The Nature of Creativity:

Mechanism, Measurement, and Analysis

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Editor in Chief, Information Visualization
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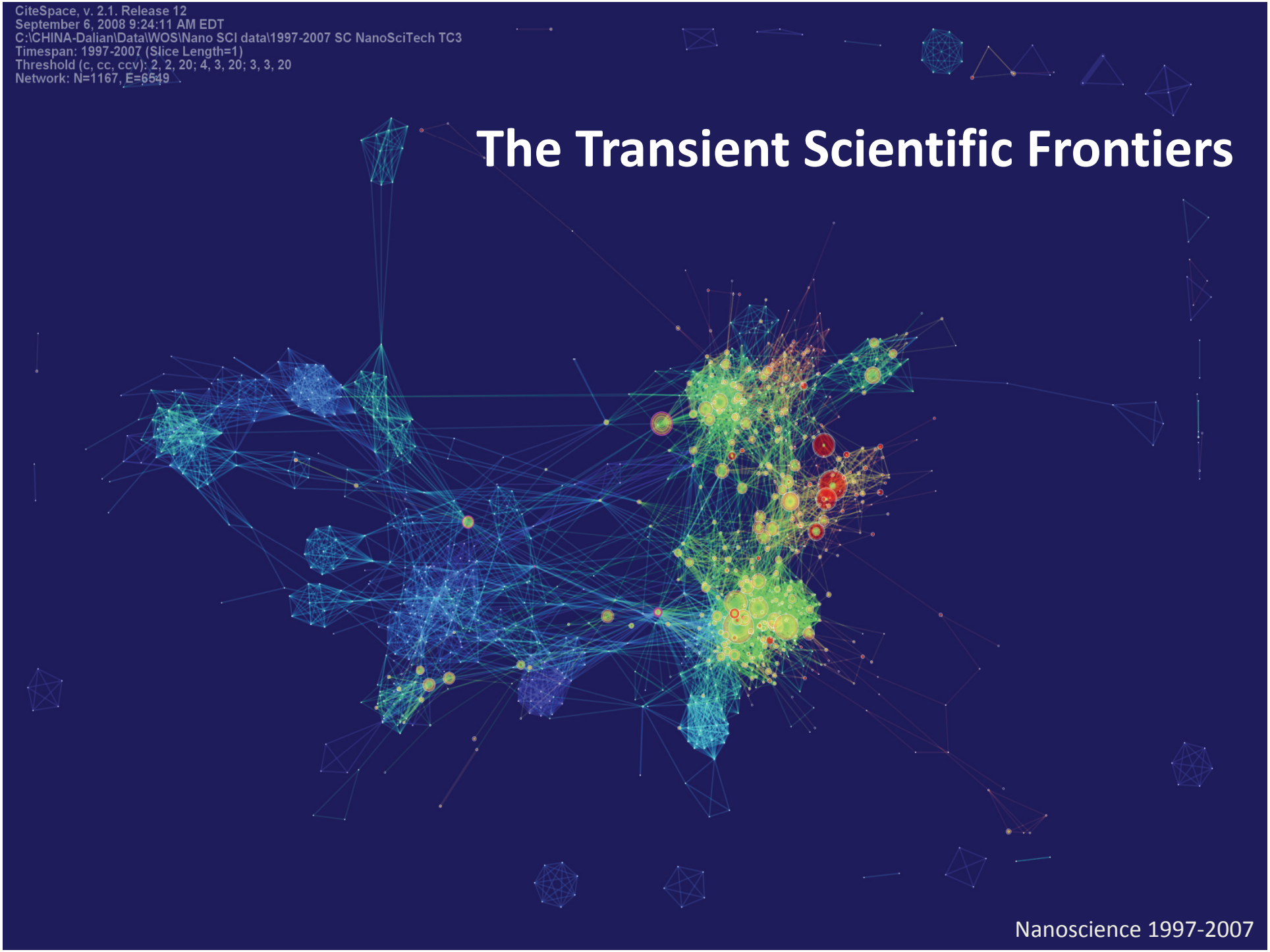
June 7-8, 2011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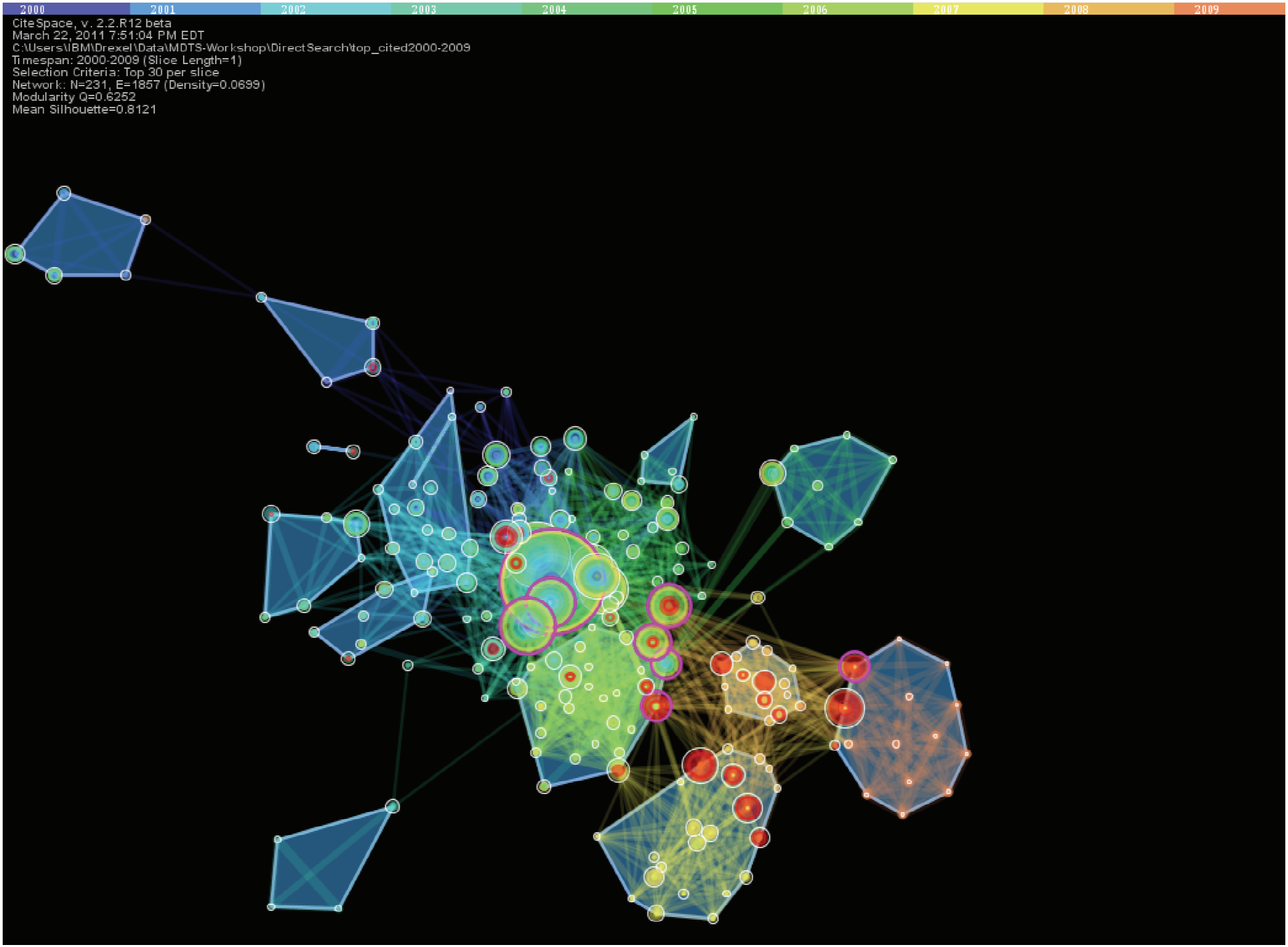
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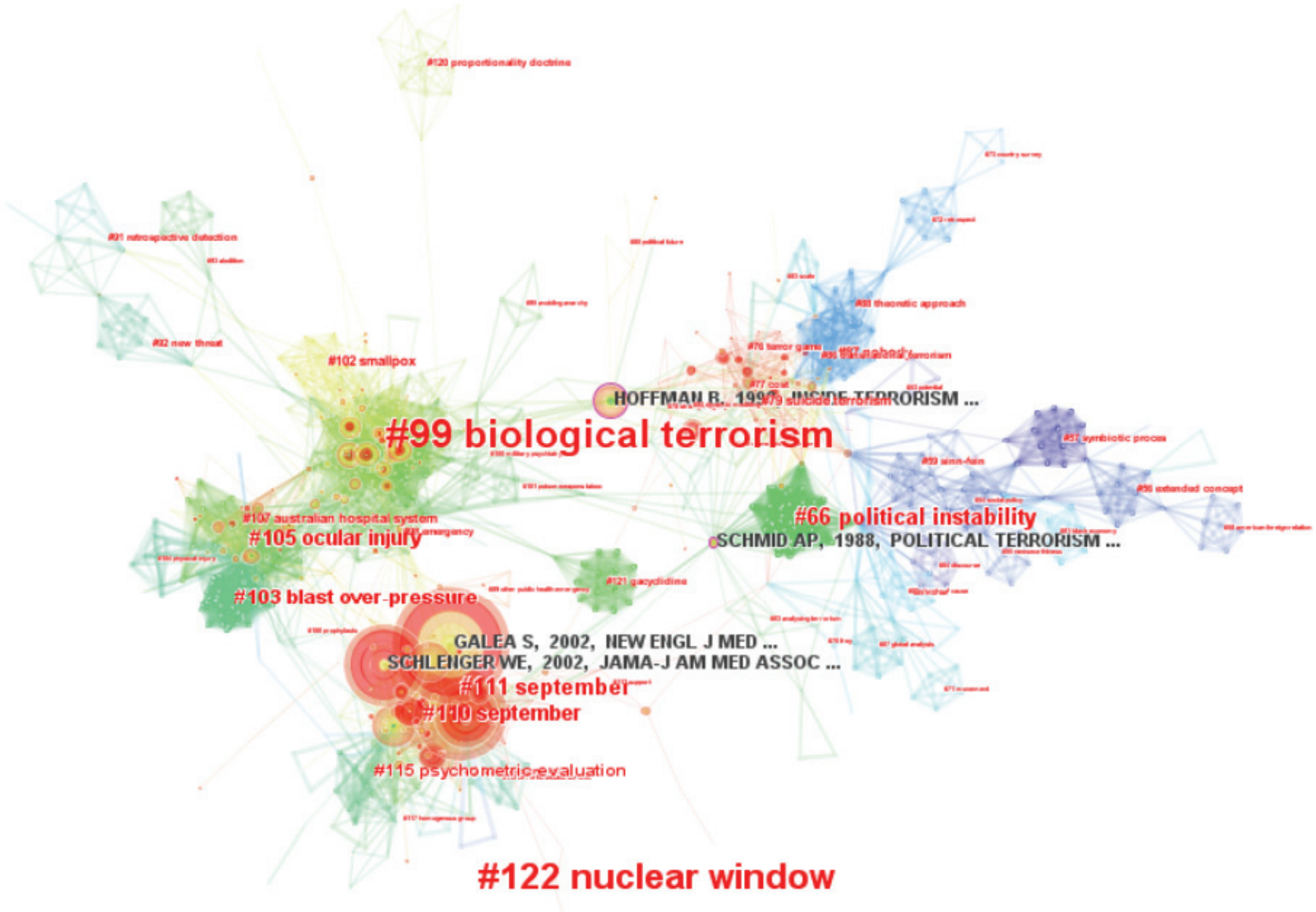

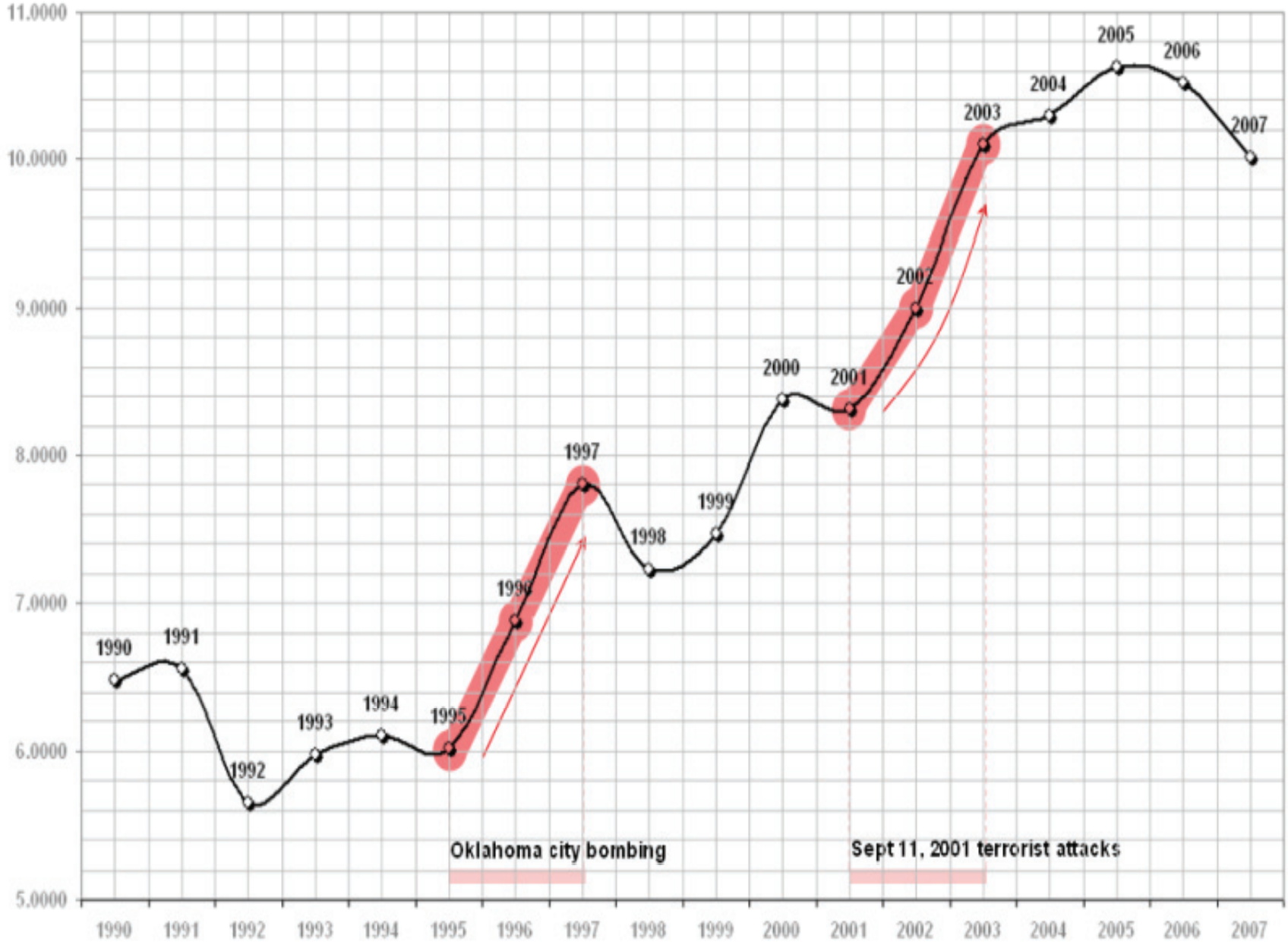
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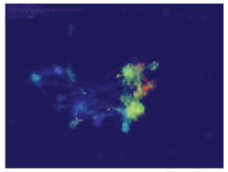
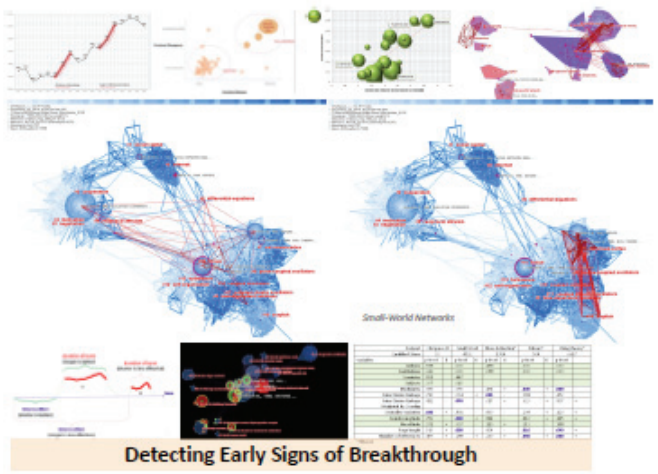
Oklahoma city bombing
Sept 11, 2001 terrorist attacks

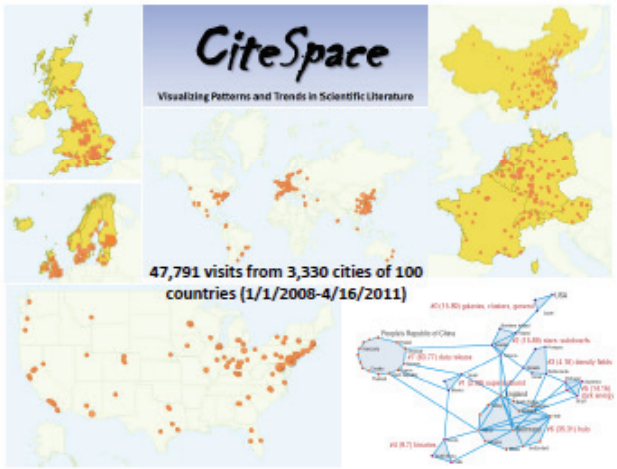
Visual Analytics of Structural and Temporal Patterns

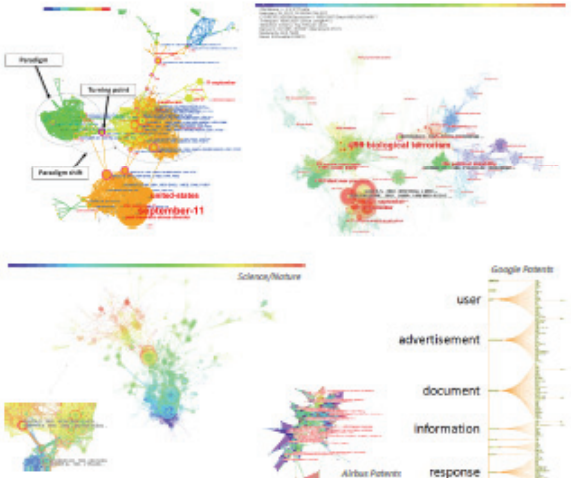
Chaomei Chen, Jian Zhang, Donald Pellegrino
The *iSchool* at Drexel



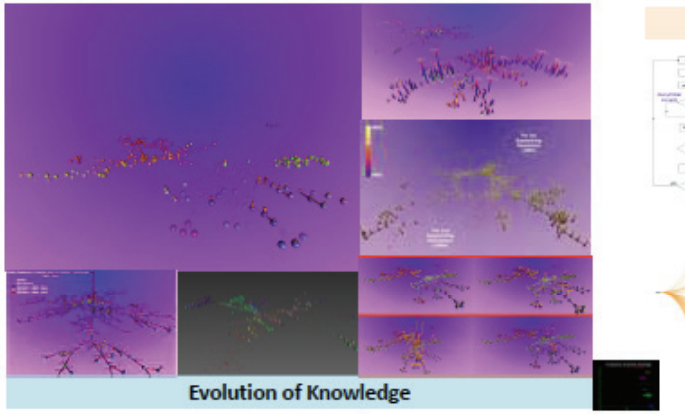


Detecting Early Signs of Breakthrough



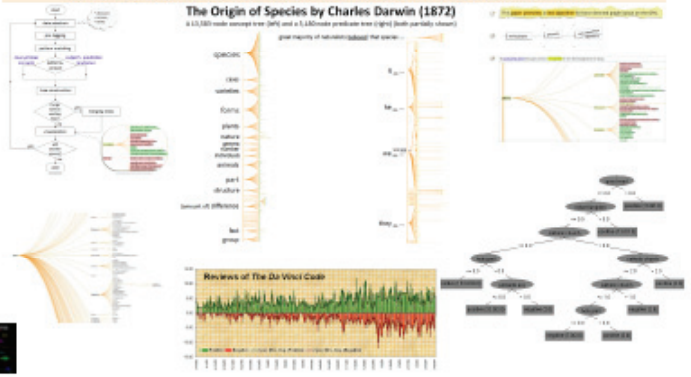


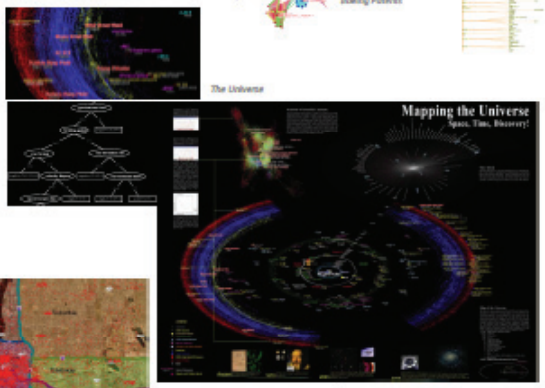
Competitive Intelligence

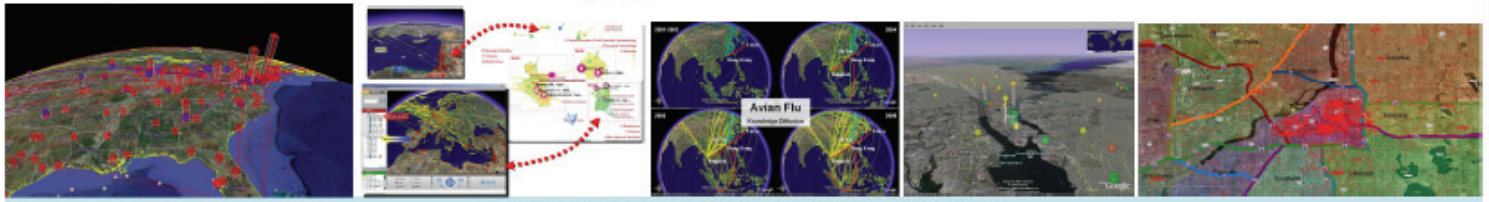


Evolution of Knowledge

Representing Conceptual Structures in Unstructured Text





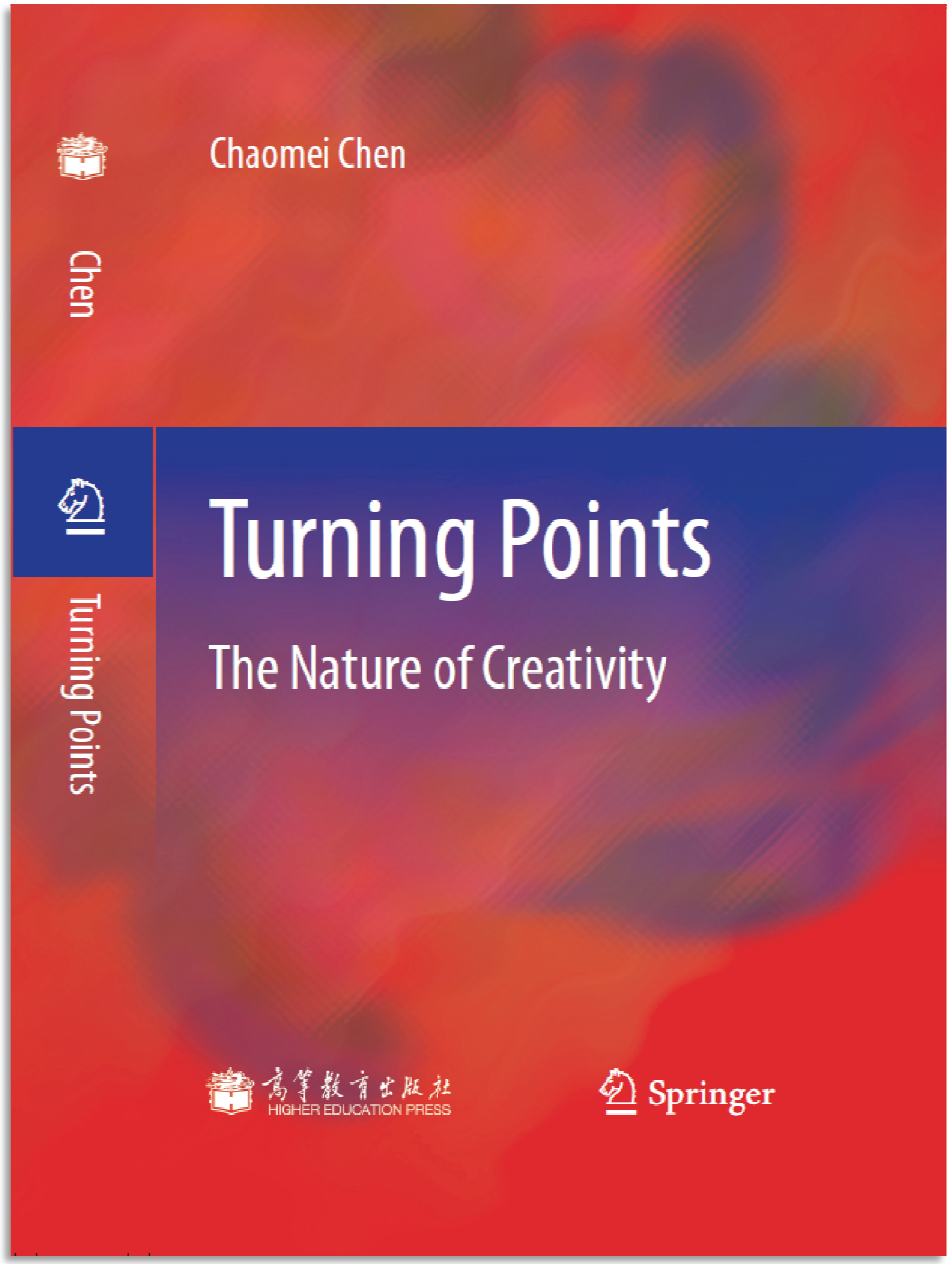


Physical and Conceptual Dynamics in Geospatial Context

CVDI is a collaboration between the University of Louisiana at Lafayette & Drexel University

UNIVERSITY OF LOUISIANA Lafayette

Drexel UNIVERSITY



- What is the nature of creativity?
- Is creativity measurable?
- Is there a systematic way to enhance our creativity?
- Where is the next creative idea likely to appear?

The goal is not to predict what exactly will be created, but generic mechanisms and measurable properties of such creation.

The Nature of Creativity

- 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

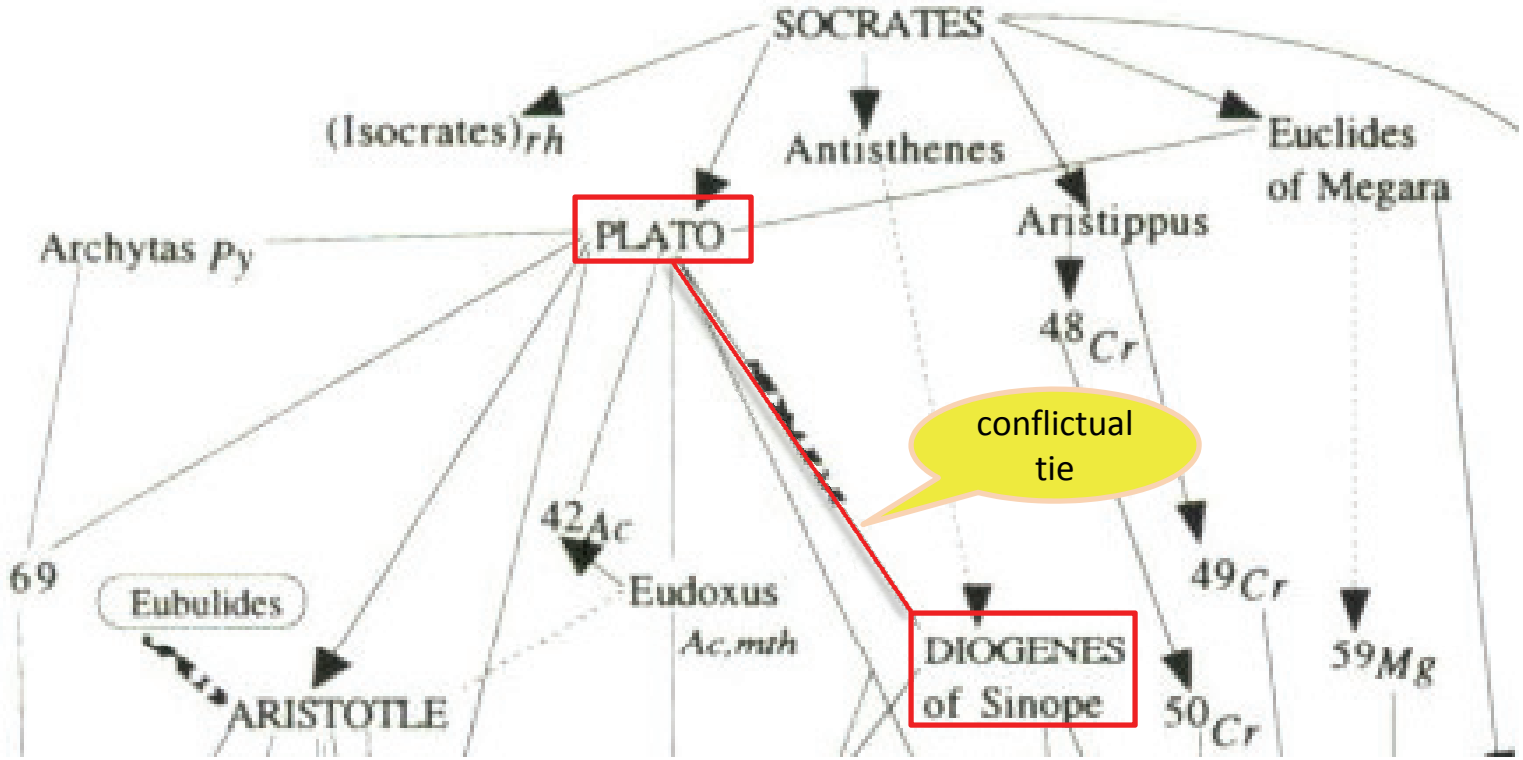
- *Creativity is the friction of the attention space at the moments when the structural blocks are grinding against one another the hardest.*

Collins (1998, p.76)

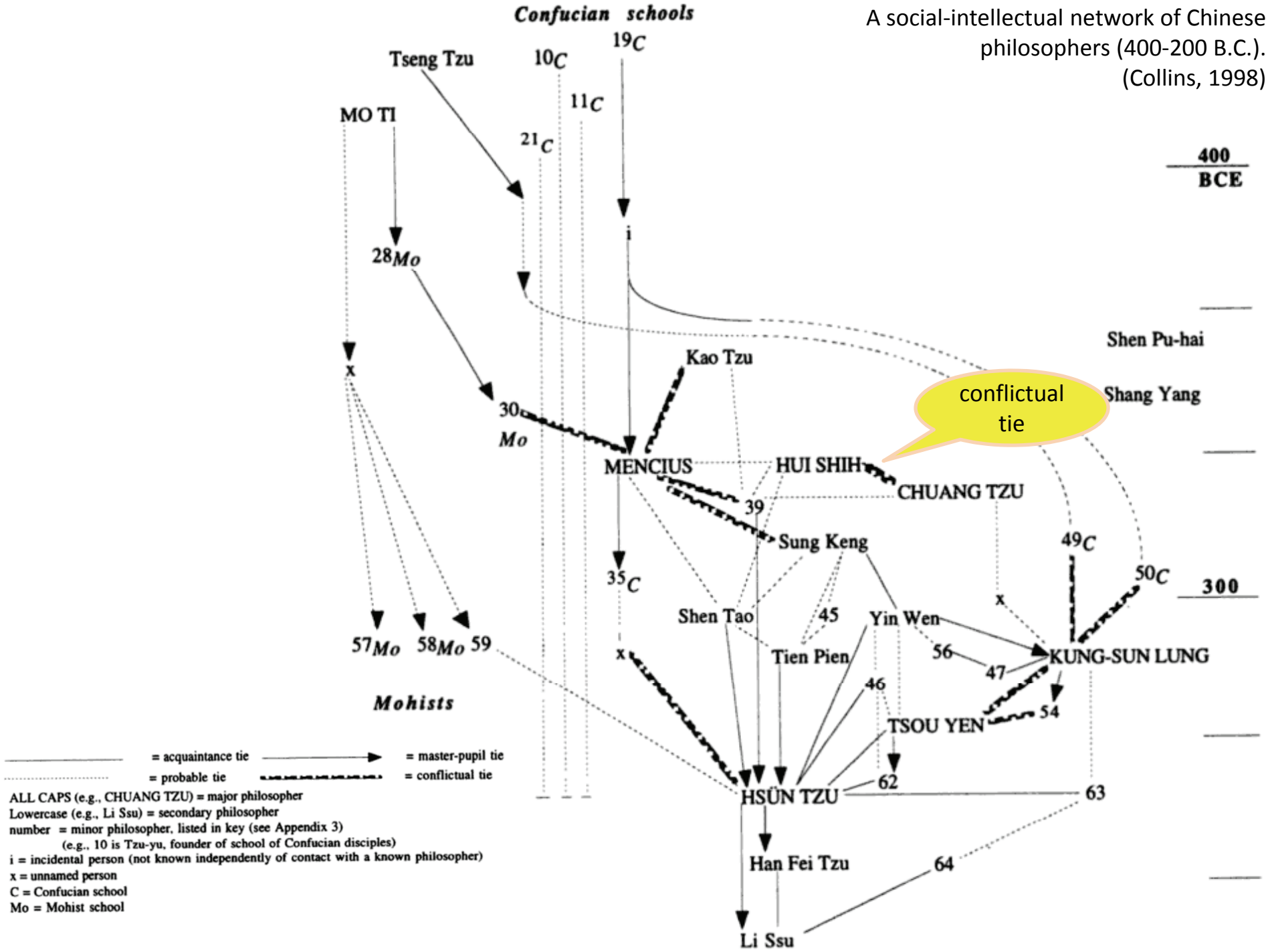
Conflicting Thoughts Make Great Philosophers

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

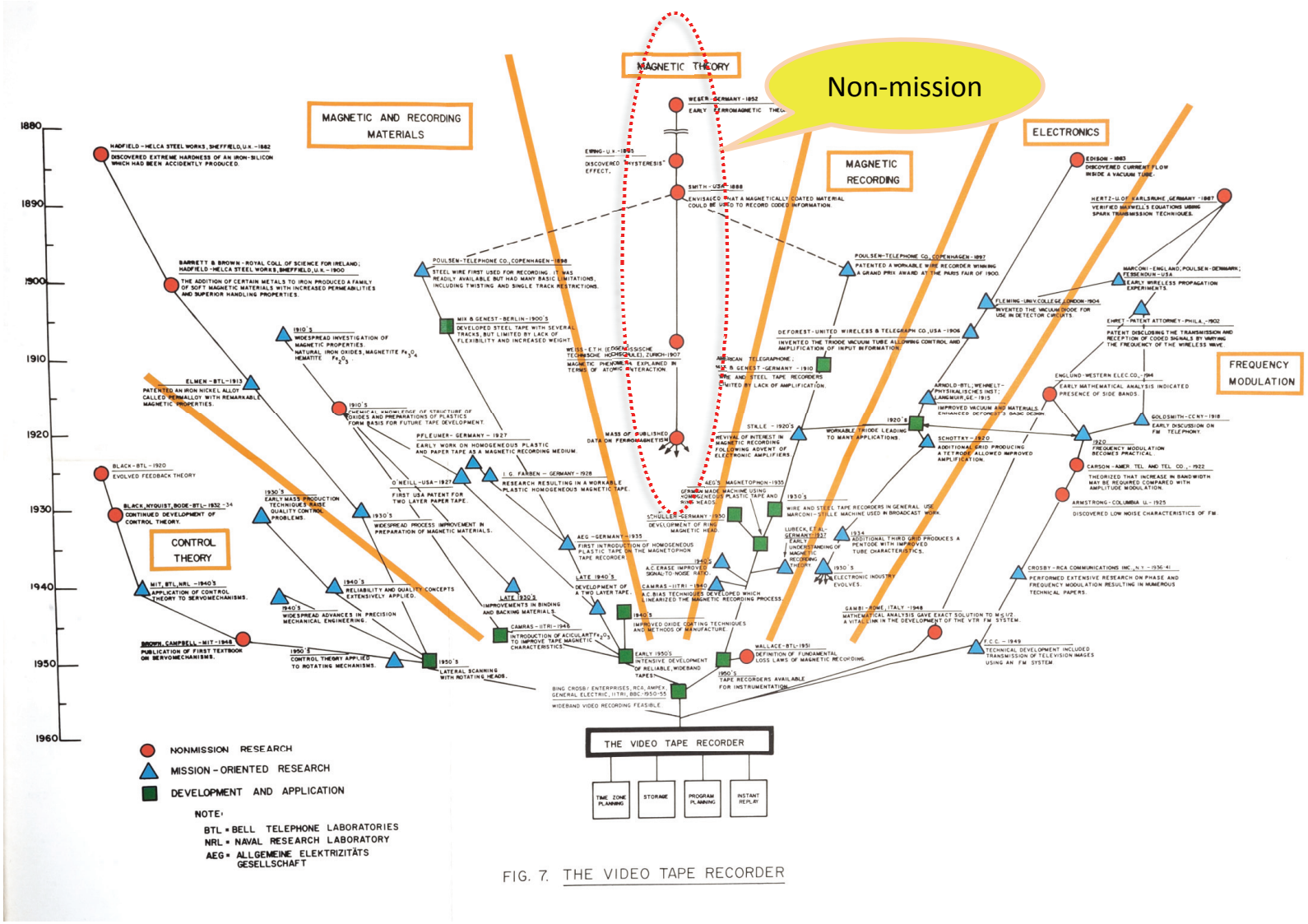


FIG. 7. THE VIDEO TAPE RECORDER

Literature-Based Discovery

For example, Don Swanson's work:

Given A~B and B~C,

Is A~C a reasonable hypothesis?

Intellectual Turning Points and Paradigm Shifts

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Visualizing Patterns and Trends in Scientific Literature

WebStart **Archive**
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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》

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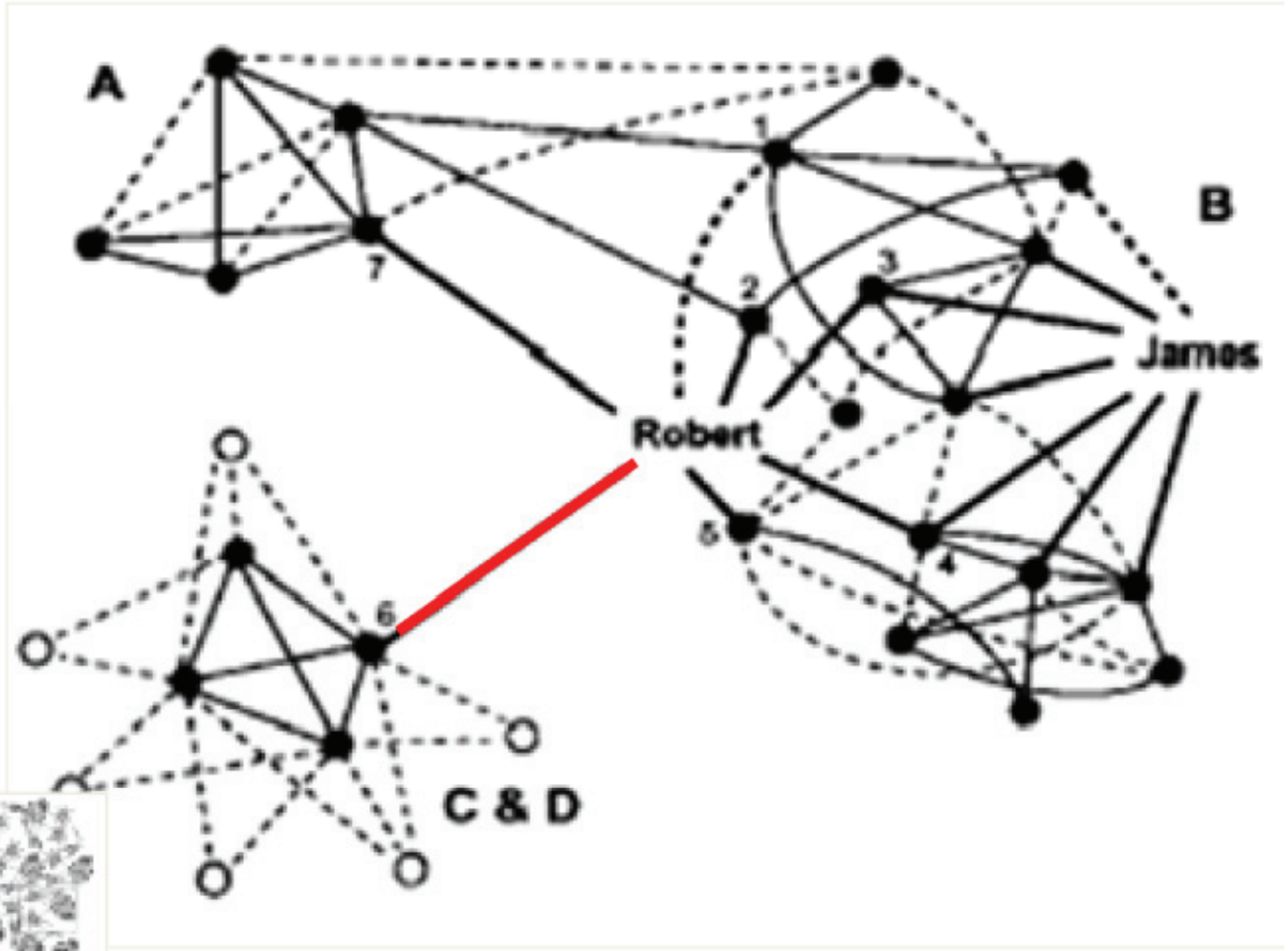
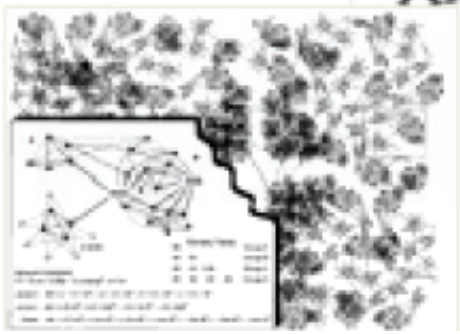
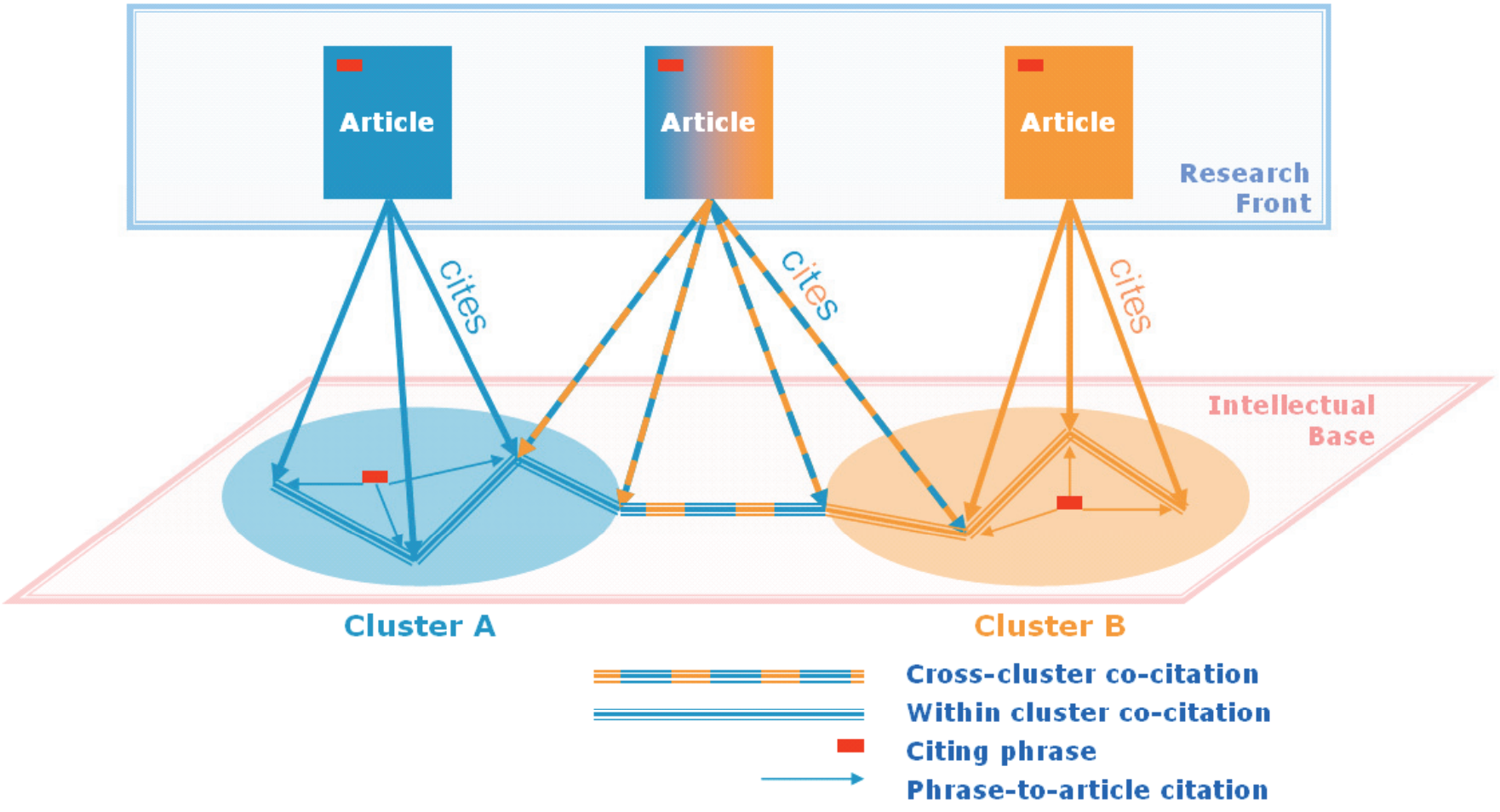
BioMedNet bmn.com

Structural Holes in Social Networks



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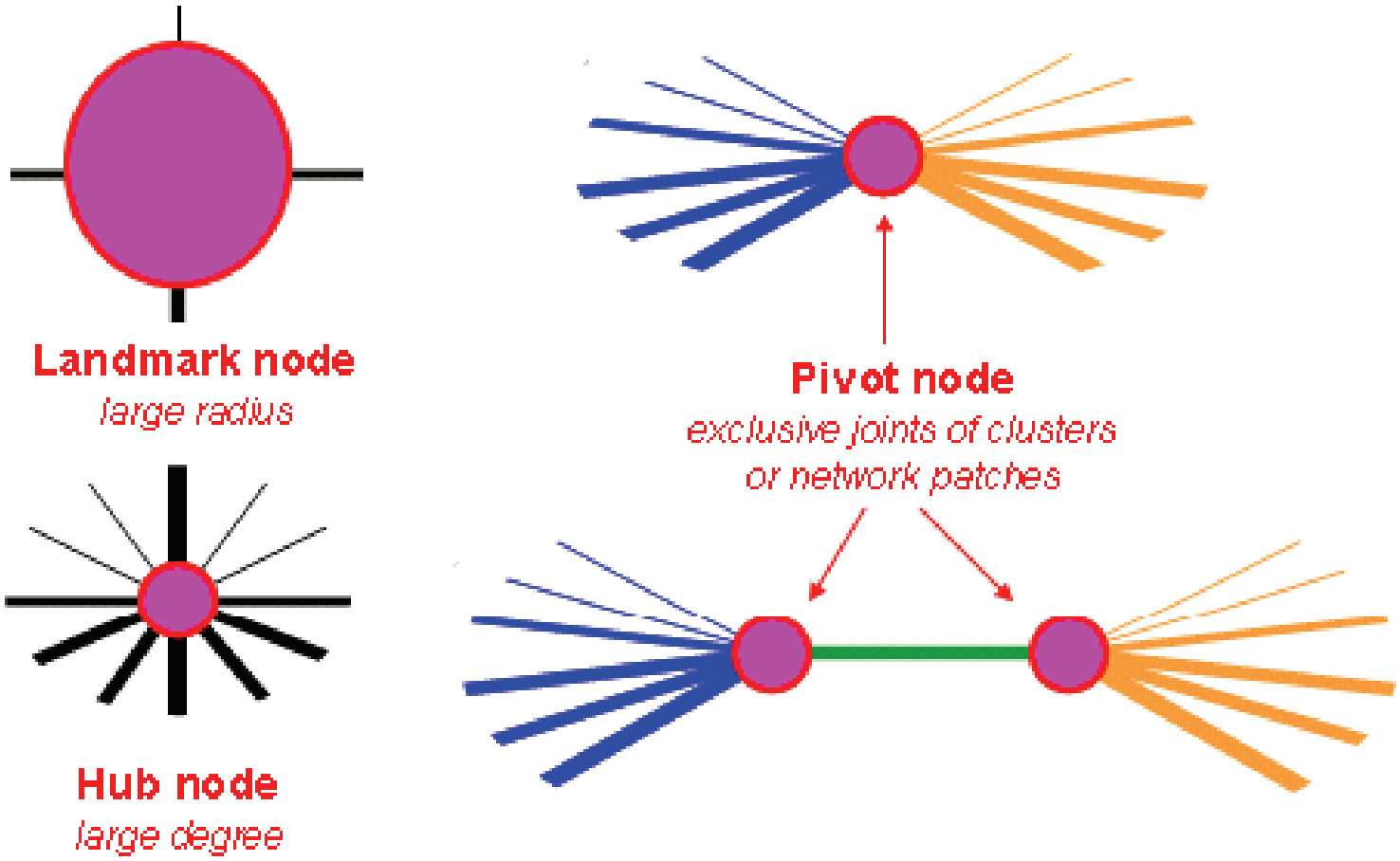
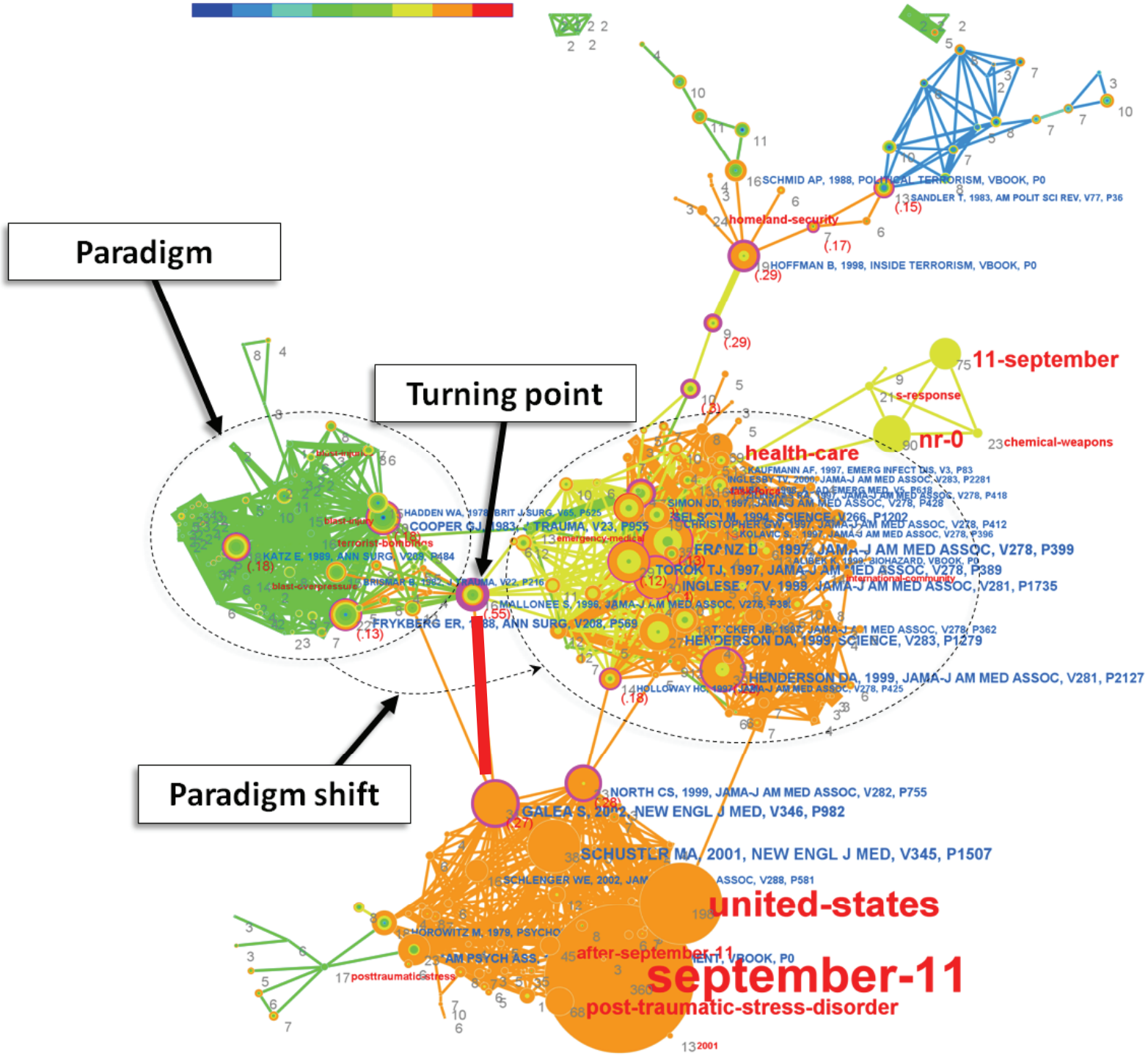
Chen, C. (2004) Searching for intellectual turning points. *PNAS*, 101 (Suppl. 1), 5303-5310




Paradigm
Turning point
Paradigm shift
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SANDLER T, 1983, AM POLIT SCI REV, V77, P36
homeland-security
HOFFMAN B, 1998, INSIDE TERRORISM, VBOOK, P0
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terrorist-bombings
blast-overpressure
emergency-medical
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SCHUSTLR MA, 2001, NEW ENGL J MED, V345, P1507
SCHLENGER WE, 2002, JAM ASSOC, V288, P581
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AM PSYCH ASS,
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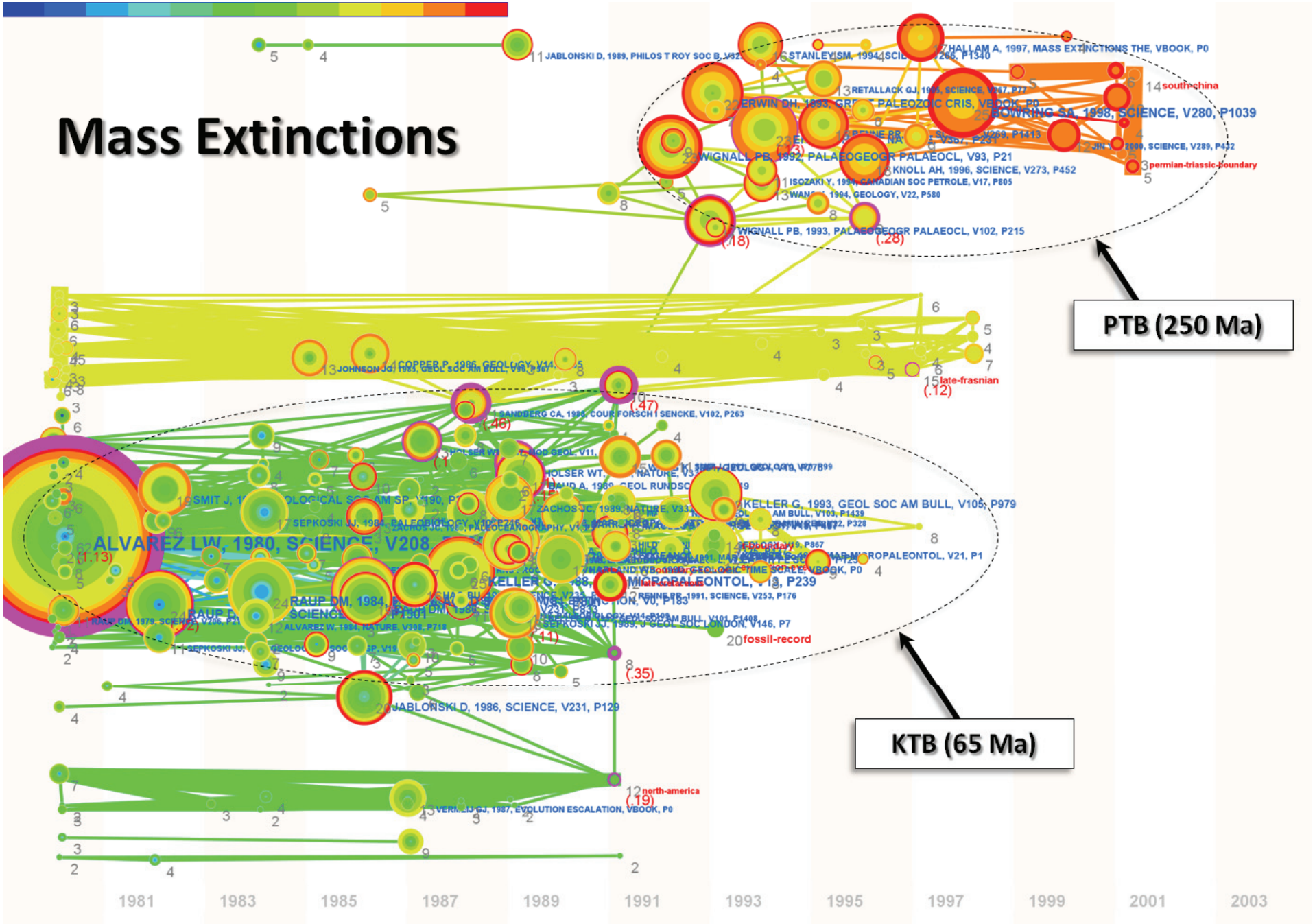
posttraumatic-stress
united-states
after-september-11
september-11
post-traumatic-stress-disorder
2001

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
PTB (250 Ma)
KTB (65 Ma)
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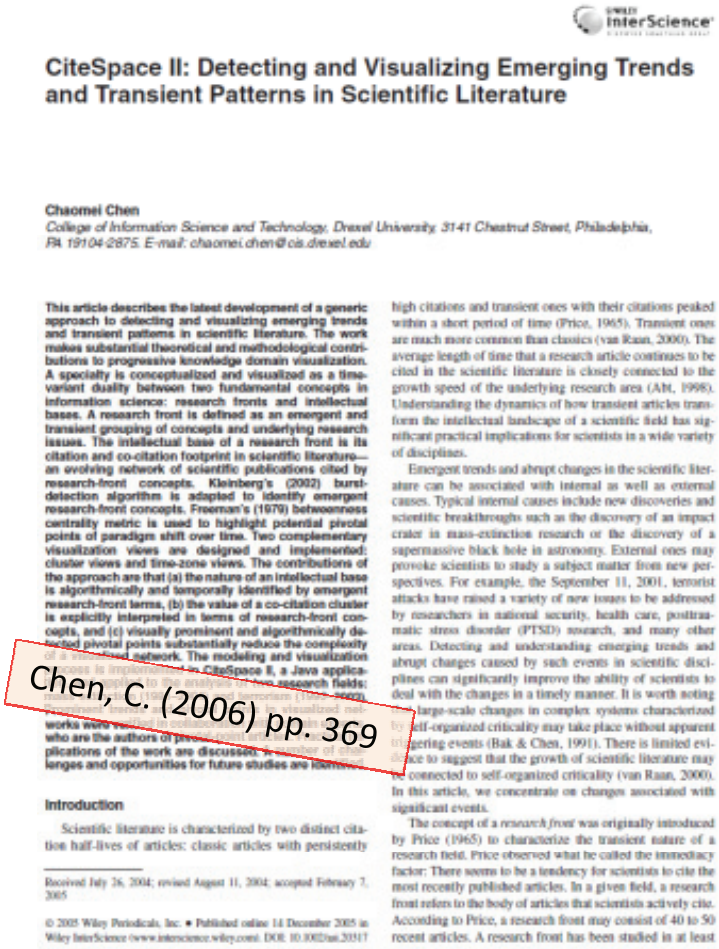

InterScience

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

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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 adopted 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] in CiteSpace II, a Java applica[illegible] research fields: [illegible] works were [illegible] who are the authors of [illegible] plications of the work are discussed. A [illegible] lenges and opportunities for future studies are identified.

Chen, C. (2006) pp. 369

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 by self-organized criticality may take place without apparent 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 has been studied in at least

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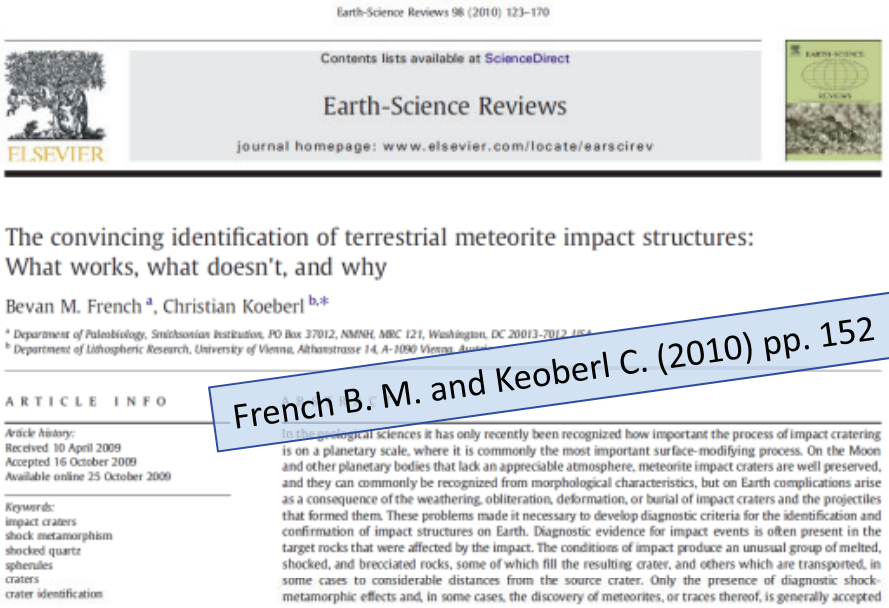

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The convincing identification of terrestrial meteorite impact structures: What works, what doesn't, and why

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

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crater identification

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

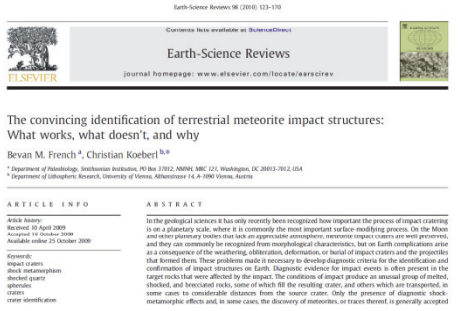
2006

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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[a] Department of Paleobiology, Smithsonian Institution, PO Box 37012, NMNH, MRC 121, Washington, DC 20013-7012, USA
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impact craters
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shocked quartz
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craters
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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

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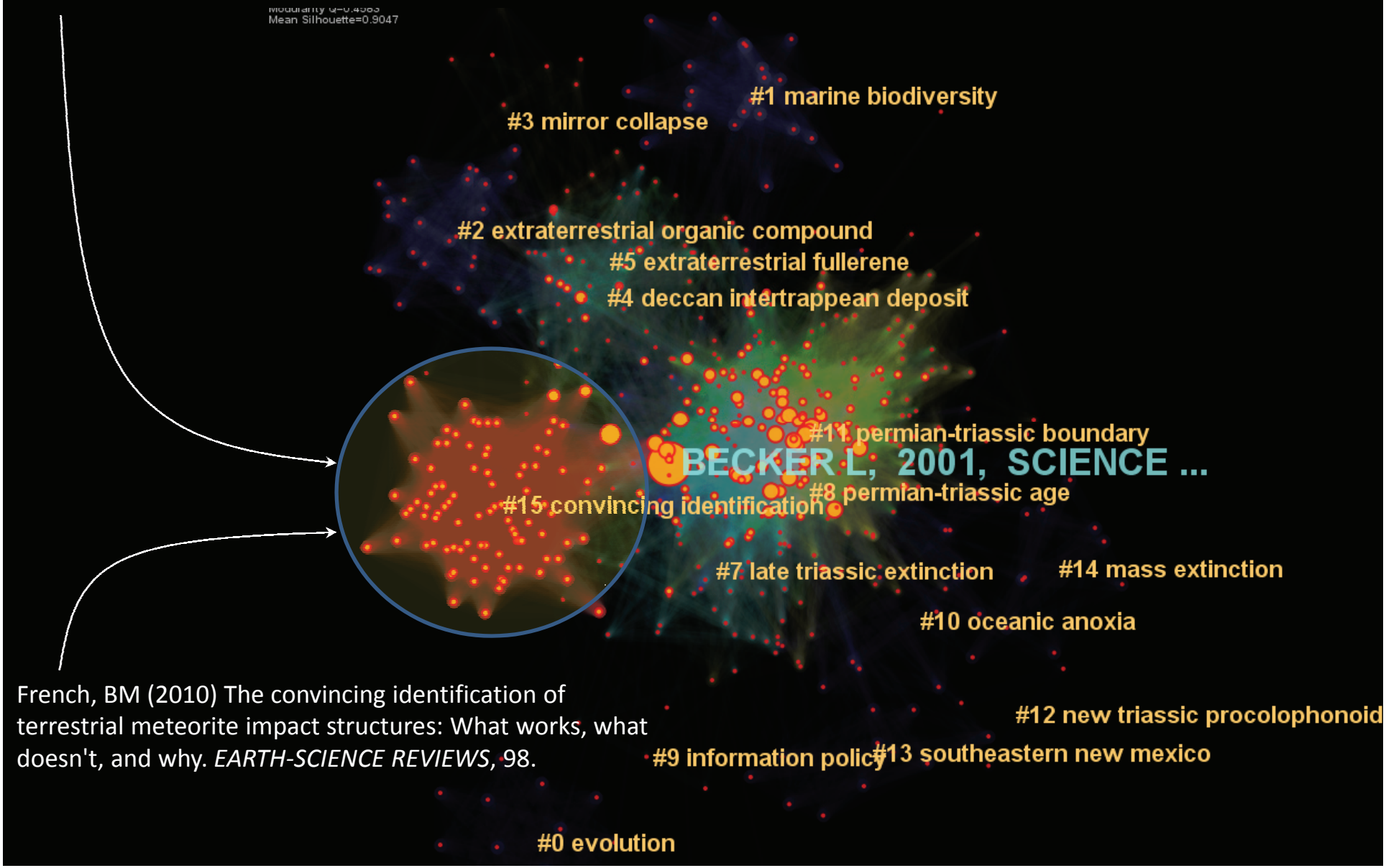
comparable to that of the Chicxulub crater to the K-T impact theory. The discovery of the Chicxulub crater dramatically boosted the credibility of the K-T impact theory. Encouraged by the successful puzzle-solving experience, many scientists appear to have adapted the same approach to solve a different 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?

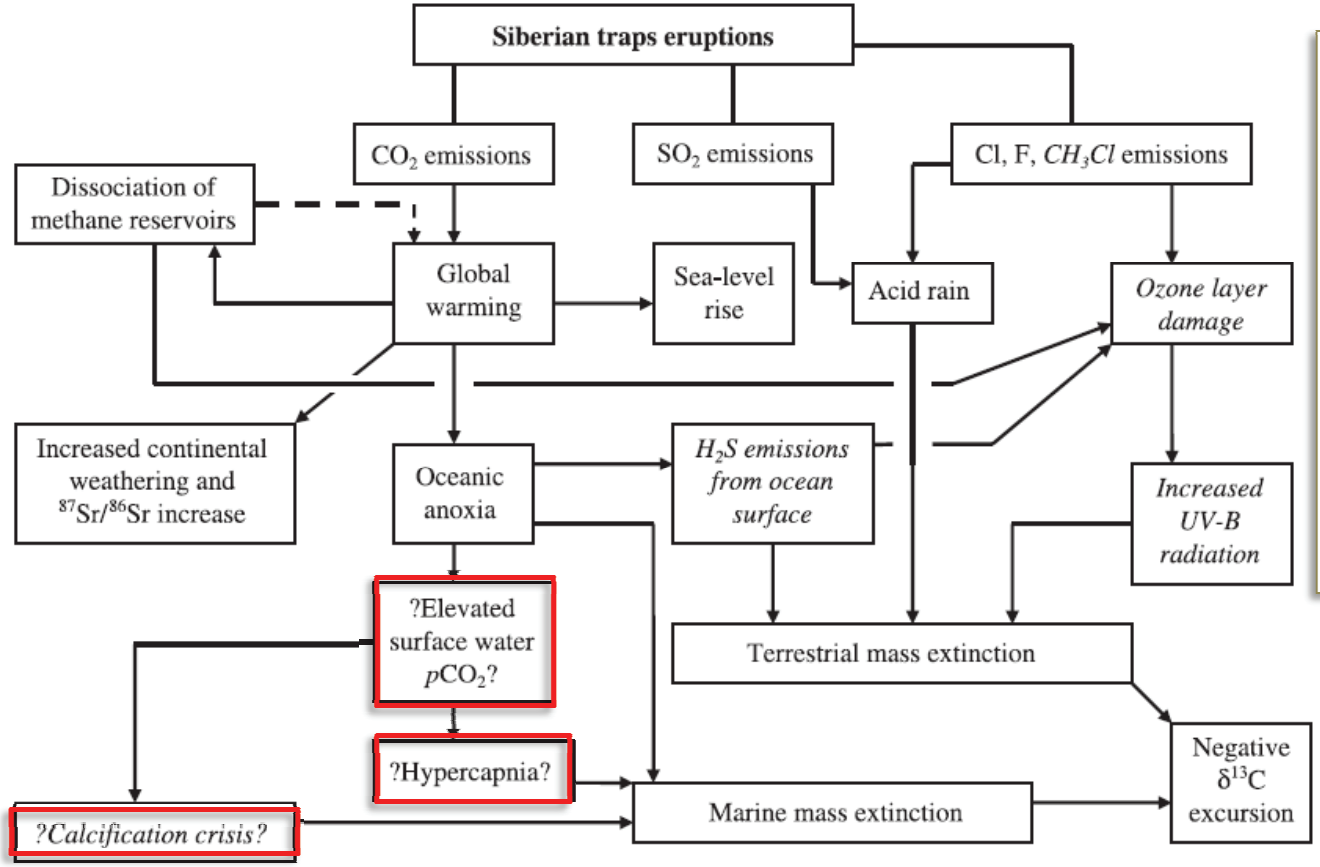


Fig. 2 Flow chart, modified from Fig. 1, summarizing the cascade of environmental consequences caused by the eruption of the Siberian Traps and the latest additions, since 2001, to current thought (shown in italics). The increase in viable terrestrial extinction mechanisms is especially notable. Although 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.

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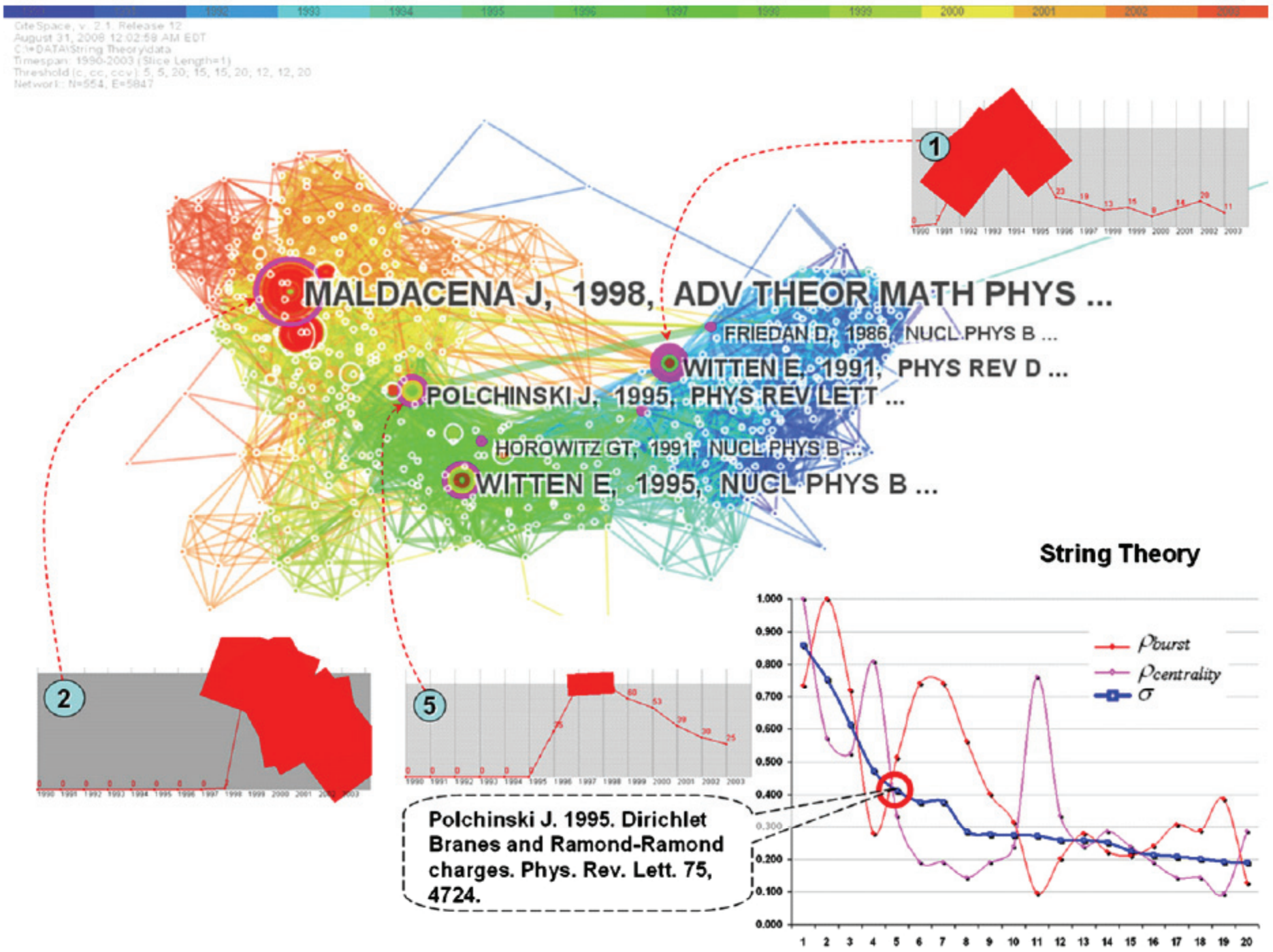
Transformative scientific discoveries
Theory of structural holes
Intellectual brokerage
Knowledge diffusion
Information foraging

ABSTRACT

We propose an expla eries in sci-
ence. The theory is f scientific
change, scientific dis ience, soci-
ology of science, soci 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


CiteSpace, v. 2.1. Release 12
August 31, 2008 12:02:59 AM EDT
C:*DATA\String Theory\data
Timespan: 1990-2003 (Slice Length=1)
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

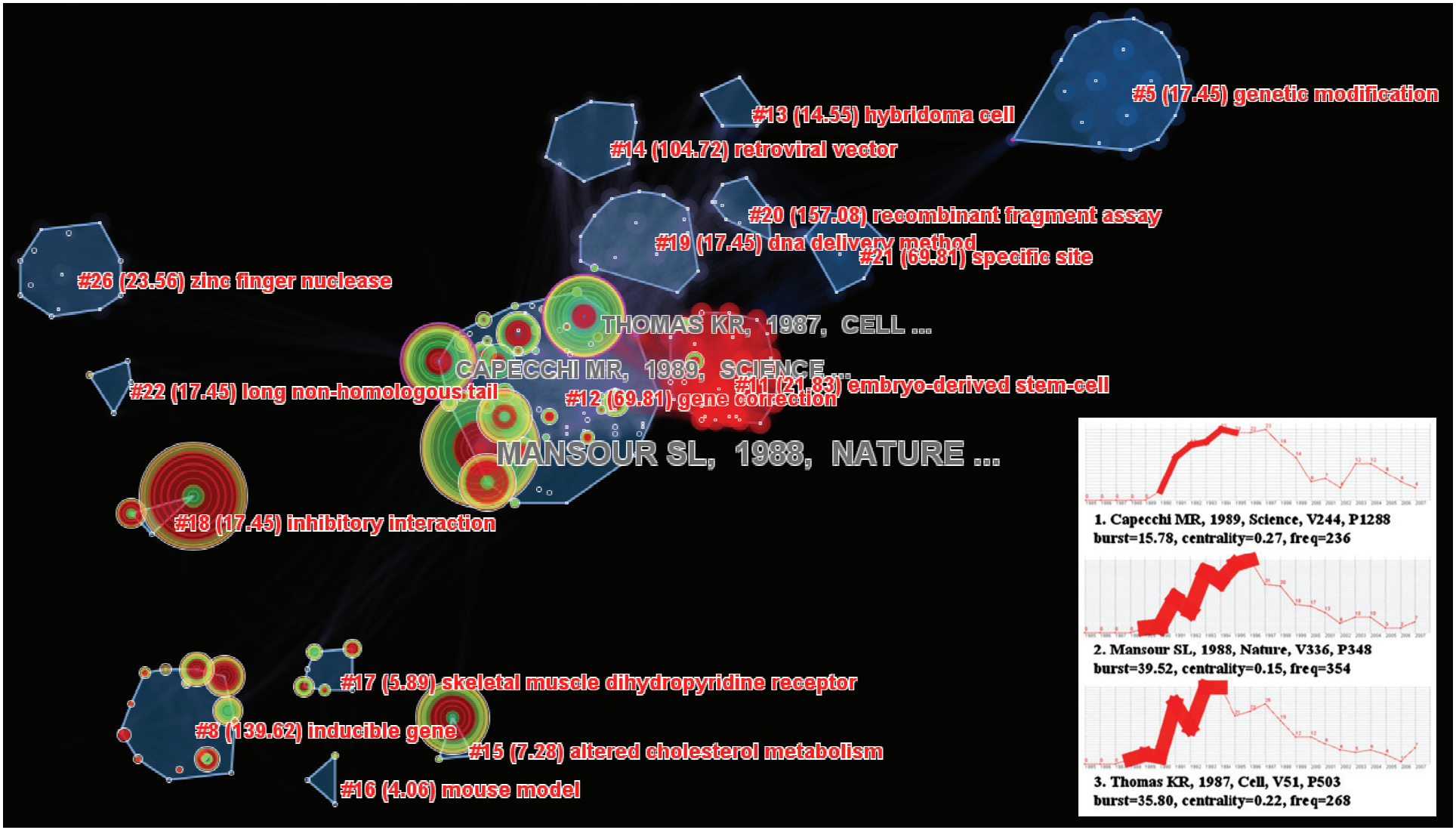
The Nature of Maldacena-1998

- 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

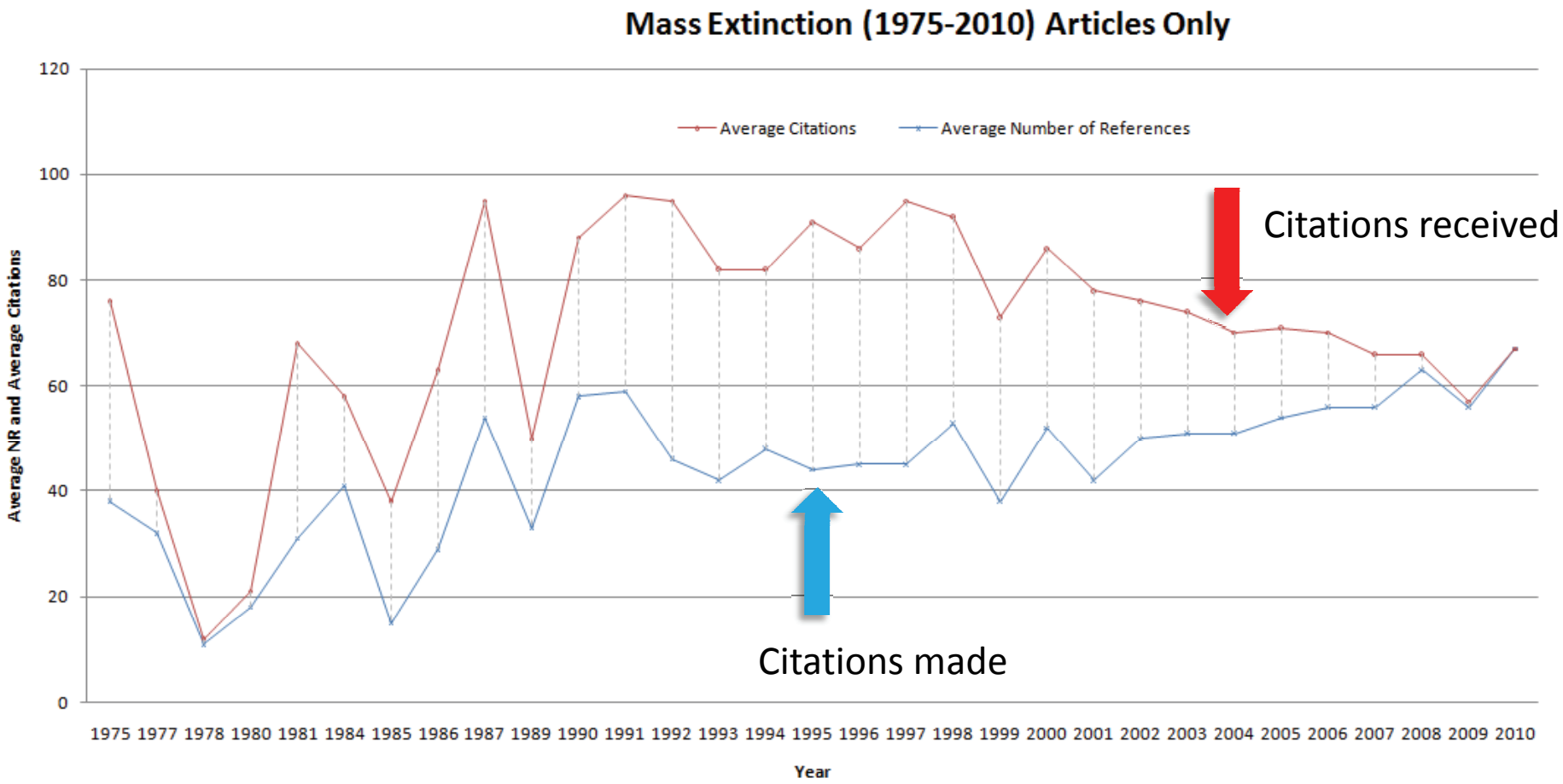
A *Sticky Effect* explains the boundary spanning and citation burst.



Measuring Creativity

Identifying Potentially Transformative Work

Citations Made ~ Citations Received



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Published online 13 August 2010 | Nature | doi:10.1038/news.2010.406

News

An easy way to boost a paper's citations

An analysis of over 50,000 *Science* papers suggests that it could pay to include more references.

Zoë Corbyn

A long reference list at the end of a research paper may be the key to ensuring that it is well cited, according to an analysis of 100 years' worth of papers published in the journal *Science*.

For a well-cited paper, just add references?

iStockphoto

The research suggests that scientists who reference the work of their peers are more likely to find their own work referenced in turn, and the effect is on the rise, with a single extra reference in an article now producing, on average, a whole additional citation for the referencing paper.

"There is a ridiculously strong relationship between the number of citations a paper receives and its number of references," Gregory Webster, the psychologist at the University of Florida in Gainesville who conducted the research, told *Nature*. "If you want to get more cited, the answer could be to cite more people."

"There is a ridiculously strong relationship between the number of citations a paper receives and its number of references," Gregory Webster, the psychologist at the University of Florida in Gainesville who conducted the research, told *Nature*. "If you want to get more cited, the answer could be to cite more people."

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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

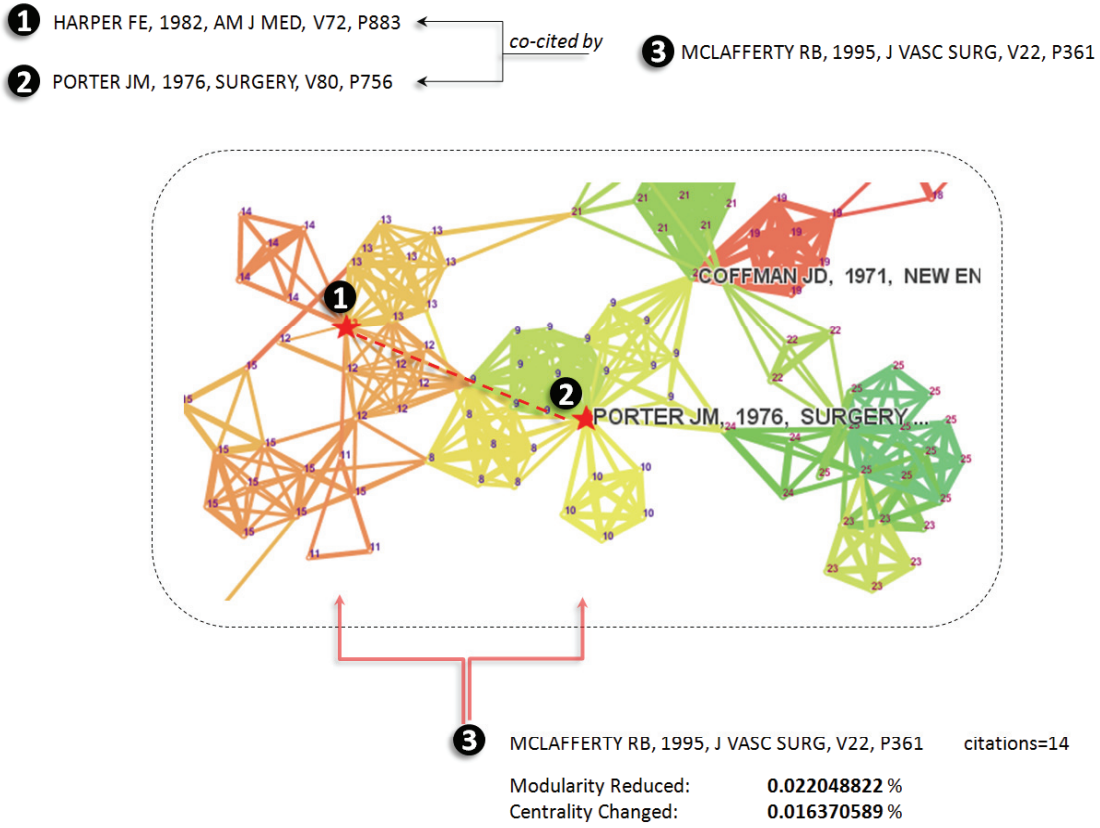
Citation ≈ number of topics synthesized

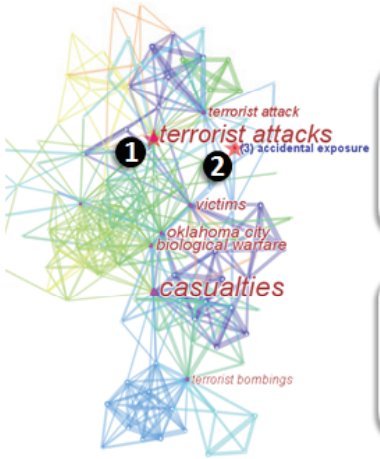
World cup ~ Octopus

Citation ≈ number of previously unexpected topics synthesized

Structural Variation

- Modularity
- Inter-Cluster Brokerage
- Centrality



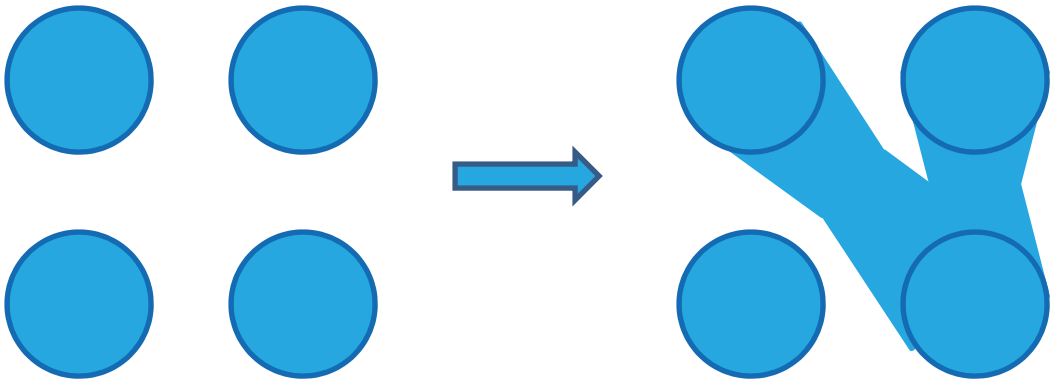


1 terrorist attacks
2 accidental exposure
co-cited by
3 *Maddox, P.J. (2001).* Bioterrorism: A renewed public health threat. *Nursing Economics, 19,* 286 – 291
Top N=30/slice
Modularity Reduced: **0.10808237** %
Centrality Changed: **0.00237439** %

a terrorist attack
b Tokyo subway
co-cited by
c MATSUDA Y, 1998, TOXICOL APPL PHARMACOL, V150, P310 (citations=8)
Top N=50/slice
Modularity Reduced: **0.13176936** %
Centrality Changed: **0.02280092** %
(Not shown in network)

Modularity

$$\Delta Modularity(a) = \frac{Modularity(G \cup Citations(a))}{Modularity(G)}$$



Inter-Cluster Brokerage

$$Brokerage(a) = \frac{\Delta_{Citation(a)} Linkage(G)}{Linkage(G)} \cdot \frac{|Citations(a) \cap G|}{NR}$$

$$\delta_{ij} = 0 \; if \; i \epsilon C_j ; 1 \; otherwise$$

$$Linkage(G) = \sum_{i,j}^{N} A_{ij} \cdot \delta_{ij} \cdot \frac{\sqrt{|C_i| \cdot |C_j|}}{max_k |C_k|}$$

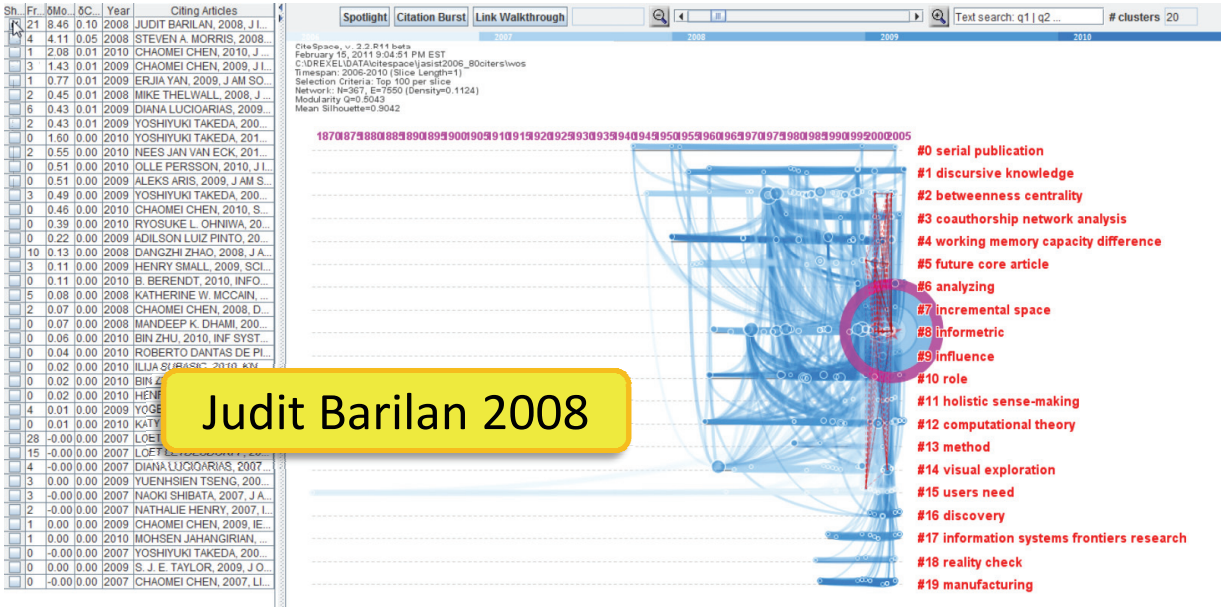
Centrality

- The node centrality of a network $\boldsymbol{G}(V, E)$, $C(\boldsymbol{G})$, is a distribution of the centrality scores of all the nodes, $<c_1, c_2, \ldots, c_n>$, where c_i is the centrality of node n_i, and n is $|V|$, the total number of nodes. The degree of structural change δE can be defined in terms of the K-L divergence, we denote this metric as $\Delta_{centrality}$.

Evaluation

- If we rank newly published papers by the significance of unprecedented connections they added to the existing structure of knowledge trails, what types of papers would be highly ranked?

Example: Papers cited the 2006 JASIST paper on CiteSpace



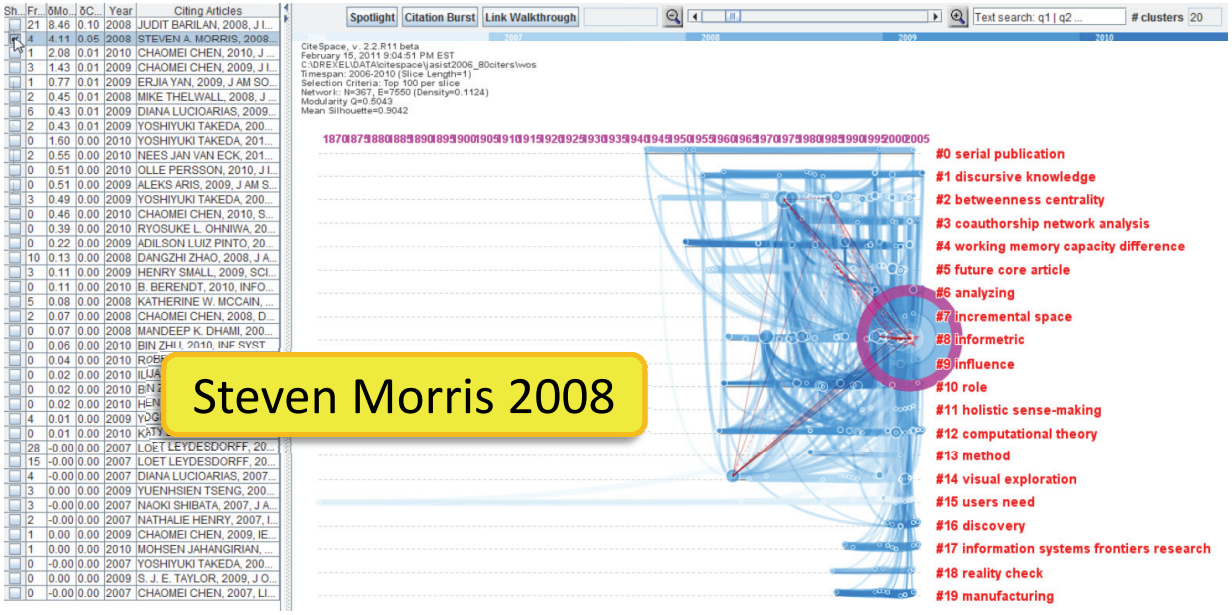


Table 2: Papers ranked by the modularity change rate ΔQ, i.e. $\Delta_{modularity}$.

ΔQ	ΔC	TC	NR	Author	Year	Title	Source
4.5329	.0567	18	610	JUDIT BARILAN	2008	Informatrics at the beginning of the 21st century - A review	JINFORMETR
2.0735	.0236	3	370	STEVEN A. MORRIS	2008	Mapping research specialties	ANNU REV INFORM SCI TECH
1.5902	.0044	3	106	CHAOMEI CHEN	2009	Towards an explanatory and computational theory of scientific discovery	JINFORMETR
.8241	.0024	1	62	ERJIA YAN	2009	Applying Centrality Measures to Impact Analysis: A Coauthorship Network Analysis	J AM SOC INF SCI TECHNOL
.7701	.0014	2	29	YOSHIYUKI TAKEDA	2009	Optics: a bibliometric approach to detect emerging research domains and intellectual bases	SCIENTOMETRICS
.7079	.0037	1	84	KATY BORNER	2009	Visual conceptualizations and models of science	JINFORMETR
.4769	.0003	0	23	YOSHIYUKI TAKEDA	2010	Tracking modularity in citation networks	SCIENTOMETRICS
.4635	.0026	1	45	YOSHIYUKI TAKEDA	2009	Nanobiotechnology as an emerging research domain from nanotechnology: A bibliometric approach	SCIENTOMETRICS
.4124	.0008	0	42	ALEKS ARIS	2009	Visual Overviews for Discovering Key Papers and Influences Across Research Fronts	J AM SOC INF SCI TECHNOL
.3574	.0012	0	33	ERJIA YAN	2009	The Use of Centrality Measures in Scientific Evaluation: A Coauthorship Network Analysis	PROC INTER CONF SCI INFOMET
.3408	.0006	1	37	NEES JAN VAN ECK	2010	Software survey: VOSviewer a computer program for bibliometric mapping	SCIENTOMETRICS
.3302	.0005	0	19	CHAOMEI CHEN	2009	Visual Analysis of Scientific Discoveries and Knowledge Diffusion	PROC INTER CONF SCI INFOMET
.3016	.0025	6	76	DIANA LUCIOARIAS	2009	The dynamics of exchanges and references among scientific texts and the autopoiesis of discursive knowledge	JINFORMETR

transformative indicator($d(t)$) $\approx \Sigma_i \beta_i \Delta G_t$

citation frequency($d(t)$) $\approx \Sigma_i \beta_i \Delta G_t$

Table 3: The Tests of Between-Subjects Effects[b]. Data source: 76 papers that cited [3].

Dependent Variable:Citations

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	112675.351[a]	4	28168.838	58.578	.000	.890
Intercept	2331.753	1	2331.753	4.849	.036	.143
ΔModularity	801.177	1	801.177	1.666	.207	.054
ΔCentrality	**4098.399**	**1**	**4098.399**	**8.523**	**.007**	.227
alpha	46.711	1	46.711	.097	.758	.003
beta	1263.181	1	1263.181	2.627	.116	.083
Error	13945.494	29	480.879			
Total	214646.000	34				
Corrected Total	126620.845	33				

a. R Squared = .890 (Adjusted R Squared = .875)
b. Weighted Least Squares Regression - Weighted by NR

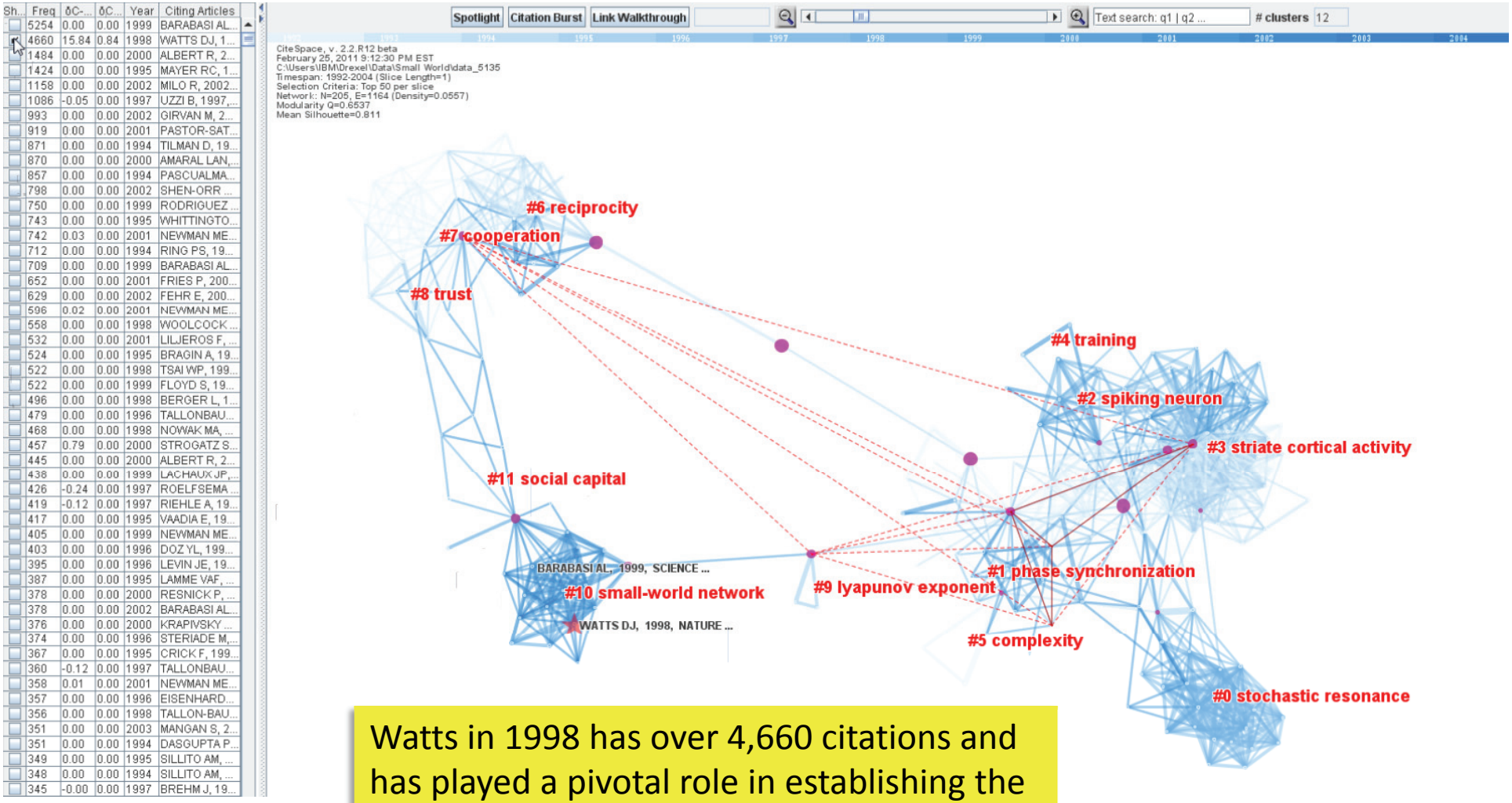
Table 4: Parameter Estimates[a]

Dependent Variable:Citations

Parameter	B	Std. Error	t	Sig.	95% Confidence Interval		Partial Eta Squared
					Lower Bound	Upper Bound	
Intercept	1.541	.700	2.202	.036	.110	2.971	.143
ΔModularity	4.861	3.766	1.291	.207	-2.841	12.564	.054
ΔCentrality	**594.105**	**203.504**	**2.919**	**.007**	**177.891**	**1010.318**	**.227**
alpha	.011	.035	.312	.758	-.061	.083	.003
beta	-.210	.130	-1.621	.116	-.476	.055	.083

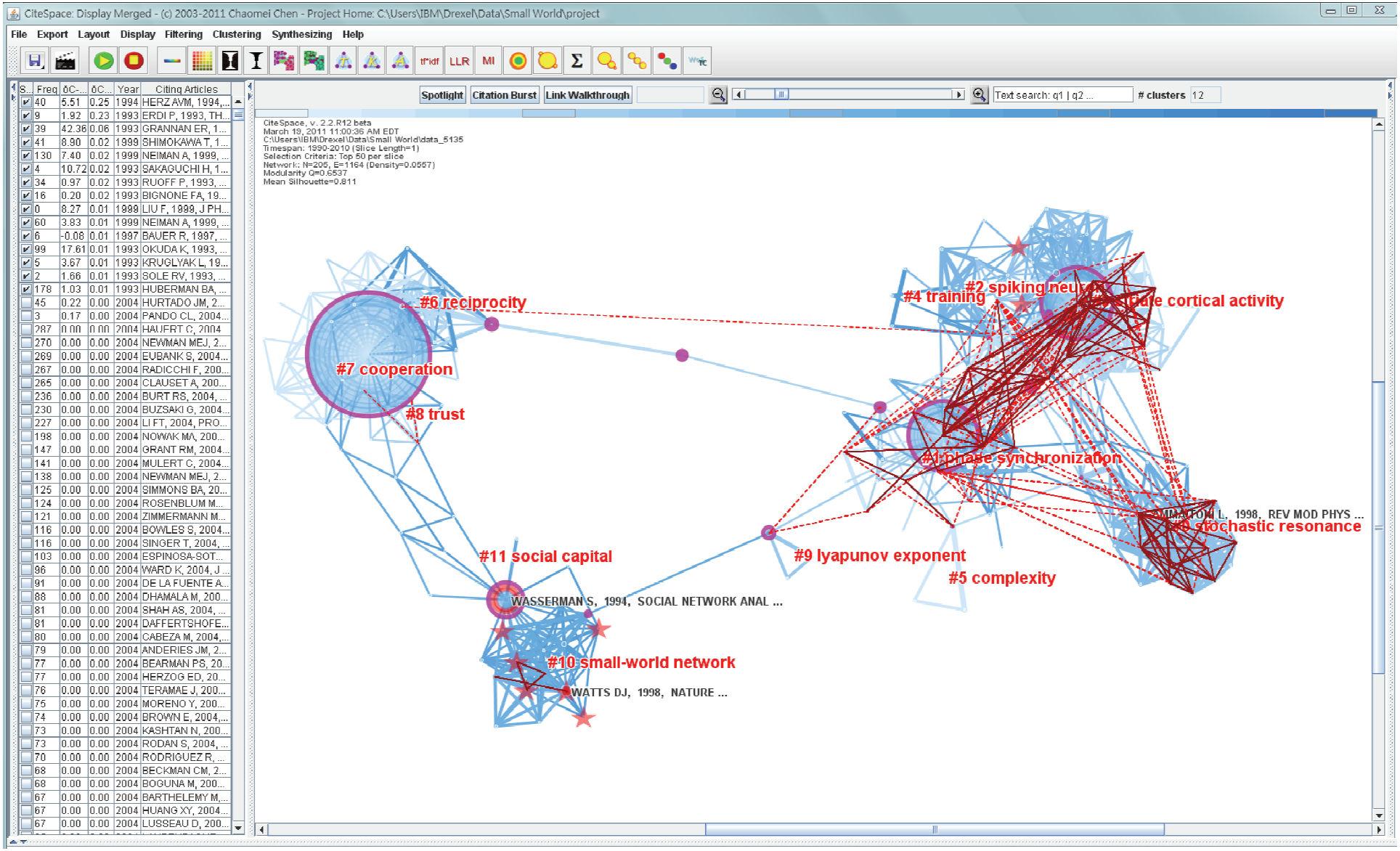
a. Weighted Least Squares Regression - Weighted by NR

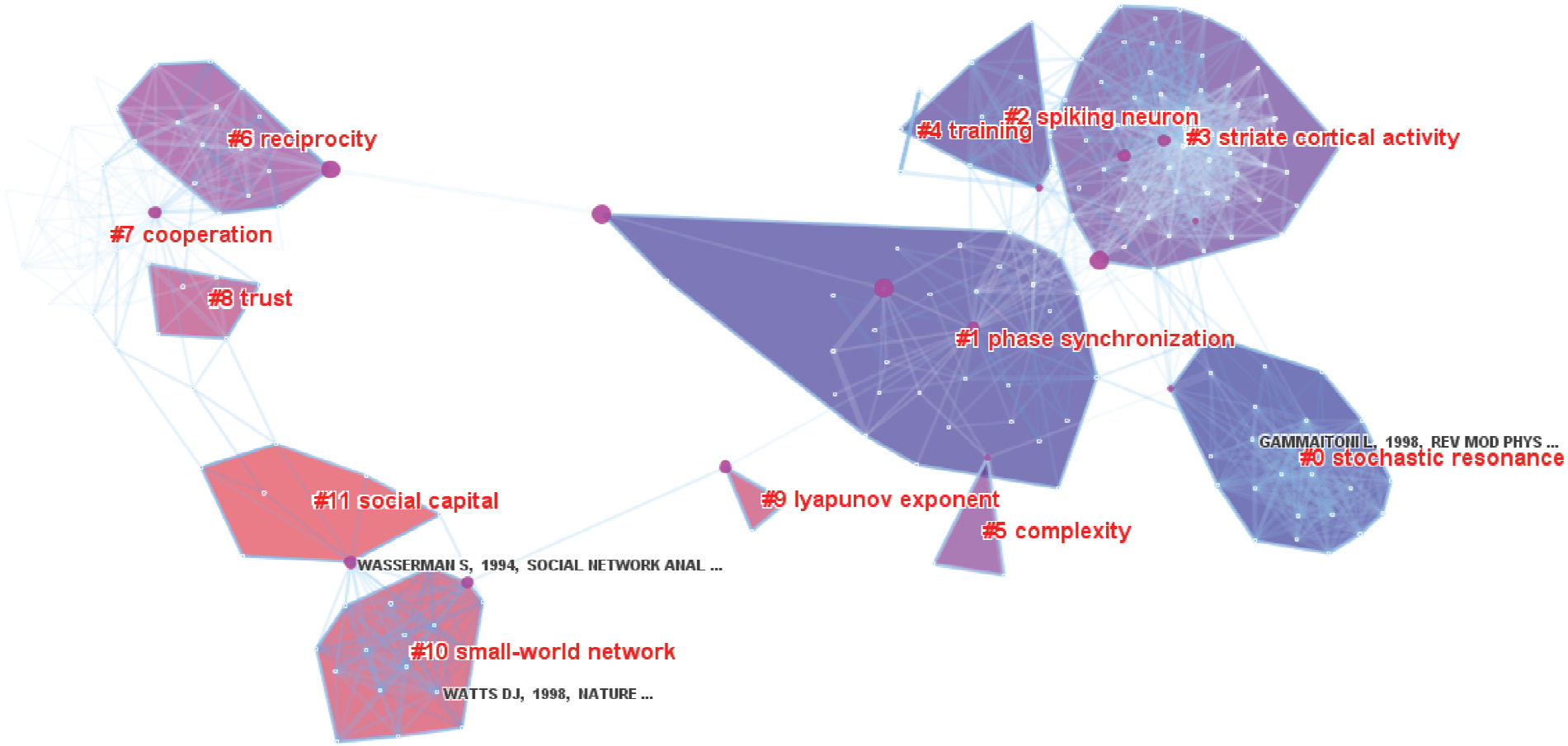
Example: Small World Networks



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.


CiteSpace: Display Merged - (c) 2003-2011 Chaomei Chen - Project Home: C:\Users\IBM\Drexel\Data\Small World\project
File Export Layout Display Filtering Clustering Synthesizing Help
Spotlight Citation Burst Link Walkthrough
Text search: q1 | q2 ...
clusters 12
CiteSpace, v. 2.2.R12 beta
March 19, 2011 11:00:36 AM EDT
C:\Users\IBM\Drexel\Data\Small World\data_5135
Timespan: 1990-2010 (Slice Length=1)
Selection Criteria: Top 50 per slice
Network: N=205, E=1164 (Density=0.0557)
Modularity Q=0.6537
Mean Silhouette=0.811
#6 reciprocity
#7 cooperation
#8 trust
#4 training
#2 spiking neuron
#3 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 ...
GAMMAITONI L, 1998, REV MOD PHYS ...


#6 reciprocity
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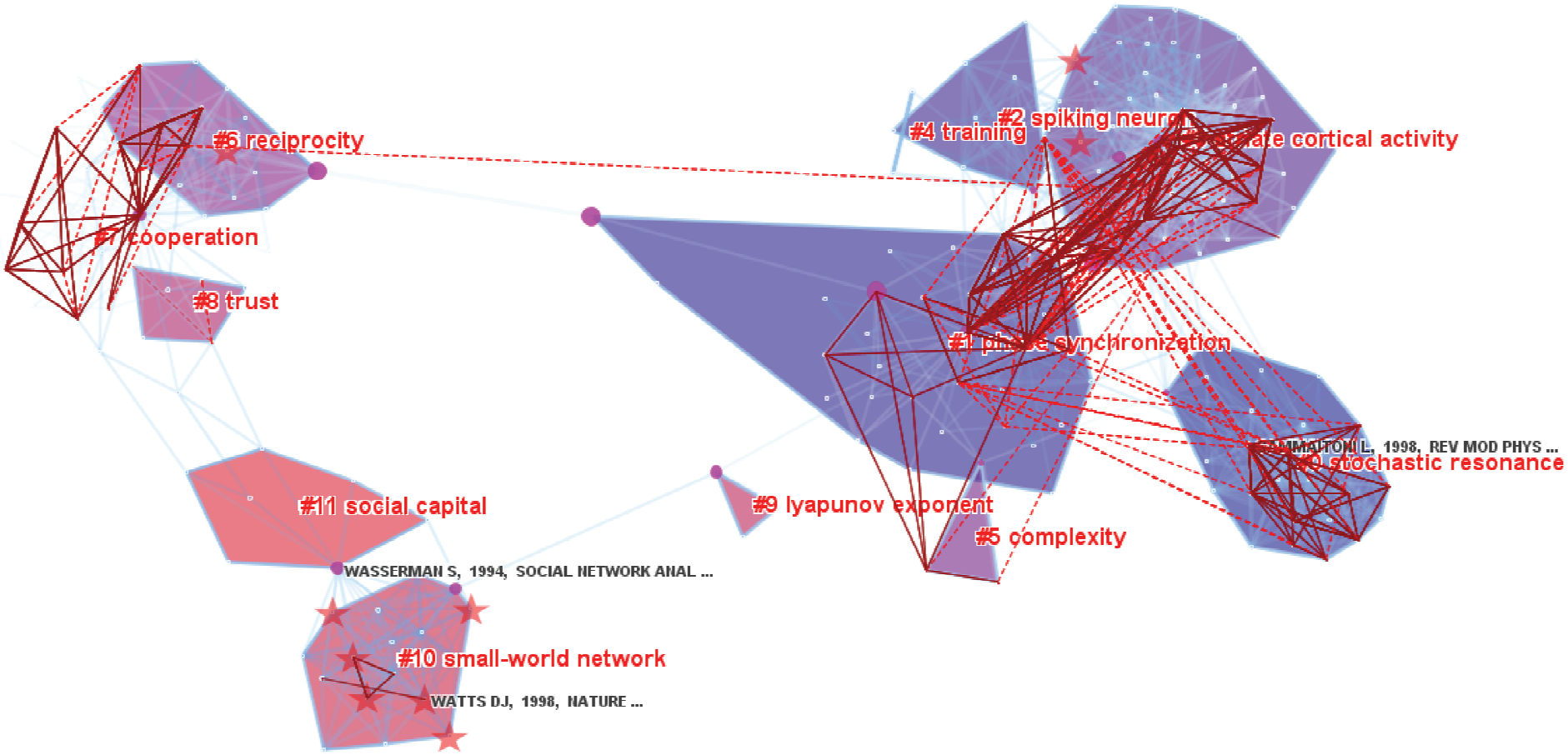
#9 lyapunov exponent
#5 complexity
GAMMAITONI L, 1998, REV MOD PHYS ...
#0 stochastic resonance



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.

Table 1. Main effects of structural variation on citations of articles.

Dataset	***D1: CiteSpace Direct Citation***		***D2: CiteSpace Related Articles***		***D3: Terrorism***		***D4: Small-World Networks***	
Duration	2006-2011		2003-2009		1996-2003		1995-2001	
# articles	48		2,412		1,049		2,200	
References per year	100		100		100		100	
Variables	B	p-level	B	p-level	B	p-level	B	p-level
ΔModularity	**-1.549**	.016	**.071**	.000	**.467**	.008	**.035**	.026
Inter-Cluster Brokerage	.107	.574	.023	.336	.006	.837	**-.031**	.039
ΔCentrality	**161.788**	.004	.512	.687	-3.694	.432	**9.158**	.000
Log(NR)	-.095	.687	**.659**	.000	**1.056**	.000	**.720**	.000
Log(Length)	.451	.372	**-.474**	.000	-1.119	.000	**-.628**	.000

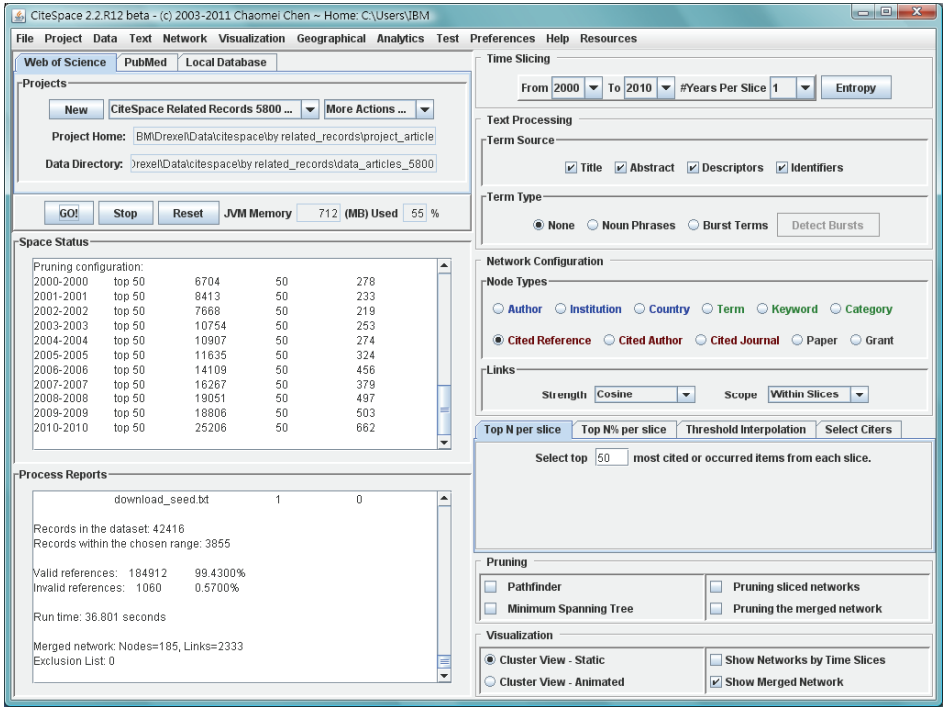
Conclusions

- Key Questions:
  - The key to creativity is the change of a viewpoint.
  - How to reveal the evolution trend and critical paths of the development of a scientific field at both macroscopic and microscopic levels?
  - How to synthesize existing studies of scientific discovery and find characteristics and mechanisms of creative thinking in scientific discovery?
  - How to build on the improved understanding of scientific discovery and establish a new analytic method that stimulates creative thinking more effectively and more transparently?
- Three Major Research Directions:
  - Multiple-Perspective Analysis of Scientific Literature
  - Literature-Based Scientific Discovery
  - Generic Mechanisms of Creative Thinking in Knowledge Discovery
- Conclusions:
  - The key questions have theoretical and practical implications on a wide range of scientific fields as well as on science policy, strategic planning, and recognizing potentially transformative research activities.
  - The explanatory and computational theory of discovery has the potential and it can be strengthened further.
  - Answering the key questions is a long-term challenging goal.

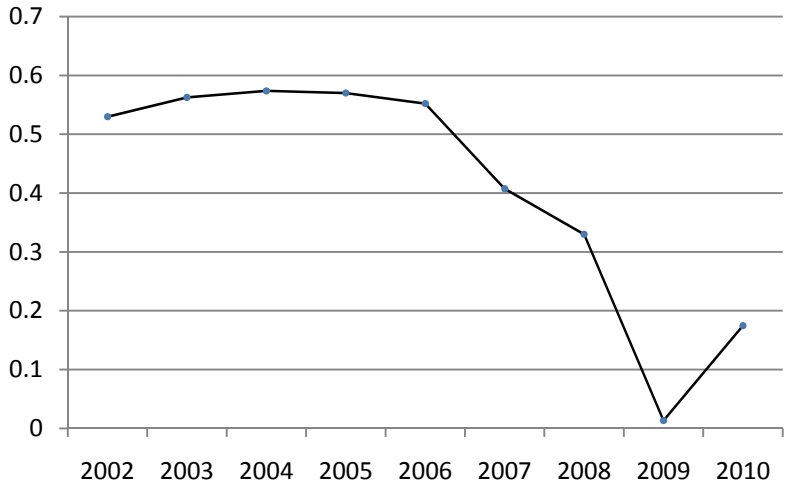
Acknowledgements

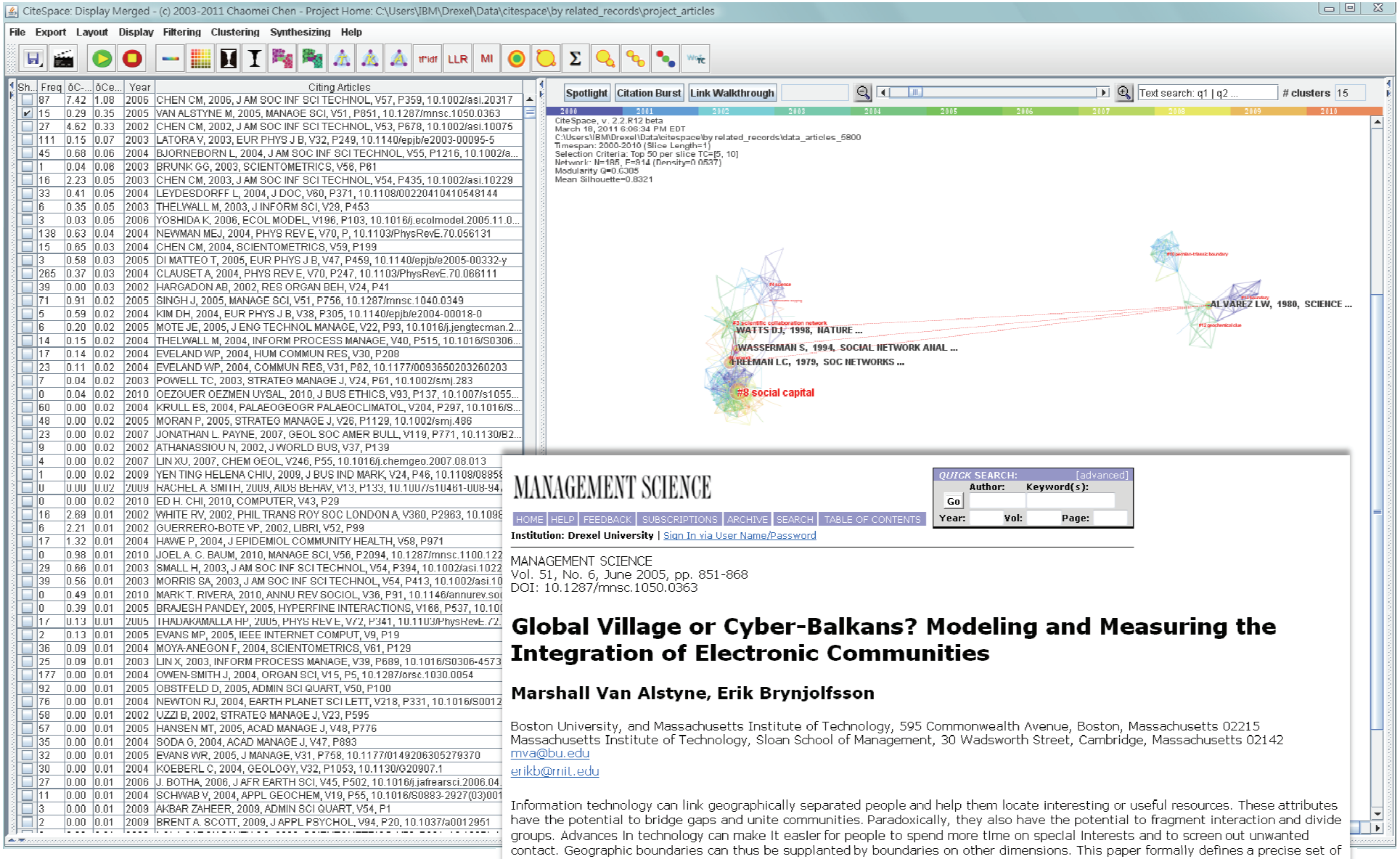
- This material is based upon work supported by the National Science Foundation under Grant No. IIS-0612129 and Contract No. NSFDACS-10P1303. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

Case Study: Citation Context Analysis Seed Paper (JASIST 2006)



year	citers	refs	clusters	modularity
2002	228	80	7	0.529851
2003	282	77	8	0.562672
2004	313	72	7	0.573726
2005	317	79	9	0.570106
2006	404	76	7	0.552117
2007	423	68	4	0.407325
2008	477	62	5	0.329891
2009	468	64	3	0.013305
2010	557	63	5	0.174634





Sh..	Freq	δC-...	δCe...	Year	Citing Articles
	87	7.42	1.08	2006	CHEN CM, 2006, J AM SOC INF SCI TECHNOL, V57, P359, 10.1002/asi.20317
✔	15	0.29	0.35	2005	VAN ALSTYNE M, 2005, MANAGE SCI, V51, P851, 10.1287/mnsc.1050.0363
	27	4.62	0.33	2002	CHEN CM, 2002, J AM SOC INF SCI TECHNOL, V53, P678, 10.1002/asi.10075
	111	0.15	0.07	2003	LATORA V, 2003, EUR PHYS J B, V32, P249, 10.1140/epjb/e2003-00095-5
	45	0.68	0.06	2004	BJORNEBORN L, 2004, J AM SOC INF SCI TECHNOL, V55, P1216, 10.1002/a...
	1	0.04	0.06	2003	BRUNK GG, 2003, SCIENTOMETRICS, V58, P61
	16	2.23	0.05	2003	CHEN CM, 2003, J AM SOC INF SCI TECHNOL, V54, P435, 10.1002/asi.10229
	33	0.41	0.05	2004	LEYDESDORFF L, 2004, J DOC, V60, P371, 10.1108/00220410410548144
	6	0.35	0.05	2003	THELWALL M, 2003, J INFORM SCI, V29, P453
	3	0.03	0.05	2006	YOSHIDA K, 2006, ECOL MODEL, V196, P103, 10.1016/j.ecolmodel.2005.11.0...
	138	0.63	0.04	2004	NEWMAN MEJ, 2004, PHYS REV E, V70, P, 10.1103/PhysRevE.70.056131
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	265	0.37	0.03	2004	CLAUSET A, 2004, PHYS REV E, V70, P247, 10.1103/PhysRevE.70.066111
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	71	0.91	0.02	2005	SINGH J, 2005, MANAGE SCI, V51, P756, 10.1287/mnsc.1040.0349
	5	0.59	0.02	2004	KIM DH, 2004, EUR PHYS J B, V38, P305, 10.1140/epjb/e2004-00018-0
	6	0.20	0.02	2005	MOTE JE, 2005, J ENG TECHNOL MANAGE, V22, P93, 10.1016/j.jengtecman.2...
	14	0.15	0.02	2004	THELWALL M, 2004, INFORM PROCESS MANAGE, V40, P515, 10.1016/S0306...
	17	0.14	0.02	2004	EVELAND WP, 2004, HUM COMMUN RES, V30, P208
	23	0.11	0.02	2004	EVELAND WP, 2004, COMMUN RES, V31, P82, 10.1177/0093650203260203
	7	0.04	0.02	2003	POWELL TC, 2003, STRATEG MANAGE J, V24, P61, 10.1002/smj.283
	0	0.04	0.02	2010	OEZGUER OEZMEN UYSAL, 2010, J BUS ETHICS, V93, P137, 10.1007/s1055...
	60	0.00	0.02	2004	KRULL ES, 2004, PALAEOGEOGR PALAEOCLIMATOL, V204, P297, 10.1016/S...
	48	0.00	0.02	2005	MORAN P, 2005, STRATEG MANAGE J, V26, P1129, 10.1002/smj.486
	23	0.00	0.02	2007	JONATHAN L. PAYNE, 2007, GEOL SOC AMER BULL, V119, P771, 10.1130/B2...
	9	0.00	0.02	2002	ATHANASSIOU N, 2002, J WORLD BUS, V37, P139
	4	0.00	0.02	2007	LIN XU, 2007, CHEM GEOL, V246, P55, 10.1016/j.chemgeo.2007.08.013
	1	0.00	0.02	2009	YEN TING HELENA CHIU, 2009, J BUS IND MARK, V24, P46, 10.1108/08858
	0	0.00	0.02	2009	RACHEL A. SMITH, 2009, AIDS BEHAV, V13, P133, 10.1007/s10461-008-94...
	0	0.00	0.02	2010	ED H. CHI, 2010, COMPUTER, V43, P29
	16	2.69	0.01	2002	WHITE RV, 2002, PHIL TRANS ROY SOC LONDON A, V360, P2963, 10.1098
	6	2.21	0.01	2002	GUERRERO-BOTE VP, 2002, LIBRI, V52, P99
	17	1.32	0.01	2004	HAWE P, 2004, J EPIDEMIOL COMMUNITY HEALTH, V58, P971
	0	0.98	0.01	2010	JOEL A. C. BAUM, 2010, MANAGE SCI, V56, P2094, 10.1287/mnsc.1100.122
	29	0.66	0.01	2003	SMALL H, 2003, J AM SOC INF SCI TECHNOL, V54, P394, 10.1002/asi.1022
	39	0.56	0.01	2003	MORRIS SA, 2003, J AM SOC INF SCI TECHNOL, V54, P413, 10.1002/asi.10
	0	0.49	0.01	2010	MARK T. RIVERA, 2010, ANNU REV SOCIOL, V36, P91, 10.1146/annurev.so
	0	0.39	0.01	2005	BRAJESH PANDEY, 2005, HYPERFINE INTERACTIONS, V166, P537, 10.10
	17	0.13	0.01	2005	THADAKAMALLA HP, 2005, PHYS REV E, V72, P341, 10.1103/PhysRevE.72.
	2	0.13	0.01	2005	EVANS MP, 2005, IEEE INTERNET COMPUT, V9, P19
	36	0.09	0.01	2004	MOYA-ANEGON F, 2004, SCIENTOMETRICS, V61, P129
	25	0.09	0.01	2003	LIN X, 2003, INFORM PROCESS MANAGE, V39, P689, 10.1016/S0306-4573
	177	0.00	0.01	2004	OWEN-SMITH J, 2004, ORGAN SCI, V15, P5, 10.1287/orsc.1030.0054
	92	0.00	0.01	2005	OBSTFELD D, 2005, ADMIN SCI QUART, V50, P100
	76	0.00	0.01	2004	NEWTON RJ, 2004, EARTH PLANET SCI LETT, V218, P331, 10.1016/S0012
	58	0.00	0.01	2002	UZZI B, 2002, STRATEG MANAGE J, V23, P595
	57	0.00	0.01	2005	HANSEN MT, 2005, ACAD MANAGE J, V48, P776
	35	0.00	0.01	2004	SODA G, 2004, ACAD MANAGE J, V47, P893
	32	0.00	0.01	2005	EVANS WR, 2005, J MANAGE, V31, P758, 10.1177/0149206305279370
	30	0.00	0.01	2004	KOEBERL C, 2004, GEOLOGY, V32, P1053, 10.1130/G20907.1
	27	0.00	0.01	2006	J. BOTHA, 2006, J AFR EARTH SCI, V45, P502, 10.1016/j.jafrearsci.2006.04.
	11	0.00	0.01	2004	SCHWAB V, 2004, APPL GEOCHEM, V19, P55, 10.1016/S0883-2927(03)001
	3	0.00	0.01	2009	AKBAR ZAHEER, 2009, ADMIN SCI QUART, V54, P1
	2	0.00	0.01	2009	BRENT A. SCOTT, 2009, J APPL PSYCHOL, V94, P20, 10.1037/a0012951

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Global Village or Cyber-Balkans? Modeling and Measuring the Integration of Electronic Communities

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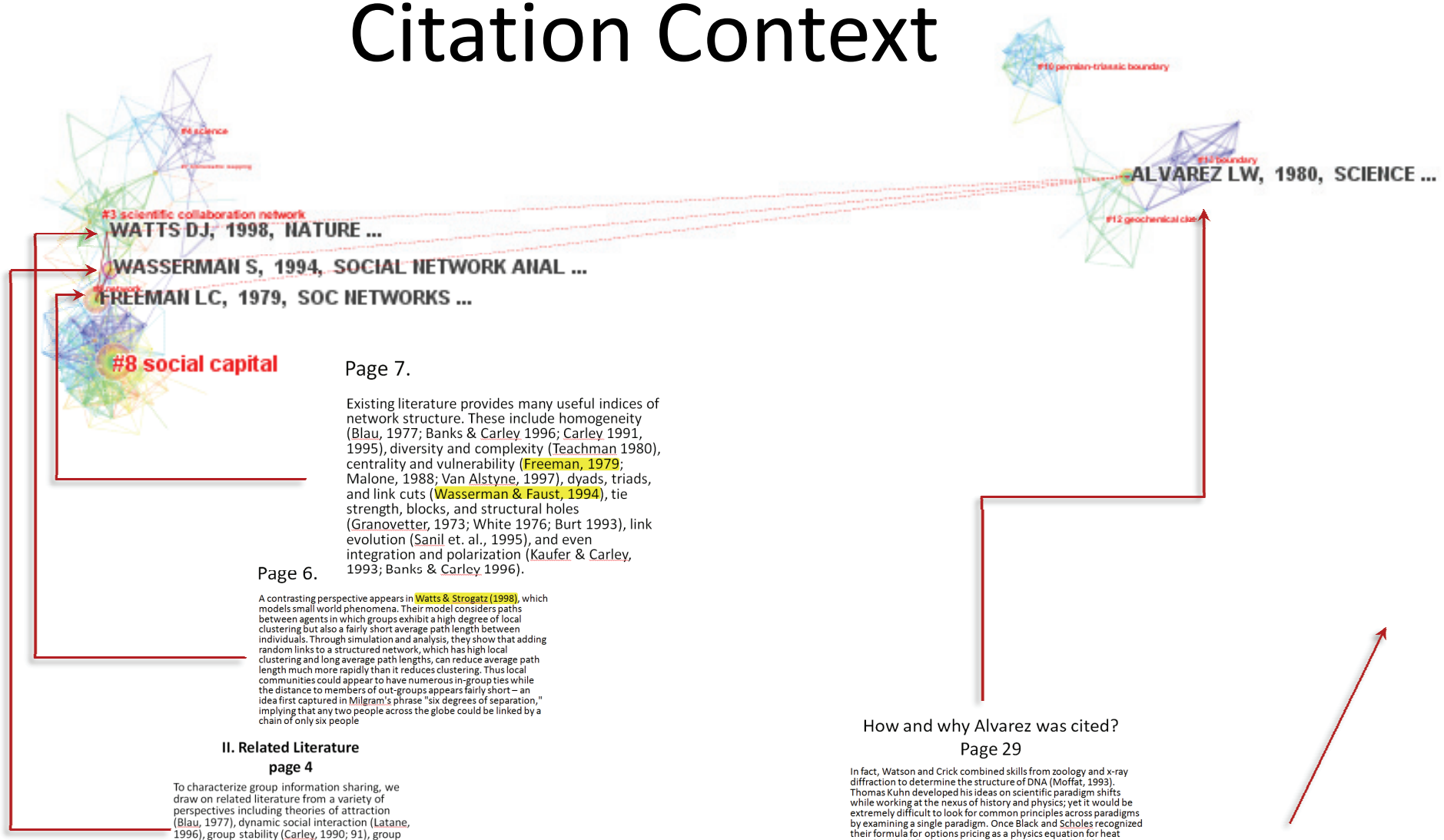
Information technology can link geographically separated people and help them locate interesting or useful resources. These attributes have the potential to bridge gaps and unite communities. Paradoxically, they also have the potential to fragment interaction and divide groups. Advances in technology can make it easier for people to spend more time on special interests and to screen out unwanted contact. Geographic boundaries can thus be supplanted by boundaries on other dimensions. This paper formally defines a precise set of measures of information integration and develops a model of individual knowledge profiles and community affiliation. These factors suggest specific conditions under which improved access, search, and screening can either integrate or fragment interaction on various dimensions. As IT capabilities continue to improve, preferences—not geography or technology—become the key determinants of community boundaries.

Key Words: globalization; information economy; information flows; computerization of society; organizational structure; economic impacts; balkanization; social networks
History: Received: October 27, 1999;

Citation Context



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Existing literature provides many useful indices of network structure. These include homogeneity (Blau, 1977; Banks & Carley 1996; Carley 1991, 1995), diversity and complexity (Teachman 1980), centrality and vulnerability (Freeman, 1979; Malone, 1988; Van Alstyne, 1997), dyads, triads, and link cuts (Wasserman & Faust, 1994), tie strength, blocks, and structural holes (Granovetter, 1973; White 1976; Burt 1993), link evolution (Sanil et. al., 1995), and even integration and polarization (Kaufer & Carley, 1993; Banks & Carley 1996).

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A contrasting perspective appears in Watts & Strogatz (1998), which models small world phenomena. Their model considers paths between agents in which groups exhibit a high degree of local clustering but also a fairly short average path length between individuals. Through simulation and analysis, they show that adding random links to a structured network, which has high local clustering and long average path lengths, can reduce average path length much more rapidly than it reduces clustering. Thus local communities could appear to have numerous in-group ties while the distance to members of out-groups appears fairly short – an idea first captured in Milgram's phrase "six degrees of separation," implying that any two people across the globe could be linked by a chain of only six people

II. Related Literature

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To characterize group information sharing, we draw on related literature from a variety of perspectives including theories of attraction (Blau, 1977), dynamic social interaction (Latane, 1996), group stability (Carley, 1990; 91), group diversity (Ancona & Caldwell, 1992), social networks (White, et al. 1976; Wellman & Wortley 1990; Wellman & Gulia 1997) network measures (Banks & Carley, 1996; Sunil, Banks & Carley 1995; Teachman, 1980; Wasserman & Faust, 1994; Watts & Strogatz, 1998) and diffusion models (Valente 1995).

How and why Alvarez was cited?

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In fact, Watson and Crick combined skills from zoology and x-ray diffraction to determine the structure of DNA (Moffat, 1993). Thomas Kuhn developed his ideas on scientific paradigm shifts while working at the nexus of history and physics; yet it would be extremely difficult to look for common principles across paradigms by examining a single paradigm. Once Black and Scholes recognized their formula for options pricing as a physics equation for heat transfer (Black & Scholes, 1973, p. 644) they could look for established parallels. Similarly, the Alvarez theory that an asteroid caused the extinction of the dinosaurs emerged from a fortuitous combination of father and son skills in astrophysics and geology (Alvarez, 1980). "Some of the greatest achievements in science come from work at the boundaries of disciplines."17 The difficulty is that it is not always clear beforehand which groups need to share information.