Evolution of Geographic Information Systems research front using information visualizing network

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Abstract

This paper studies the development of GIS from a new point of view, which both from the accumulation of GIS scientific articles and the evolution process of GIS using co-citation analysis. After 10 years' slow development from 1977, the number of GIS scientific literature began to increase rapidly since the early 1990s. By using the newly developed information visualization technology, the authors make Author Co-citation Analysis (ACA) and Document Co-citation Analysis (DCA) for 12,417 GIS scientific articles indexed in SCI-Expanded, SSCI, A&HCI. The result reveals the evolution process of GIS from intellectual base to several application fronts: hydrology, land use planning, landslide hazard, landscape ecology, when these applications in engineering areas also accelerate development of GIS. The pivotal authors and literature in the evolution process of GIS from intellectual base to applied fronts are also detected by the visualization of ACA and DCA of GIS scientific literature.

1 Introduction

The term GIS is defined from two aspects, the "tool versus science". On the one hand, GIS (*Geographic Information Systems*) refers to a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world(Burrough 1986). On the other hand, GIS (*Geographic Information Science*) concerning the analysis of the fundamental issues raised by the use of GIS, it's sufficiently close to the core of the discipline that it can serve as a shield for the rest of the discipline, a motivating core(Wright et al. 1997). No matter GIS is defined as a tool or science, there is a evolution process for GIS in the forepassed 30 years since its inchoation.

Price studied the growth of the number of scientists, scientific journals and papers, and has found that science has been characterized by some specifically rules for the past 300 years, for example, the exponential growth rate (Price 1975). Along with the growth of number of scientific literature, there is qualitative changes inspired by the technological revolution. From the aspect of scientometrics, this article firstly studies the accumulation of numbers of GIS scientific articles, then we use visualization technology to detect the evolution process of GIS from the germination to the mature stage, the change of research fronts, and pivotal points in the development process of GIS, in order to get a comprehensive and visualized understanding about GIS.

2 Data and Method

The primary source of data is Web of Science (WOS), including SCI-Expanded, SSCI, A&HCI, which provide access to current and retrospective bibliographic information, author abstracts, and cited references found in newly 10,000 of the world's leading scholarly science and technical journals, social sciences journals covering and arts & humanities journals. WOS allows researchers to conduct broad-based, comprehensive searches, provides cited reference searching, the unique ISI search and retrieval feature that lets users track the literature forward, backward.

The documents studied are retrieved from WOS for the period from 1975 to 2006. The authors make a general search in citation databases of SCI-Expanded, SSCI, A&HCI, the

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search strategy is performed as *TS=(GIS OR "Geograph* Information System*" OR "Geograph* information science*" OR "GIS-cience*")* in Advanced Search and restricted by choosing the language for English and document type for Article, the scope of the search included four topic fields in each bibliographic record: title, abstract, descriptors. 12,417 records are listed, in which there are 10,892 in SCI-Expanded, 2,478 in SSCI, and 117 records in A&HCI. Then the authors change the search strategy as *TI=(GIS OR "Geograph* Information System*" OR "Geograph* information science*" OR "GIS-cience*")*, and make the same restriction for the language and document type, get 3,841 records, when 3,177 in SCI-Expanded, 978 in SSCI, and 63 records in A&HCI. The overall research result is not equal to the sum of results in the 3 citation databases. The reason is that some articles are indexed by 2 or 3 databases synchronously.

2.1 The growth of GIS articles

Figure 1 shows the growth of of number of GIS papers. In 1977, when the first scholarly article regarding GIS was published, but in the following ten years, the growth of GIS literature is very slow. Since 1990, the number of GIS articles increased very quickly. And for the source of citation databases, the number of records retrieved from SCI is much more than GIS articles indexed in SSCI and A&HCI, which indicates that the GIS is mainly developed and applied in natural science and technical areas. However, since 2000, the application of GIS in social science areas grew also significantly.

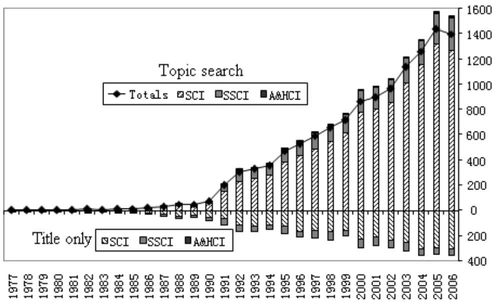

Figure 1: Numbers of GIS articles indexed in SCIE, SSCI, A&HCI(1975-2006）

2.2 Development of information visualization technologies

The goal of our research is to detect the birth and maturing process of GIS. In this paper, information visualization technology based on citation analysis is adopted to perform quantitative and qualitative studies for more than then thousands of scientific literature of GIS. Based on citation indexing initiated by Garfield(Garfield 1955), Price put forward the citation analysis method(Price 1965), which was further developed by Small(Small 1973) and White(White et al. 1981), had been the research foundation of modern Scientometrics. Information visualization aims to unveil the underlying structure of large or abstract data sets using visual representations that utilize the powerful processing capabilities of the human visual perceptual system. One important embranchment of information visualization is citation analysis, in which information visualization is used to explore the large data collections, which makes people to understand and analyze data, detect the underlying rules and patterns in data(Li et al. 2007). Various efforts for information visualization based on citation analysis have been undertaken for many years, the majority of these studies are performed at the discipline or specialty level(Boyack et al. 2002). There are also many visualization tools proposed by researchers, among them CiteSpace introduced by Chaomei Chen is a java application for analyzing and visualizing co-citation networks(Chen 2004). Its primary goal is to facilitate the analysis of emerging trends in a knowledge domain. It allows users to take a time series of snapshots of a knowledge domain and subsequently merge these snapshots(Chen 2006). Since its release of the first version, this program has been download more than 10,000 times in 36 countries. This article adopts CiteSpace II, the version of CiteSpace 2.1. R 7 released on Dec. 19,2007.

3 Author Co-citation Analysis: Evolution from theories to application

The authors firstly make Author Co-citation Analyisi in CiteSpace for the dataset of 12,417 records retrieved from WOS published between 1977 and 2006 on GIS. The 30-year time span between 1977 and 2006 was divided into fifteen 2-year time slices. Three sets of threshold levels (c, cc, ccv), namely citation threshold, co-citation threshold, and co-citation coefficient threshold, were set as follows, early slice:(6, 3, 10), middle slice: (10, 6, 18), last slice:(10, 6, 18), and linear interpolated thresholds are assigned to the rest of slices(Chen 2006). Table 1 shows the first configuration for a 263-author co-citation network, since no nodes and links are selected from the first six slices, then we adjust the scope of the overall time frame to 1985 - 2006, and the thresholds are reset to (8, 4, 14),(10, 6, 20) and (10, 6, 20).

Table 1: The construction configuration for a 264-author co-citation network

Time slices	c	cc	ccv	Articles	Nodes	Links
77-78	6	3	0.10	21	0	0
79-80	6	3	0.11	84	0	0
81-82	7	3	0.12	83	0	0
83-84	7	4	0.13	161	0	0
85-86	8	4	0.14	378	0	0
87-88	8	4	0.15	621	0	0
89-90	9	5	0.16	1409	1	0
91-92	9	5	0.17	5727	15	42
93-94	10	6	0.18	8670	12	8
95-96	10	6	0.18	14346	41	59
97-98	10	6	0.18	20446	57	89
99-00	10	6	0.18	27312	74	126
01-02	10	6	0.18	33202	110	215
03-04	10	6	0.18	42824	172	401
05-06	10	6	0.18	52838	222	507
Total				208122	704	1447

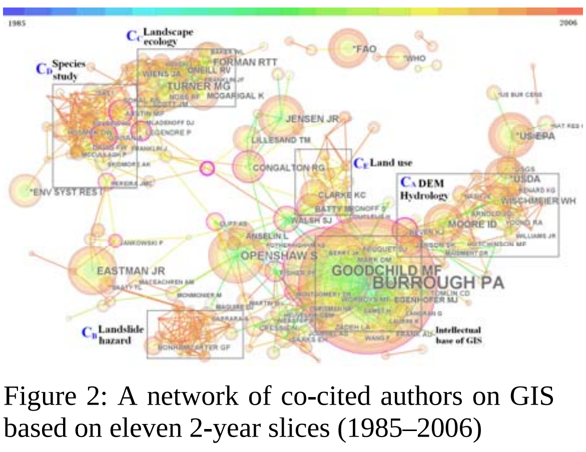

Figure 2: A network of co-cited authors on GIS based on eleven 2-year slices (1985–2006)

Figure 2 shows the network of co-cited authors on GIS, there are 253 nodes and 888 links selected in the network when reset the time span and thresholds. Each node stands for one author, citation tree rings represent the citation history of an article. The color of a citation ring denotes the frequency of corresponding citations. The thickness of a ring is proportional to the number of citations in a given time slice(Chen 2006). Those points highlighted in the display with a purple ring are called pivotal points, turning points, or tipping points, which characterize the transition from one cluster of co-cited authors (articles) to another cluster. Contribution of Pivotal points to the evolution of scientific fields usually has two kinds of situation: (1) Theoretical breakthrough in the knowledge domain, which upgrade the existing study to a higher level. (2) Exploit a new sub-field based on the existing intellectual base, which leads to a shift of focus(Chen 2006). There are five densely connected clusters in Figure 2. When selecting several nodes in one cluster of items, CiteSpace could display and label the necessary characteristic about the selected node, and we could find corresponding records in PubMed and Google Scholar, etc through the automatic link, therefore to label the selected cluster.

The most prominent node in the visualization is Burrough PA, when the frequency is 811, and the centrality is 0.17, Burrough's *Principles of geographical information systems for land resources assessment* (1986), which provides a strong theoretical basis for GIS, and is recommended in GIS programs in many universities, including Pennsylvania State University, University of Wisconsin-Madison, University of California-Berkeley, University of Minnesota, etc. The second edition of Burrough's book was published in 1998, which is also the classical text in GIS(Longley *et al.* 2005). Near Burrough, another prominent node is Goodchild MF, whose frequency is 538, and the centrality is 0.13 in the network. Awarded the Prix Vautrin Lud in 2007, the first scientist in GIS to be awarded this prize, and regarded by many as Geography's equivalent of the Nobel Prize, Goodchild was considered the father of GIScience. In 1992, he introduced the term *Geographic Information Science* for the first time, and outlined the scope of the field indirectly by listing the major components of the

Geographic Information Science research agenda(Goodchild 1992a, Mark 2000). His representative work *The Accuracy of Spatial Database* is the first book in the world to addresses the problem of accuracy of spatial databases, taking approaches which vary from statistical to descriptive(Goodchild *et al.* 1989). And the topic of spatial database accuracy was given highest priority as the first Center initiative in NCGIA Core Curriculum 1990 Version(Goodchild 1992b).

In general, from 1970s to mid-1980s, GIS was in its formative period, namely GIS protoscience. From later 1980s to early 1990s, Burrough and Goodchild's two classical books indicates that GIS had enter a period of normal science, which has theoretical foundation and paradigm formation, thus lead the fast development of GIS and extensive application in other fields from the entire 1990s and new century.

The other important nodes supporting the paradigm formation of GIS are Cliff AD, Mark DM et al. In 1973, Cliff and Ord published Spatial Autocorrelation, a monograph which drew together their previously scattered papers on the topic and which established itself as something of a classic work of quantitative geography. Spatial autocorrelation is a statistical technique that examines the degree of similarity between variables across geographic space(Cliff *et al.* 1973, Legendre 1993). In 1981, Cliff and Ord's another book *Spatial Processes: Models & Applications* was published. In the two books, Cliff and Ord pioneered the development of tests for spatial autocorrelation on irregular areal units, generalizing the earlier tests and examining in detail the associated inference theory(Goodchild *et al.* 2004).

The four prominent author clusters are derived from the GIS intellectual base: (a) Cluster A is DEM, Hydrology. (b) Cluster B is landslide hazard. (c) Cluster C refers to landscape ecology. (d) Cluster D is urban development and land use.

The representative authors in cluster A include Beven KJ, Jenson SK, Moore ID, Montgomery DR et al. When cluster A and the intellectual base are connected via the pivotal point Mark DM. Based on D8 algorithm introduced by Mark, Jenson and Domingue (1988) in cluster A argued the concept of drainage enforcement with an automated basin delineation program that acknowledged the existence of spurious sinks in the DEM, which has been implemented into the Arc/Info Grid module and ArcView Spatial Analyst extension as part of the fill algorithm(Jenson *et al.* 1988, Saunders *et al.* 2000). Beven KJ is the other pivotal point in cluster A, he introduced the hydrological model namely TOPMODEL, which is a set of programs for rainfall-runoff modelling in single or multiple subcatchments in a semi-distributed way and using gridded elevation data for the catchment area(Montesinos-Barrios *et al.* 2001). On the basis of field evidence and physical theories, Montgomery and Dietrich discussed the existence of a slope dependent contributing area threshold required to support a channel head(Montgomery *et al.* 1989). They measured source area and local slope at channel heads in Tennessee Valley, Marin County, California. The area-slope conditions required for shallow landsliding can be explained with a coupled function of saturation overland flow predicted by topographic convergence(Iida 1984) and an analytical equation for infinite slope instability(Hattanji 2004).

Cluster B is mainly consisted of orange links, which indicates the co-citation occurs mainly after 2005. The authors in this cluster focus on the landslide and other hazard, including Carrara A, Guzzetti F, Chung CF, Clerici A et al. As figure 2 shows, cluster B and cluster A are combined via the pivotal point Montgomery-1989 when Carrara A in cluster B and Montgomery were co-cited in 2003 for the first time, and we could conclude that cluster B is derived from cluster A.

Authors in cluster C and D focus on the studies of GIS in landscape ecology. The pivotal points are Guisan A, Austin MP and Legendre P. As figure 2 shows, cluster C is connected with GIS intellectual base via the links of Legendre and Cliff. In Legendre's article, he argued how spatial autocorrelation, introduced by Cliff, in ecological variables can be described and measured and presented several ways of explicitly introducing spatial structures into ecological model(Legendre 1993). Cluster C is consisted of links mostly in green, representative authors are Forman RTT and Oneill RV, their contribution mainly concentrate on the theory foundation of GIS in landscape ecology. And Cluster D is orange, which means the co-citation occurs after 2003, and this part represents the research fronts of GIS in landscape ecology. And the famous statistical software, such as SAS, SPSS, R project, and ESRI are all in cluster C, which also indicates that the application of GIS and social statistical software in biology and ecology is very general. For example, the famous Bioconductor is a project for the analysis and comprehension of genomic data based on R project.

Authors in cluter E mainly focus on GIS in urban development and land use, such as Batty M, Couclelis H, Clarke KC, White R, Carver SJ, Sui DZ, Yeh AGO et al. and the most prominent method applying GIS in land use is cellular aumata. Concept of CA was introduced by Von Neumann, Ulam and Burk in late 1940s and 1950s, and until the early of 1990s, it has been linked with GIS and used to simulate spatial-temporal processes to study land use land cover change. Many attempts were made to develop CA theories and model, such as Couclelis' CA model of rodent populations(Couclelis 1988), cellular automata applications in urban growth modeling based on a process of diffusion-limited aggregation(Batty *et al.* 1994), growth of San Fransisco Bay Clarke et al(Clarke *et al.* 1997), DSS system with a probabilistic CA model fed with GIS data layers processed through an AHP MCE procedure(Wu 1998, Wu *et al.* 1998), etc.

4 Document co-citation network of GIS: pivotal points in the evolution of GIS

Here the authors describe the merged network of co-cited articles of GIS dataset using document co-citation analysis in CiteSpace. The dataset is the same as ACA mentioned above. In CiteSpace, the time span is set to 1985 to 2006, and three thresholds are (3,2,12),(6,3,16),(6,3,20), time slice length is 1.

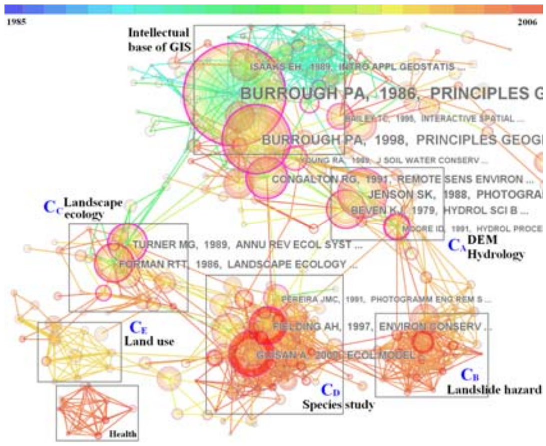

Figure 3: A network of co-cited articles on GIS (1985–2006)

We can see that the visualization of DCA in Figure 3 is very similar to that of ACA in Figure 2. Surrounding the GIS intellectual base, several densely connected clusters are derived. (a) Cluster A is hydrology (mid 1990s). (b) Cluster B is landslide hazard (2003-2004)cellular automata and its application in urban development (2001-2002). (c) Cluster C is landscape ecology. (d) Cluster D refers to GIS in habitat (2001-2005). (e) Cluster E is GIS in urban development and land use (2001-2002). In addition to these clusters, there is a small separate cluster focus on GIS in health study.

There are some important information for the pivotal points in five clusters.

(a) Most pivotal points appeared around 1990, such as Moore, Carrara, Carver, Jenson, Pereira's articles, Only the pivotal point of Beven KJ's article was published in 1979, when GIS was in its early stage namely protoscience. Hereinto late 1980s and early 1990s is the most prominent period, when the "GIScience" paradigm emerged, defined by Goodchild as ''the science behind the systems'' and concerned with the set of fundamental questions raised by GIS and allied technologies(Goodchild 1992a, Goodchild 2004). In this formation process of GIScience, GIS began to be cognizant by researchers in other fields except geography as a discipline or normal science, thus lead the fast development of GIS in various applied areas, such as hydrology, landscape, land use mentioned above.

(b) For some pivotal points, there may be a long time's lag from the publication year to the time research fronts formed. For almost two decades in the 1960s and 1970s, GIS and the applied areas developed in parallel with few interactions(Sui *et al.* 1999). Until 1980s, when geographers made efforts to increase analytical capabilities of GIS(Ding *et al.* 1992, Goodchild *et al.* 1992) and researchers' new demand in various areas for accurate digital representations of the terrain(Clark 1998, Sui *et al.* 1999) and spatial analysis, many attempts to integrate their needs into GIS have been carried out. For example, Beven's TOPMODEL was originally developed in 1979 to simulate catchment under humid conditions. The overall times cited was more than 1000 since its publication year. However, Beven's article was cited at a low level, until 1993, it began to be cited frequently (here we set the threshold of frequently cited as 20), when the integration of TOPMODEL into GIS from a hydrological perspective began to be applied(Chariat *et al.* 1993, Stuart *et al.* 1993, Huang *et al.* 2002), when this integration also accelerated the development and application of GIS in the areas of soil and water conservation, agriculture, hydrology. Contrast to Beven'a article, Burrough's book was cited frequently since its publication year, the overall times cited searched in google scholar was 2565 (Burrough's *Principles of geographical information systems* has two editions, the first edition was published in 1986 and the second edition in 1998, here we sum the times cited of the two editions). The comparing of cited situation of Beven and Burrough's articles was showed in Figure 4.

(c) Although some article are not highly cited, they are still pivotal points lead to new research fronts because of their high centrality in the clusters of network. For example, Carrara A's article was cited 126 searched in WOS and 143 in google scholar. Carver SJ's article published in 1991 was cited 102 times searched in WOS and 162 in google scholar, etc. (Searched 28 November 2007)

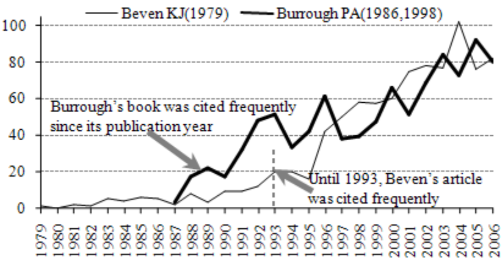

Figure 4: Distribution of times cited by years searched in Web of Science for Beven KJ's article (1979) and Burrough's Book(1986,1998)

5 Discussion

It has been three decades since the first GIS coined and elaborated by Tomlinson in 1963 namely the Canada Geographic Information System. However, the fastigium of GIS started from the early 1990s, when the GIS scientific literature began to grow quickly. The revolution of information technology in 1990s also aided the rise of GIS. Based on the visualization of author co-citation analysis and document co-citation analysis of GIS scientific literature, this article show the evolution process of GIS from theories to application areas ,which also indicates the transformation from protoscience to normal science for GIS. On the one hand, the growing theoretical and empirical need for spatial data and analysis methods challenged researchers in many areas. On the other hand, the development of GIS technology has made a variety of analytical tools available for this need. So, the deadlock of GIS technology and applied areas developed in parallel with few interactions was broken after the emerging of "GIScience" paradigm in late 1980s. Since then, progress in GIS has been substantial and rapid. The visualizations of DCA and ACA show the main application of GIS focus on DEM and hydrology, land use planning, landslide hazard, landscape ecology, etc. And the result of DCA also reveals the important literature in pivotal points in the evolution process of GIS research fronts, which represent the formation of paradigm as a discipline, a shift of focus, or a change of perspective for the development of GIS and its application areas.

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References

Burrough, P.A., 1986, *Principles of geographical information systems for land resources assessment* (New York: Oxford University Press).

Wright, D.J., Goodchild, M.F. and Proctor, J.D., 1997, GIS: Tool or Science? Demystifying the Persistent Ambiguity of GIS as" Tool" Versus" Science". *Annals of the Association of American Geographers*, 87, pp. 346-362.

Price, D.J., 1975, *Science since Babylon* (New Haven: Yale University Press).

Garfield, E., 1955, Citation indexes for science: A new dimension in documentation through association of ideas. *Science*, 122, pp. 108-111.

Price, D.J., 1965, Networks of scientific papers. *Science*, 149, pp. 510-515.

Small, H., 1973, Co-citation in the scientific literature: A new measure of the relationship between two documents. *Journal of the American Society for Information Science*, 24, pp. 265-269.

White, H. and Griffith, B., 1981, Author cocitation: A literature measure of intelligent structure. *Journal of the American Society for Information Science*, 32, pp. 163–171.

Li, Y. and Hou, H., 2007, Study on visualization of citation analysis. *Journal of the China Society for Scientific andTechnical Information*, 26, pp. 301-308.

Boyack, K.W., Wylie, B.N. and Davidson, G.S., 2002, Information Visualization, Human-Computer Interaction, and Cognitive Psychology: Domain Visualizations. *Lecture Notes In Computer Science; Vol. 2539*, pp. 145-160.

Chen, C., 2004, Searching for intellectual turning points: Progressive knowledge domain visualization. *Proceedings of the National Academy of Sciences*, 101, pp. 5303-5310.

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, pp. 359-377.

Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W., 2005, *Geographical Information Systems: Principles, Techniques, Management and Applications, 2nd Edition* (New York: Wiley).

Goodchild, M.F., 1992a, Geographical information science. *International Journal of Geographical Information Science*, 6, pp. 31-45.

Mark, D.M., 2000, Geographic Information Science: Defining the Field. In *Foundations of Geographic Information Science*, M. Duckham, M.F. Goodchild and M.F. Worboys (Eds.), pp. 3-18 (New York: Taylor and Francis).

Goodchild, M.F. and Gopal, S., 1989, *The Accuracy of Spatial Databases*CRC Press).

Goodchild, M.F., 1992b, NCGIA Research Initiative 1 Accuracy of Spatial Databases. Santa Barbara, University of California).

Cliff, A.D. and Ord, J.K., 1973, *Spatial autocorrelation*Pion London).

Legendre, P., 1993, Spatial Autocorrelation: Trouble or New Paradigm? *Ecology*, 74, pp. 1659-1673.

Goodchild, M.F. and Haining, R.P., 2004, GIS and spatial data analysis: Converging perspectives. *Fifty Years Of Regional Science*.

Saunders, W. and Texas, A., 2000, Preparation of DEMs for Use in Environmental Modeling Analysis. *Hydrologic and Hydraulic Modeling Support with Geographic Information Systems*.

Montesinos-Barrios, P. and Beven, K., 2001, Evaluation of TOPMODEL. In *Agricultural Non-Point Source Water Quality*

Models: Their Use And Application, D.L.T. Editors: John E. Parsons, Rodney L. Huffman (Ed.).

Montgomery, D.R. and Dietrich, W.E., 1989, Source Areas, Drainage Density, and Channel Initiation. *Water Resources Research WRERAQ*, 25.

Iida, T., 1984, A hydrological method of estimation of the topographic effect on the saturated throughflow. *Trans. Jpn. Geomorphol. Union*, 5, pp. 1–12.

Hattanji, T., 2004, Threshold conditions for channel initiation in a humid forested mountain: an approach from hydro-geomorphic observations. Doctoral Program, University of Tsukuba.

Couclelis, H., 1988, Of mice and men: what rodent populations can teach us about complex spatial dynamics. *Environment and Planning A*, 20, pp. 99-109.

Batty, M. and Longley, P., 1994, *Fractal cities: a geometry of form and function*Academic Press).

Clarke, K.C., Hoppen, S. and Gaydos, L., 1997, A self-modifying cellular automaton model of historical urbanization in the San Francisco Bay area. *Environment and Planning B*, 24, pp. 247–262.

Wu, F., 1998, SimLand: a prototype to simulate land conversion through the integrated GIS and CA with AHP-derived transition rules. *International Journal of Geographical Information Science*, 12, pp. 63-82.

Wu, F. and Webster, C.J., 1998, Simulation of land development through the integration of cellular automata and multicriteria evaluation. *Environment and Planning B*, 25, pp. 103-126.

Beven, K.J. and Kirkby, M.J., 1979, A Physically Based, Variable Contributing Area Model of Basin Hydrology. *Hydrological Sciences Bulletin*, 24.

Montgomery, D.R. and Dietrich, W.E., 1994, A physically based model for the topographic control on shallow landsliding. *Water Resources Research*, 30, pp. 1153-1172.

Goodchild, M.F., 2004, GIScience, Geography, Form, and Process. *Annals of the Association of American Geographers*, 94, p. 709.

Sui, D.Z. and Maggio, R.C., 1999, Integrating GIS with hydrological modeling: practices, problems, and prospects. *Computers, environment and urban systems*, 23, pp. 33-51.

Ding, Y.M. and Fotheringham, A.S., 1992, The integration of spatial analysis and GIS. *Computers Environment and Urban Systems*, 16, pp. 3-19.

Goodchild, M. and Haining, R., 1992, Integrating GIS and Spatial Data Analysis： Problems and Possibilities. *Geographical Information Systems*, 6, pp. 407-423.

Clark, M.J., 1998, Putting water in its place: a perspective on GIS in hydrology and water management. *Hydrological Processes*, 12, pp. 823-834.

Chariat, S. and Delleur, J.W., 1993, Integrating a physically based hydrological model with GRASS. *Application of GIS in hydrology and water Resources Management IAHS. Publ*, 211, pp. 143-150.

Stuart, N. and Stocks, C., 1993, Hydrological modelling within GIS: an integrated approach. In *Applications of Geographic Information Systems in Hydrology and Water Resources Management, IAHS Publication*.

Huang, B. and Jiang, B., 2002, AVTOP: a full integration of TOPMODEL into GIS. *Environmental Modelling & Software*, 17, pp. 261-268.

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