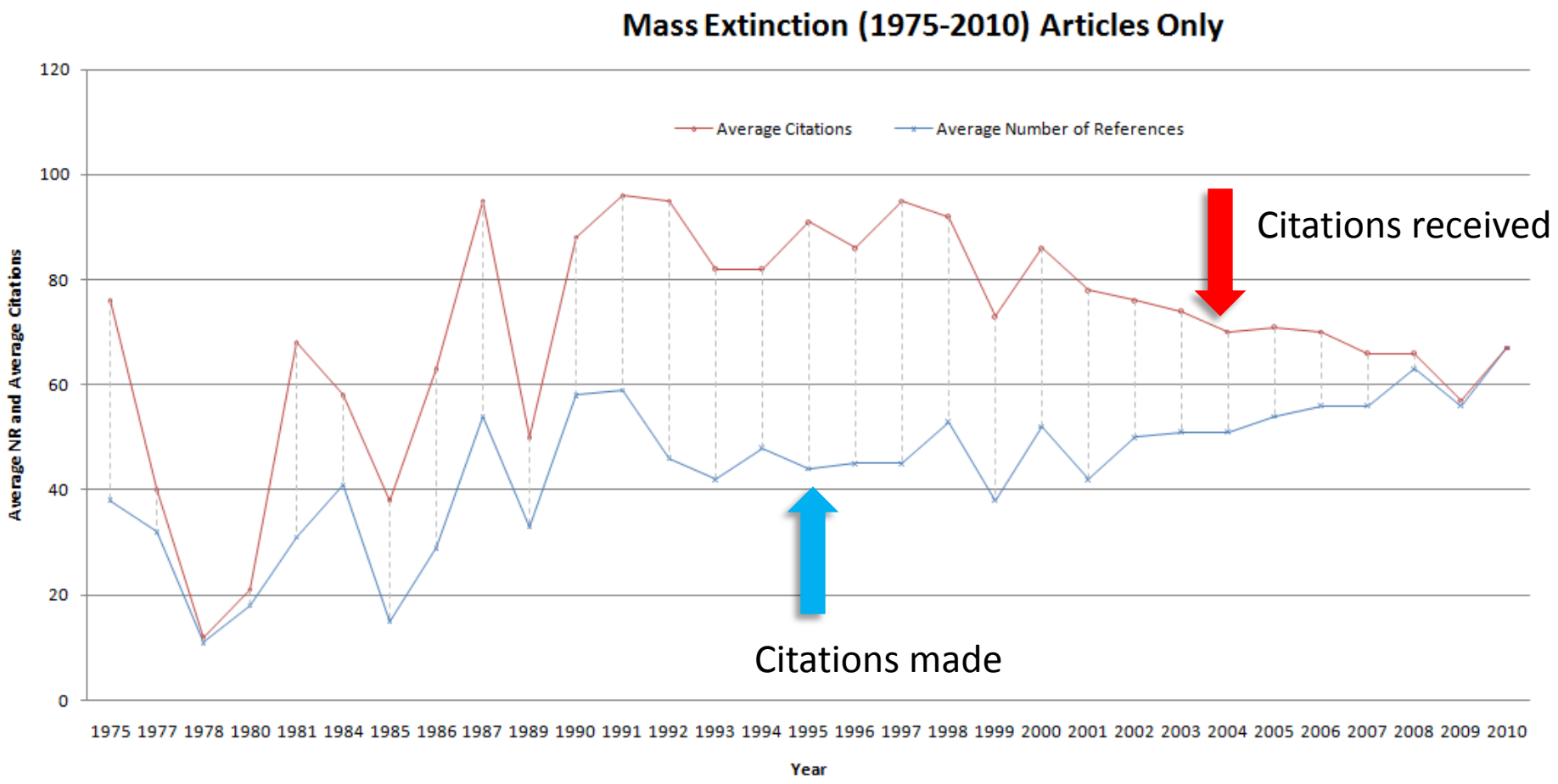
A *Sticky Effect* explains the boundary spanning and citation burst.



Measuring Creativity

Identifying Potentially Transformative Work

Citations Made ~ Citations Received



Theories of Discovery ➔Three Hypotheses

1. The number of references cited by a paper is not the real reason to explain its subsequent citations or other measures of its impact.
2. The conceptual diversity with respect to the state of the art is more fundamental to its potential impact.
3. The novelty, originality, and revolutionary change of knowledge landscape is an even more fundamental predictor for a high citation count in subsequent years.

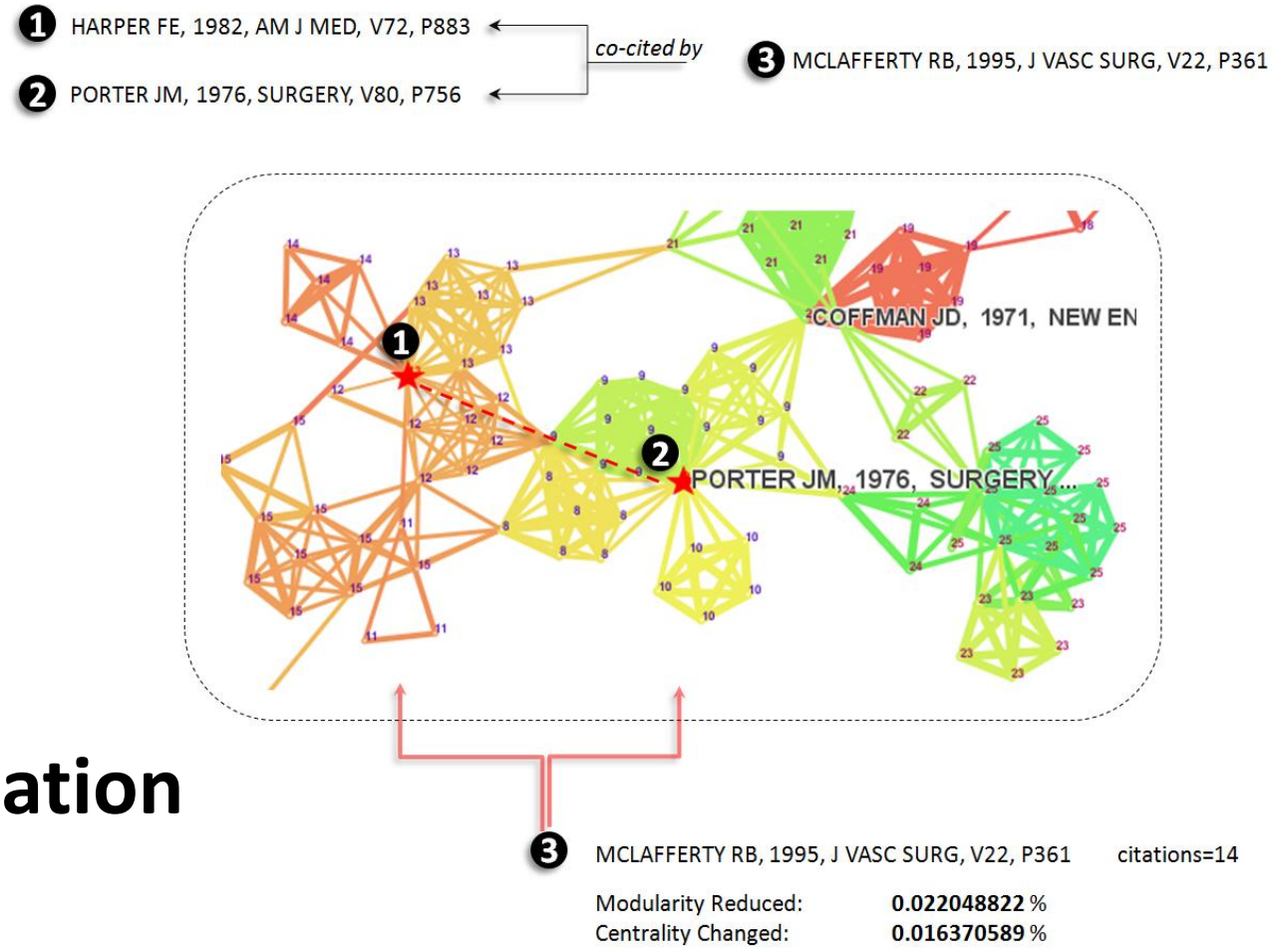
Citation ≈ number of references cited

World cup ~ Beer

Citation ≈ number of topics synthesized

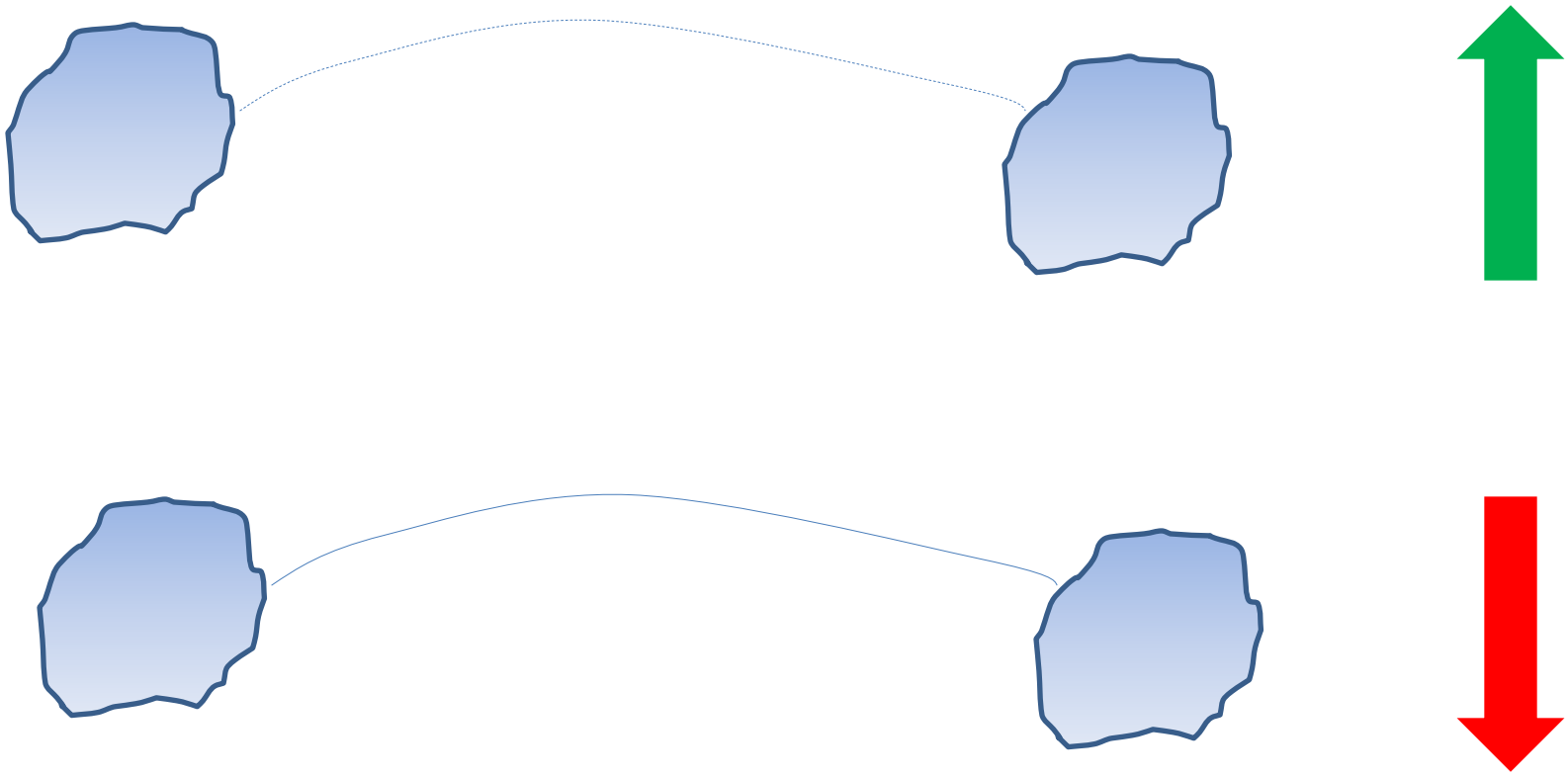
World cup ~ Octopus

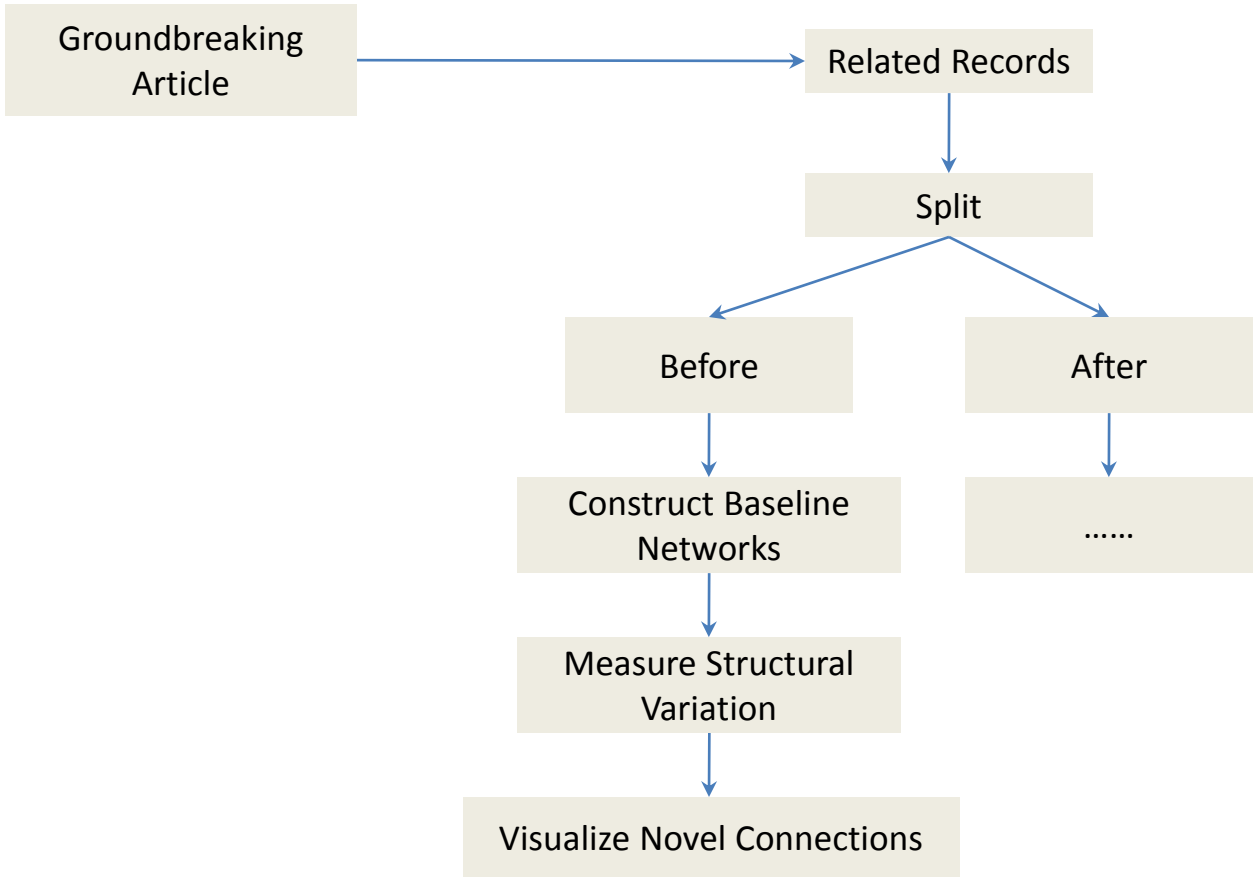
Citation ≈ number of previously unexpected topics synthesized



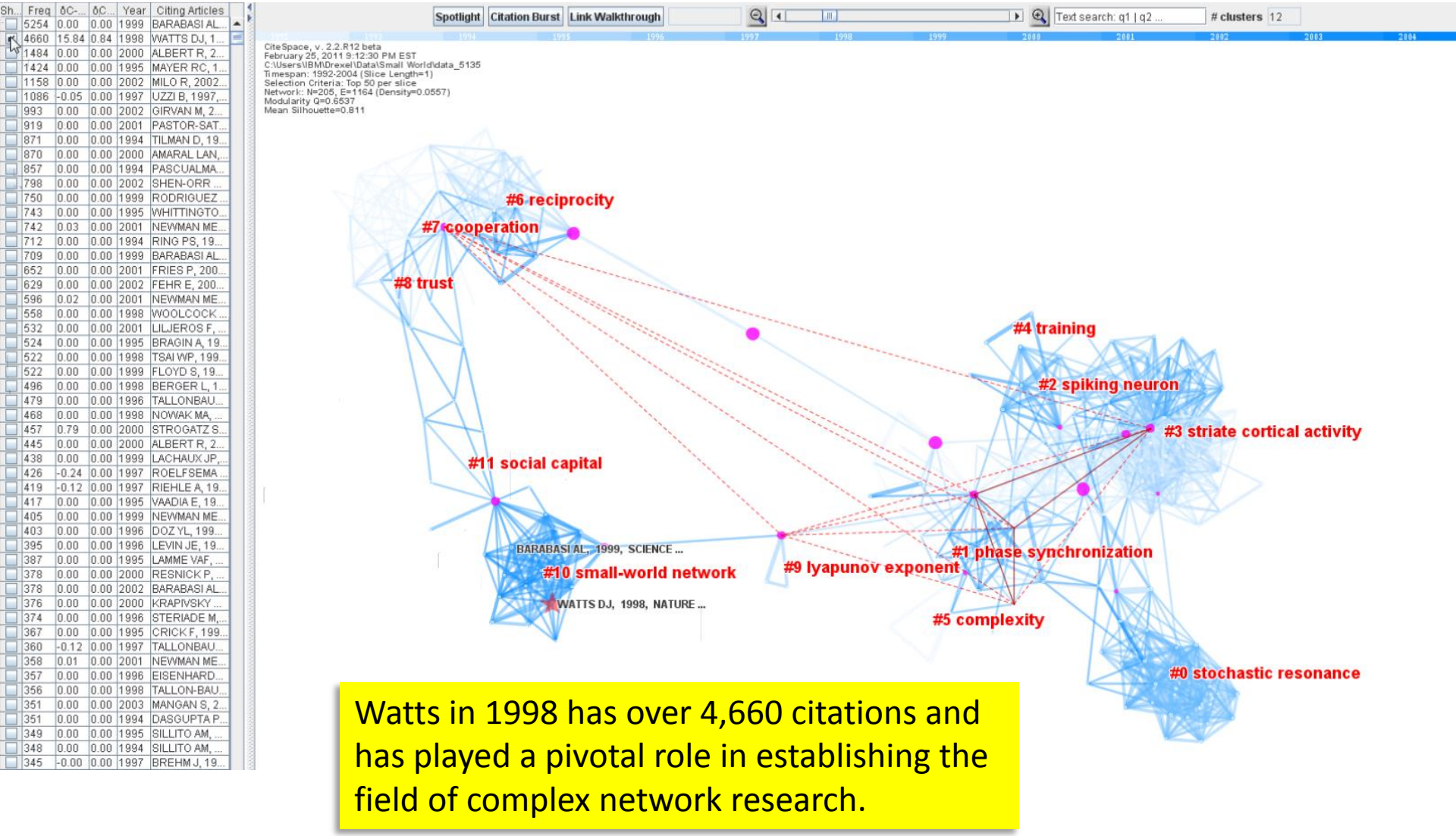
Structural Variation

- Modularity
- Inter-Cluster Brokerage
- Centrality



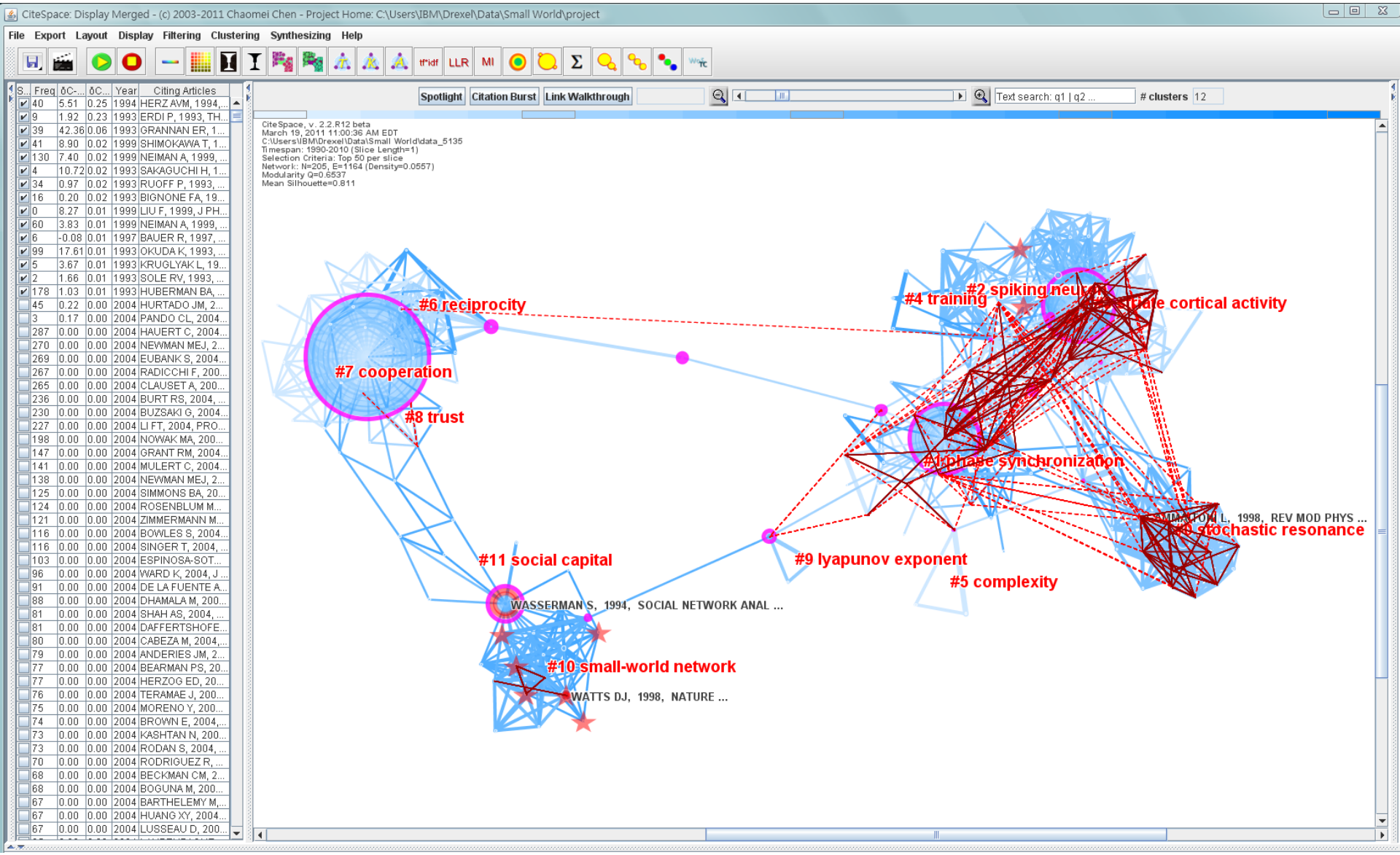

Groundbreaking Article
Related Records
Split
Before
After
Construct Baseline Networks
……
Measure Structural Variation
Visualize Novel Connections

Example 1: Small World Networks



Sh...	Freq	δC-...	δC...	Year	Citing Articles
	5254	0.00	0.00	1999	BARABASI AL...
	4660	15.84	0.84	1998	WATTS DJ, 1...
	1484	0.00	0.00	2000	ALBERT R, 2...
	1424	0.00	0.00	1995	MAYER RC, 1...
	1158	0.00	0.00	2002	MILO R, 2002...
	1086	-0.05	0.00	1997	UZZI B, 1997,...
	993	0.00	0.00	2002	GIRVAN M, 2...
	919	0.00	0.00	2001	PASTOR-SAT...
	871	0.00	0.00	1994	TILMAN D, 19...
	870	0.00	0.00	2000	AMARAL LAN,...
	857	0.00	0.00	1994	PASCUALMA...
	798	0.00	0.00	2002	SHEN-ORR ...
	750	0.00	0.00	1999	RODRIGUEZ...
	743	0.00	0.00	1995	WHITTINGTO...
	742	0.03	0.00	2001	NEWMAN ME...
	712	0.00	0.00	1994	RING PS, 19...
	709	0.00	0.00	1999	BARABASI AL...
	652	0.00	0.00	2001	FRIES P, 200...
	629	0.00	0.00	2002	FEHR E, 200...
	596	0.02	0.00	2001	NEWMAN ME...
	558	0.00	0.00	1998	WOOLCOCK ...
	532	0.00	0.00	2001	LILJEROS F, ...
	524	0.00	0.00	1995	BRAGIN A, 19...
	522	0.00	0.00	1998	TSAI WP, 199...
	522	0.00	0.00	1999	FLOYD S, 19...
	496	0.00	0.00	1998	BERGER L, 1...
	479	0.00	0.00	1996	TALLONBAU...
	468	0.00	0.00	1998	NOWAK MA, ...
	457	0.79	0.00	2000	STROGATZ S...
	445	0.00	0.00	2000	ALBERT R, 2...
	438	0.00	0.00	1999	LACHAUX JP,...
	426	-0.24	0.00	1997	ROELFSEMA ...
	419	-0.12	0.00	1997	RIEHLE A, 19...
	417	0.00	0.00	1995	VAADIA E, 19...
	405	0.00	0.00	1999	NEWMAN ME...
	403	0.00	0.00	1996	DOZ YL, 199...
	395	0.00	0.00	1996	LEVIN JE, 19...
	387	0.00	0.00	1995	LAMME VAF, ...
	378	0.00	0.00	2000	RESNICK P, ...
	378	0.00	0.00	2002	BARABASI AL...
	376	0.00	0.00	2000	KRAPIVSKY ...
	374	0.00	0.00	1996	STERIADE M,...
	367	0.00	0.00	1995	CRICK F, 199...
	360	-0.12	0.00	1997	TALLONBAU...
	358	0.01	0.00	2001	NEWMAN ME...
	357	0.00	0.00	1996	EISENHARD...
	356	0.00	0.00	1998	TALLON-BAU...
	351	0.00	0.00	2003	MANGAN S, 2...
	351	0.00	0.00	1994	DASGUPTA P...
	349	0.00	0.00	1995	SILLITO AM, ...
	348	0.00	0.00	1994	SILLITO AM, ...
	345	-0.00	0.00	1997	BREHM J, 19...

Watts in 1998 has over 4,660 citations and has played a pivotal role in establishing the field of complex network research.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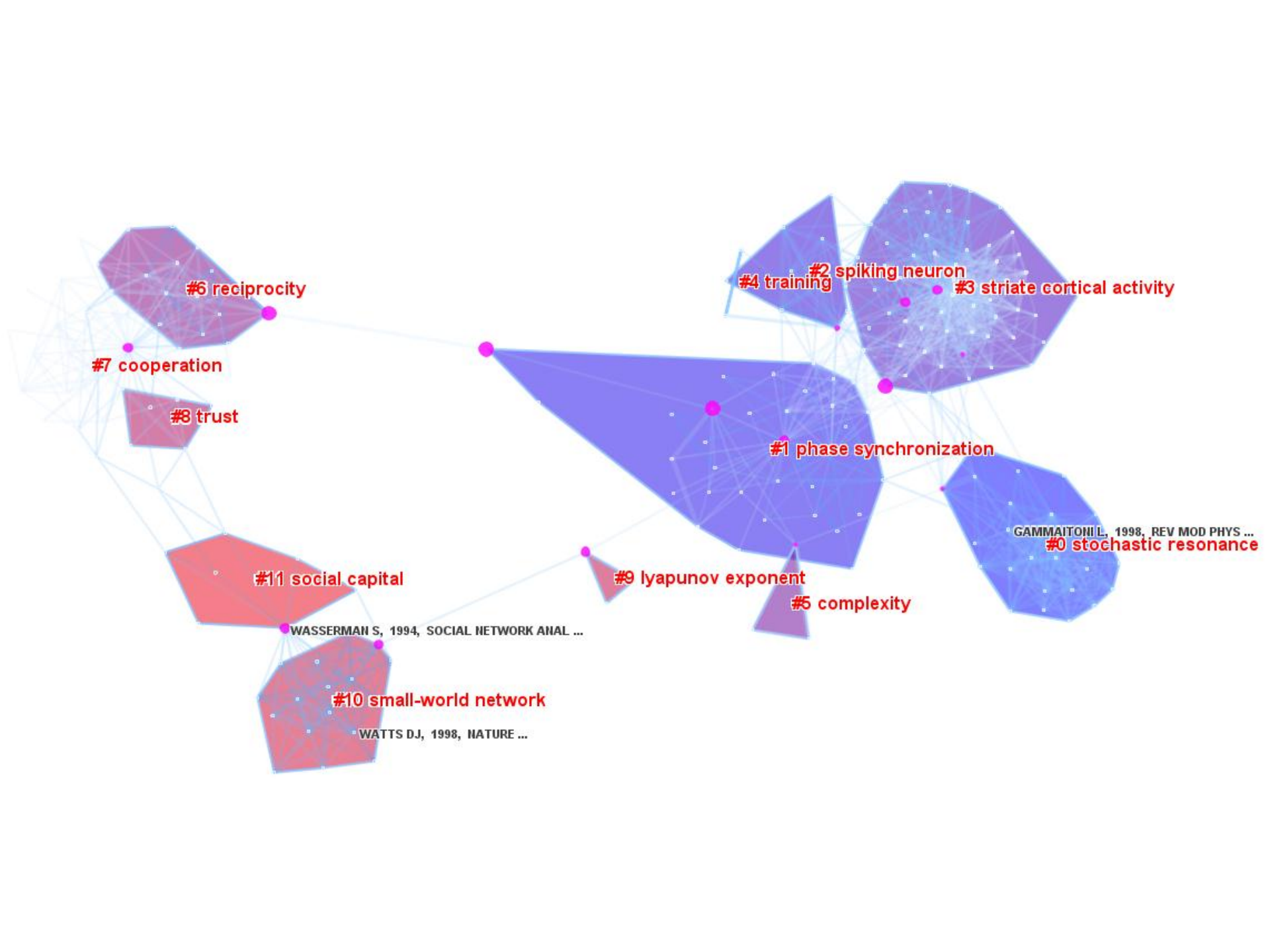
Modularity Q=0.6537
Mean Silhouette=0.811
#6 reciprocity
#7 cooperation
#8 trust
#4 training
#2 spiking neuron
cortical activity
#1 phase synchronization
#0 stochastic resonance
#9 lyapunov exponent
#5 complexity
#11 social capital
WASSERMAN S, 1994, SOCIAL NETWORK ANAL ...
#10 small-world network
WATTS DJ, 1998, NATURE ...
1998, REV MOD PHYS ...


#6 reciprocity
#7 cooperation
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#1 phase synchronization
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#0 stochastic resonance
#11 social capital
#9 lyapunov exponent
#5 complexity
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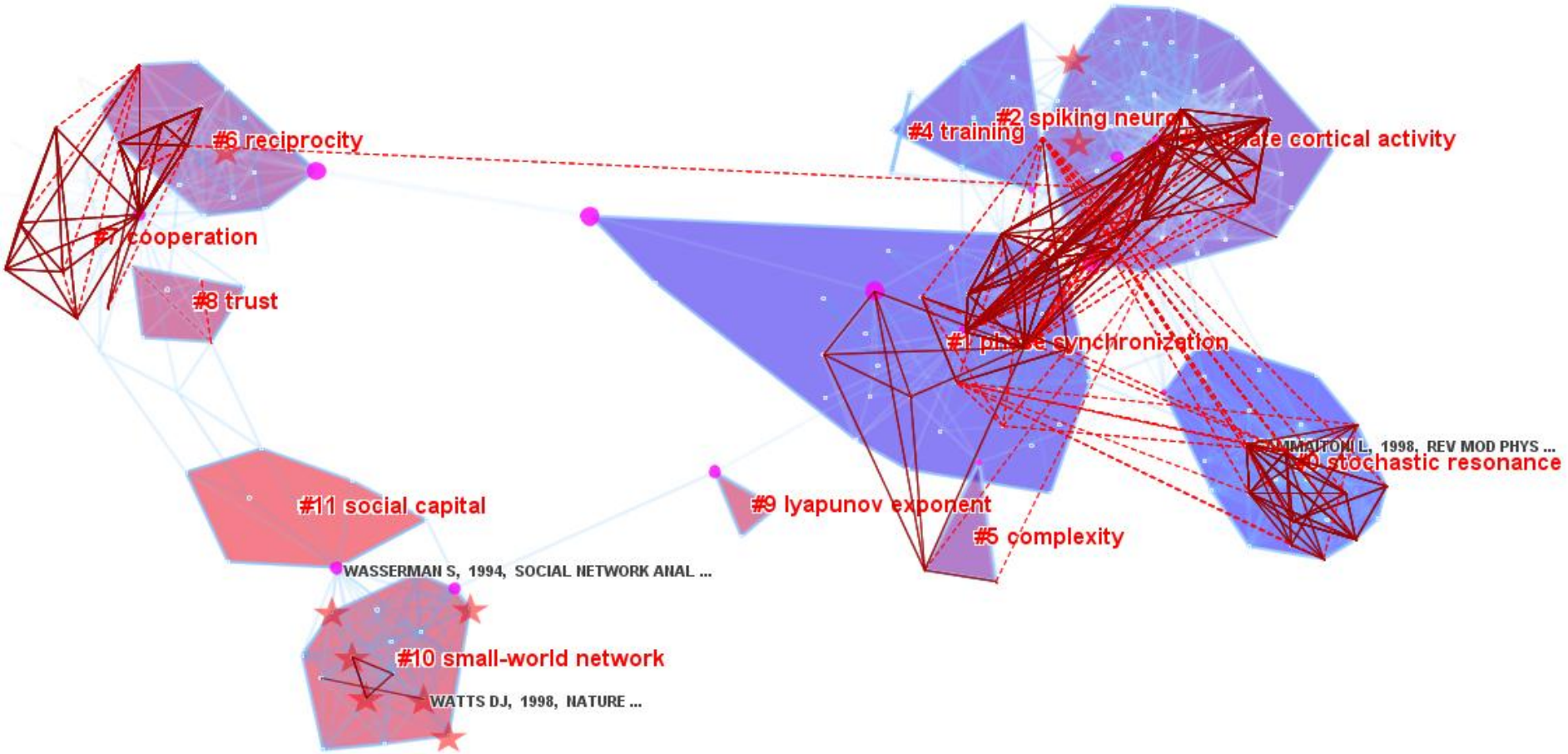
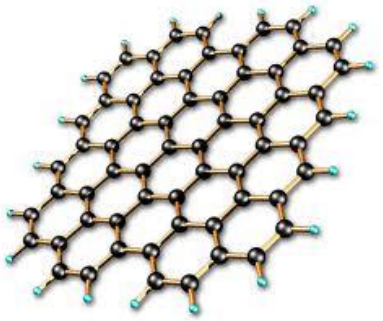
#10 small-world network
WATTS DJ, 1998, NATURE ...



A network of co-cited references derived from 5,135 articles published on small-world networks between 1990-2010. The network of 205 references and 1,164 co-citation links is divided into 12 clusters with a modularity of 0.6537 and the mean silhouette of 0.811. The red lines are made by the top-15 articles measured by the centrality variation rate.

Example 2: Graphene



2008 Thomson Reuters Citation Laureates

In 2008 **Andre K. Geim** was named a Thomson Reuters Citation Laureate in Physics for the discovery and analysis of graphene (with Kostya Novoselov). Below are more details.

- **Andre K. Geim** won the Nobel Prize in Physics in 2010.
- ROLE: FRS, Langworthy Research Professor, Chair of Condensed Matter Physics, and Director of Manchester Centre for Mesoscience and Nanotechnology, University of Manchester, Manchester, UK

In 2008 **Kostya Novoselov** was named a Thomson Reuters Citation Laureate in Physics for the discovery and analysis of graphene (with Andre K. Geim). Below are more details.

- **Kostya Novoselov** won the Nobel Prize in Physics in 2010.
- ROLE: Royal Society Research Fellow, Department of Condensed Matter Physics, University of Manchester, Manchester, UK

The Nobel Prize in Physics 2010
Andre Geim, Konstantin Novoselov

The Nobel Prize in Physics 2010
Nobel Prize Award Ceremony
Andre Geim
Konstantin Novoselov

Photo: U. Montan

Andre Geim

Photo: U. Montan

Konstantin Novoselov

The Nobel Prize in Physics 2010 was awarded jointly to Andre Geim and Konstantin Novoselov *"for groundbreaking experiments regarding the two-dimensional material graphene"*

Highly Cited Papers by Andre K. Geim and Colleagues, Published Since 2004
(Ranked by total citations)

Rank	Paper	Cites
1	K.S. Novoselov, *et al.*, "Two-dimensional gas of massless Direc fermions in graphene," *Nature*, 438 (7065): 197-200, 2005.	643
2	K.S. Novoselov, *et al.*, "Electric field effect in atomically thin carbon films," *Science*, 306 (5296): 666-9, 2004.	570
3	A.K. Geim, K.S. Novoselov, "The rise of graphene," *Nature Materials*, 6(3): 183-91, 2007.	224
4	K.S. Novoselov, *et al.*, "Two-dimensional atomic crystals," *PNAS*, 102(30): 10451-3, 2005.	166
5	K.S. Novoselov, *et al.*, "Unconventional quantum Hall effect and Berry's phase of 2p bilayer graphene," *Nature Physics*, 2(3): 177-80, 2006.	148

SOURCE: Thomson Reuters Web of Science®

Ever since Geim published his first paper on graphene in *Science* in October, 2004—"Electric field effect in atomically thin carbon films"—the two-dimensional variation on graphite has taken materials science and condensed-matter physics by storm, while launching Geim into prominence among Thomson Reuters' measures of hot researchers in the field. Geim's 2004 *Science* paper has now been cited nearly 600 times (see adjoining table), eclipsed only by a November, 2005 article in *Nature* on the unique quantum mechanical properties of these materials, "Two-dimensional gas of massless Dirac fermions in graphene," which has been cited roughly 650 times. Beginning in early 2007, this paper spent more than a year on the upper rungs of the *Science Watch*® Physics Top Ten.

U. Manchester's Andre Geim: Sticking with Graphene—For Now
The *Science Watch*® (Print Version) Newsletter Interview

Title: Electric field effect in atomically thin carbon films
Author(s): Novoselov KS, Geim AK, Morozov SV, et al.
Source: **SCIENCE** Volume: **306** Issue: **5296** Pages: **666-669** Published: **OCT 22 2004**
Times Cited: **4,514**

Seed
(2004)

16 References Cited by the Seed Article

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12. ROTKIN SV — Possibility of a metallic field-effect transistor — APPLIED PHYSICS LETTERS 84 : 3139 DOI 10.1063/1.1710717 2004
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15. SPAIN IL — ELECTRONIC TRANSPORT-PROPERTIES OF GRAPHITE, CARBONS, AND RELATED MATERIALS — CHEMISTRY AND PHYSICS OF CARBON 16 : 119 1981
16. STAN MR — Molecular electronics: From devices and interconnect to circuits and architecture — PROCEEDINGS OF THE IEEE 91 : 1940 DOI 10.1109/JPROC.2003.818327 2003

7,203
Related Records
(1980-2011)

6,033
DT=Article

554
(1999-2003)

3,243
(2004-2008)

Select Citers
Citations >= 10

Top 100 per year
(1999-2004)

29,848 References
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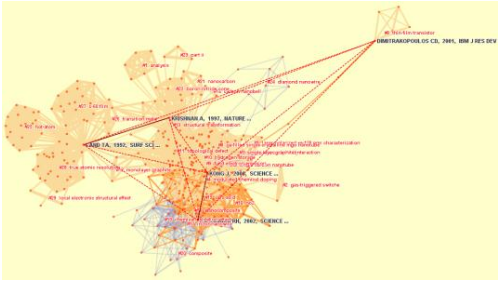
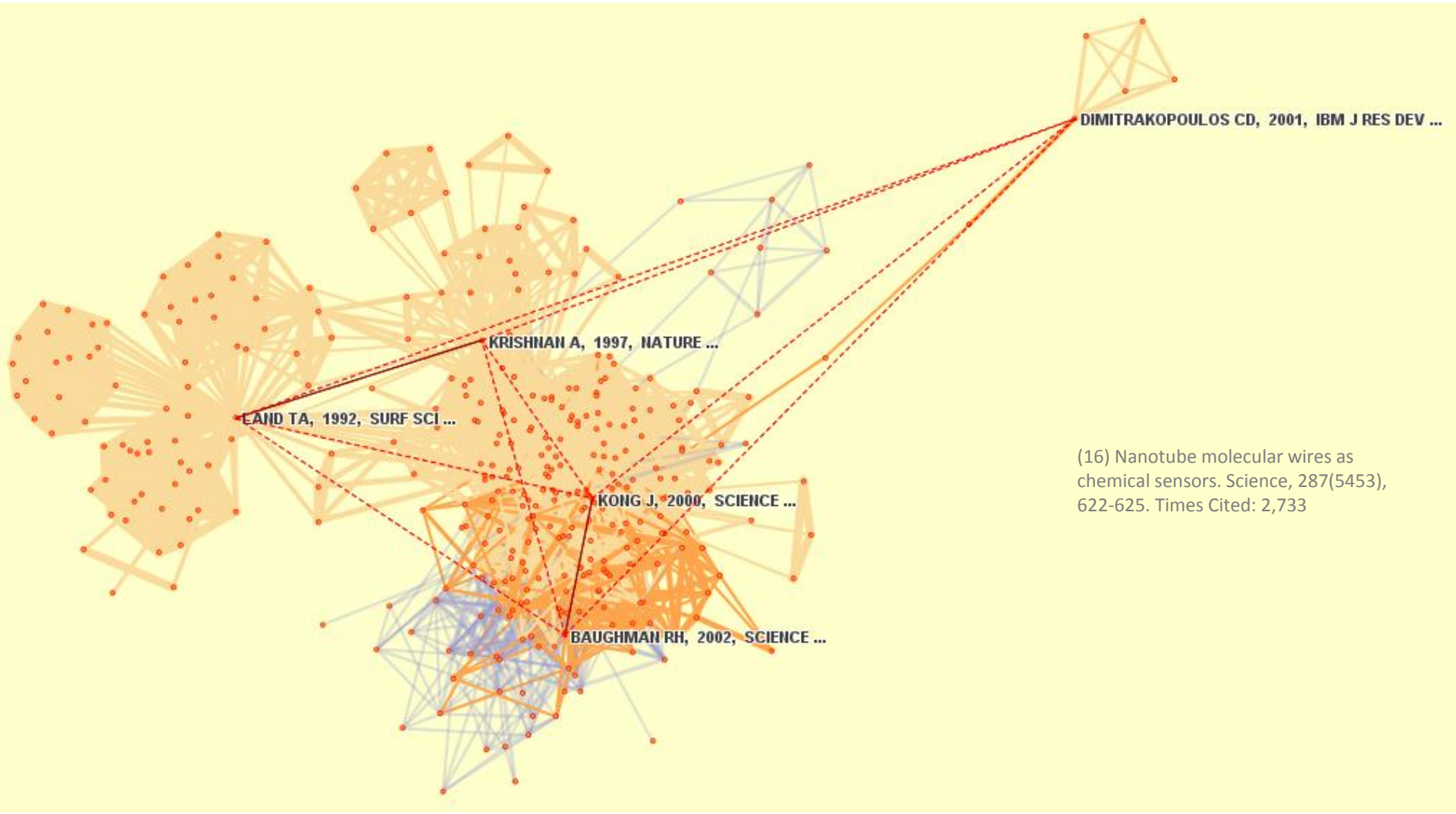
Baseline: Entire history



(14) STM INVESTIGATION OF SINGLE LAYER GRAPHITE STRUCTURES PRODUCED ON PT(111) BY HYDROCARBON DECOMPOSITION. Surface Science, 264(3), 261-270. Times Cited: 217

(8) Graphitic cones and the nucleation of curved carbon surfaces. Nature, 388(6641), 451-454. Times Cited: 297

(1) Organic thin-film transistors: A review of recent advances. IBM J Res Dev, 45(1), 11-27. Time Cited: 663



(16) Nanotube molecular wires as chemical sensors. Science, 287(5453), 622-625. Times Cited: 2,733

(2) Carbon nanotubes - the route toward applications. Science, 297(5582), 787-792. Times Cited: 3,460.

(14) STM INVESTIGATION OF SINGLE LAYER GRAPHITE STRUCTURES PRODUCED ON PT(111) BY HYDROCARBON DECOMPOSITION. Surface Science, 264(3), 261-270. Times Cited: 217

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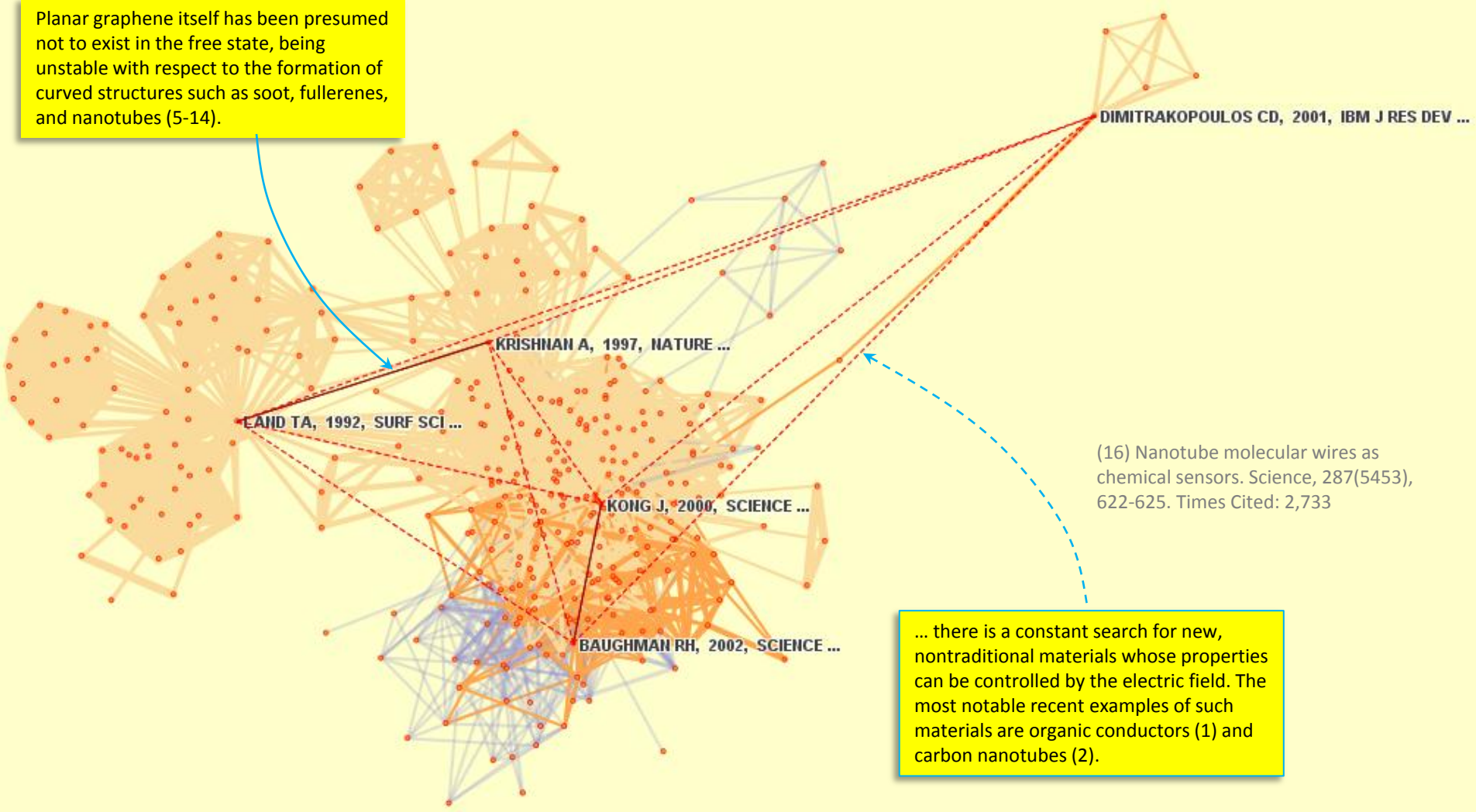
(1) Organic thin-film transistors: A review of recent advances. IBM J Res Dev, 45(1), 11-27. Time Cited: 663

Planar graphene itself has been presumed not to exist in the free state, being unstable with respect to the formation of curved structures such as soot, fullerenes, and nanotubes (5-14).



(16) Nanotube molecular wires as chemical sensors. Science, 287(5453), 622-625. Times Cited: 2,733

… there is a constant search for new, nontraditional materials whose properties can be controlled by the electric field. The most notable recent examples of such materials are organic conductors (1) and carbon nanotubes (2).

(2) Carbon nanotubes - the route toward applications. Science, 297(5582), 787-792. Times Cited: 3,460.

Conclusions

- The key insight to the nature of creativity is how we may change our viewpoints.
- Visualizing science needs to address how it may stimulate our thinking, broaden our horizon and reduce biases.

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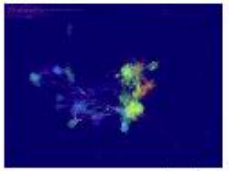
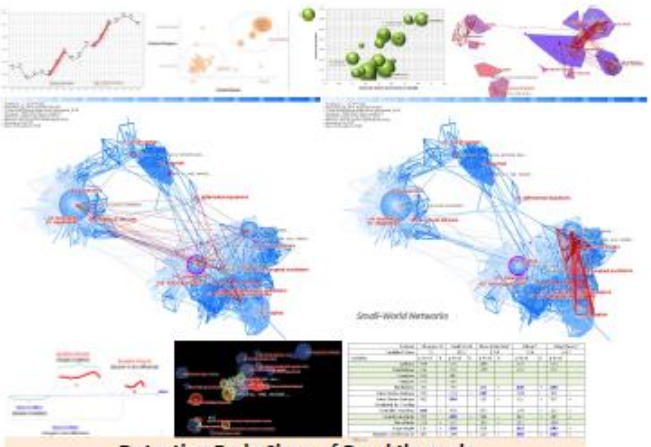
Visual Analytics of Structural and Temporal Patterns

Chaomei Chen, Jian Zhang, Donald Pellegrino
The *iSchool* at Drexel

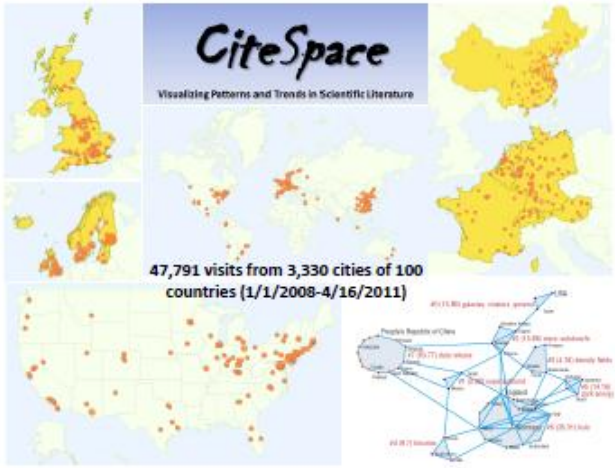


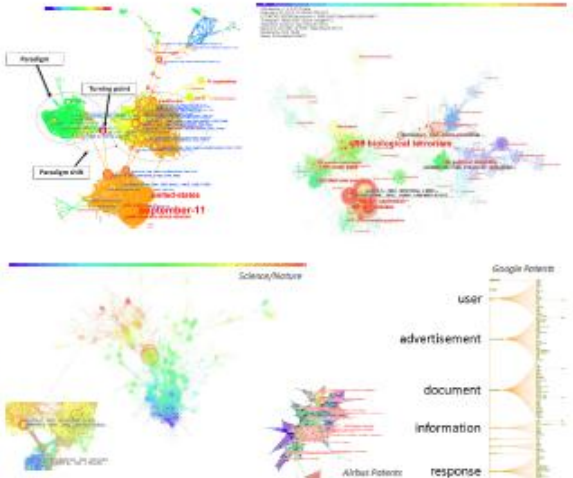
Detecting Early Signs of Breakthrough



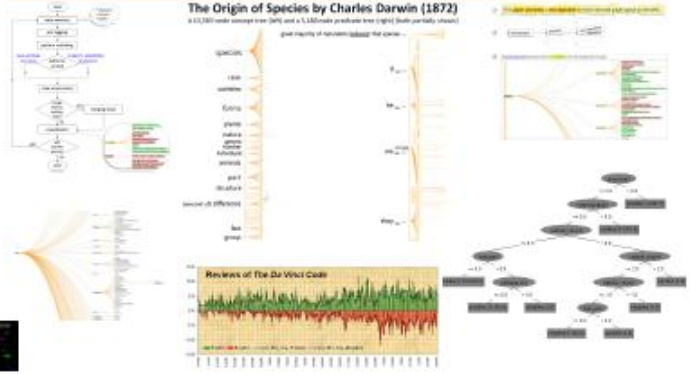
CiteSpace

Visualizing Patterns and Trends in Scientific Literature

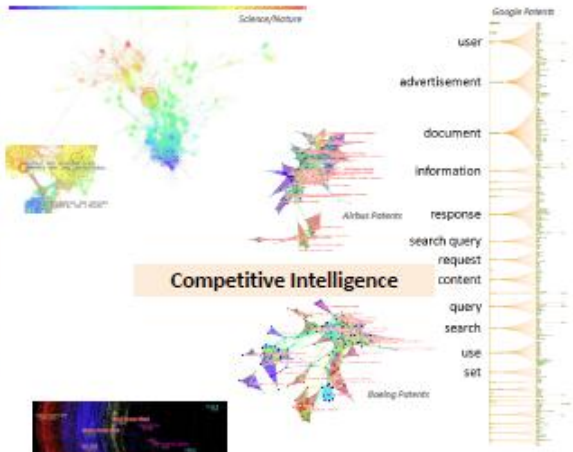




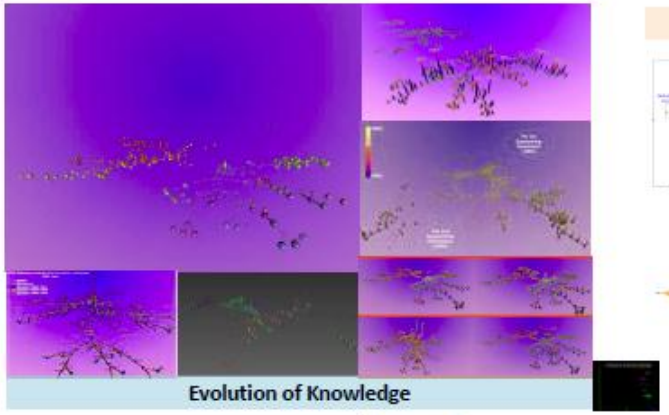
Representing Conceptual Structures in Unstructured Text

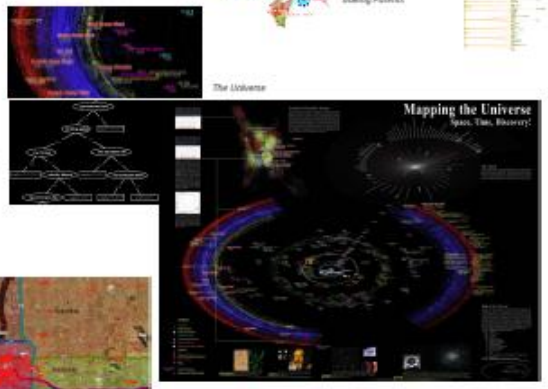


Competitive Intelligence

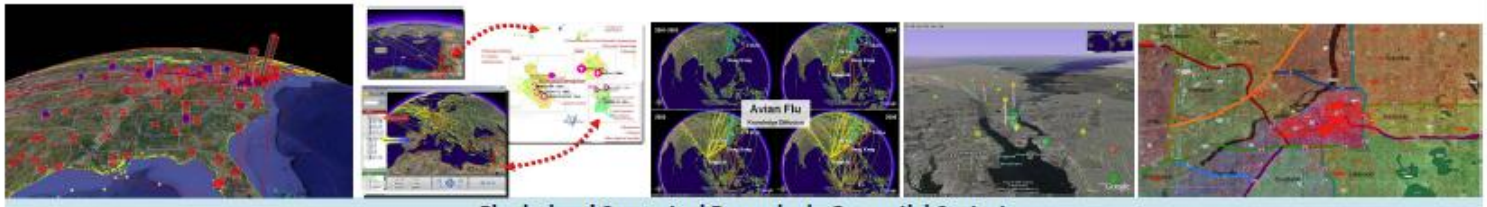


Evolution of Knowledge





Physical and Conceptual Dynamics in Geospatial Context



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