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Geographical Information Science observatories, theoretical and methodological transitions

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Abstract

Over the past decades geographical information science has been progressively recognized as a scientific field of its own. Initially starting from a purely engineering perspective, geographical information science is now based on a series of fundamental theories and methods that largely contribute to its recognition in academia. The objective of this paper is to make an argument for more study of the ecosystem of geographical information science through an observational framework, and to examine the processes and abstraction of the different communities that interact with information about geographical spaces. The main idea is to explore and further develop the concept of a geographical information science observatory, the objective of which is to focus not only on geographical information as such, but also and indeed primarily on the users of geographical information, their motivations, and the theoretical, methodological, and technological frameworks with which they develop their information.

Keywords

Geographical Information Science; Observatories; Knowledge transfer

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I FROM OBSERVATORIES TO GISCIENCE OBSERVATORIES

The emergence of geographical information science (GIScience) observatories brings new approaches whose objectives are not only to study “geographical information” as such, but also to observe the users of this information at large, their motivations, and what theoretical and methodological frameworks they apply (Adams et al. 2014, McKenzie 2015, Miller 2017). In this regard there is an important distinction to mention: while geographical information observatories are oriented towards scientific instrumentation that affords a holistic view of geographical data, geographical information science observatories should have a much larger scope as oriented not only to the data dimension but also the range of methods, disciplines, applications and users involved at large.

The intrinsic notion of an observatory leads us to first consider its primary and historical essence. In fact, an early prototype of the observatory appeared in the 9th century under the caliphate of Al Mamum and the House of Wisdom. This observatory was a scientific and intellectual center that welcomed a large number of scholars, resulting in a vibrant academy that included several disciplines from philosophy to mathematics, medicine, and astronomy to mention a few. Being an active scientific center, the House of Wisdom triggered many scientific interactions between its members, technological advances, and engineering developments (Al-Khalili, 2011). In the 16th century a similar effort and scientific observatory was promoted by the Danish astronomical and alchemy laboratory Uranibor established and operated by Tycho Brahe. This laboratory was not only dedicated to astronomy, but also to meteorology, astrology, and alchemy. It was opened to scientists, students and artisans bringing together different levels of expertise and fostering many innovations such maritime navigation instruments (Chisholm, 1911).

Communication and cooperation between different disciplines lead to several theoretical and methodological transitions between fundamental and applied sciences (Garstin, 2013). This concept of transition, or “Boundary-bridging”, supports scientific transfers and even theoretical and methodological reconfigurations, fostering scientific, technical, and societal advances (Klein 1990, Dogan 2001, Miller 2017}. As cogently argued in George E. P. Box’s essay on “Science and Statistics” (1976), a good exemplar for the iterative and complementary development of theory and practice in successful science, and where transitions of these kinds repeatedly occurred, can be found in Ronald Fisher’s career as a statistician and scientist. He noted how the innovations that Fisher made to develop many modern statistical theories were done in the context of solving domain problems in fields as diverse as astronomy, psychology, genetics, biology, and economics. Inspired by this concept of transition, we suggest a contemporary essay combining observation and transition around geographical information science. Surprisingly, and while still in exponential growth, the geographical information universe is still poorly understood (Janowicz et al 2014), this being a further motivation for the study of the potential interest of a scientific observatory of this emerging scientific domain.

Our motivation behind this approach is twofold. First, geographical information science has been progressively defined as a science (Goodchild 1992), so it might be now a relevant time to explore the possible impact of our discipline on science at large, and how our field learns from other disciplines. Secondly, the emergence of many and diverse geographical information communities over conventional or distributed Web infrastructures now clearly favor the observation of these emerging geographical information ecosystems. Most disciplines, especially young ones such as geographical information science, do not have well defined boundaries and constitute artificial sets that are in continuous movement (Ostreng 2007), and will claim transition areas that favor exchanges (Matthew and Herbert 2004).

A scientific discipline will often gather different domains creating interdisciplinary interactions (Bruun et al. 2005), and this is manifest for geographical information science. Our goal is to explore and further develop the concept of a geographical information science observatory, the objective of which is to focus not only on geographical information as such, but also and indeed primarily on the users of geographical information, their motivations, and the theoretical, methodological, and technological frameworks with which they develop their information practices, and finally what they think of them (i.e., user feedback) (Adams and Gahegan 2016). By instrumenting such observatories, the aim is to provide better opportunities for cross-fertilization within the field and to improve the potential of geographical information science in research and academia.

II GISCIENCE OBSERVATORIES: WHY, WHAT AND HOW

A fundamental assumption and motivation of our essay is that first restricting the observation of geographical information practices to the information dimension does not give full credit to the many exploratory opportunities offered. Secondly, while GIScience is nowadays considered as a pluridisciplinary scientific discipline that studies the fundamental nature and properties of geographical information as well as its use, a GIScience observatory should precisely provide the methods and infrastructures that will examine the different practices, methods, theoretical frameworks as well as the user communities involved and their motivations. In brief the objectives of a GIScience observatory should be as follows:

- To observe what happens to geographical data, methods, models, theories as they are used within a research community.
- To study the underlying scientific processes and to implement the means to capture relevant details of research activities so that they can be replicated and their outcomes better understood.
- To bring along a methodological framework to the observation of geographical information science (or at least to contribute to).

Exploring and modelling the interactions between geographical information, supporting theoretical frameworks and technologies, researchers, and end-users should logically favor collaborations and synergies, and a better understanding of the respective contributions of researchers, end-users, and decision-makers (Yang et al. 2010, Hey and Trefethen 2005, Ribes and Lee 2010). In other words, a geographical information science observatory reassigns the intention towards the study of the processes and abstraction of a community that interacts with geographical spaces. This extends the usual sense given to geographical information infrastructure observatories which are mainly oriented towards the study of a given geographical and/or societal system in order to infer some novel knowledge (Georis et al. 2017). Beyond this proposal, several methodological questions, as well as regarding what observations one might expect to find, are left open for future study of the observations and transitions related to geographical information science:

- What can we objectively learn from the observation of the practices of geographical information science? Does this bring a better understanding of the underlying spatio-temporal phenomena?
- How to observe and with which instruments? What should we measure and how? Which data and how to collect it? Which functionalities should the observational tools possess?
- How to take into account both explicit and implicit users' practices and experiences?
- How to identify cross-disciplinary transitions?

Moreover, a geographical information science observatory should not be considered as an isolated monolith, but as a vibrant and active component of several observatories, institutions, researchers and end-users that should ideally interact with other scientific observatories. It should be interoperable and associated to other disciplinary observatories active in the social sciences (https://socialobservatories.org/) or within technological practices (https://en.unesco.org/go-spin).

In order to be effective, and not just a theoretical concept, an observatory has to become the place where researchers do things, as was the case in the House of Wisdom. In order to achieve this objective such a discipline-specific infrastructure should be first appealing enough to attract researchers and practitioners when interacting with geographical information. Secondly a successful observatory should be instrumented with appropriate mechanisms in order to make our inferences (what information should be derived, and how?), leading to related ethical questions, such as to what degree should researchers be aware of the fact that they are part of an observatory? Indeed, a geographical information science observatory should facilitate opportunistic collaborations between different disciplines by providing a methodological and common support, favoring discoveries and cross-disciplinary interactions, as well as timely responses to specific events and phenomena (Miller 2017).

Clearly the emergence of the Web as a repository of geographical information infrastructures, and by providing a federated and integrated view on geographical information across different thematic dimensions, will play a major role in supporting the development of geographical information science observatories. In the context of geographical information science, the complexity and large extent of the different phenomena to represent provide to the concept of the observatory a crucial property of supporting community-wide and cross-disciplinary collaborations, as well as opportunities to detect and identify unexpected patterns and events, and overall a better global understanding. In this ambition one can see parallels to other visionary proposals in GIScience, such as the Digital Earth, but with an observational lens that can as easily point to the community of users as to the Earth itself (Gould et al. 2008).

III GISCIENCE OBSERVATORIES: FROM PRACTICES TO TRANSITIONS

Accordingly, we propose a multidimensional approach that encompasses a theoretical, methodological, and experimental vision, whose objective is to observe geographical information science practices, as well as any transitions coming from and leading towards other sciences (Figure 1). This figure outlines the main notions that will allow the observation of a GIScience community throughout its range and perimeter, scientific theories support, methods, models, tools, and reference data, not forgetting territorial practices and applications under development. As the concept of GIScience observatory might be considered as multiple and not limited to a unique one, we outline in this figure the possibility of having several complementary observational frameworks interacting together, as well as pathways should exist between different scientific worlds, not limited to the "geographical" one.

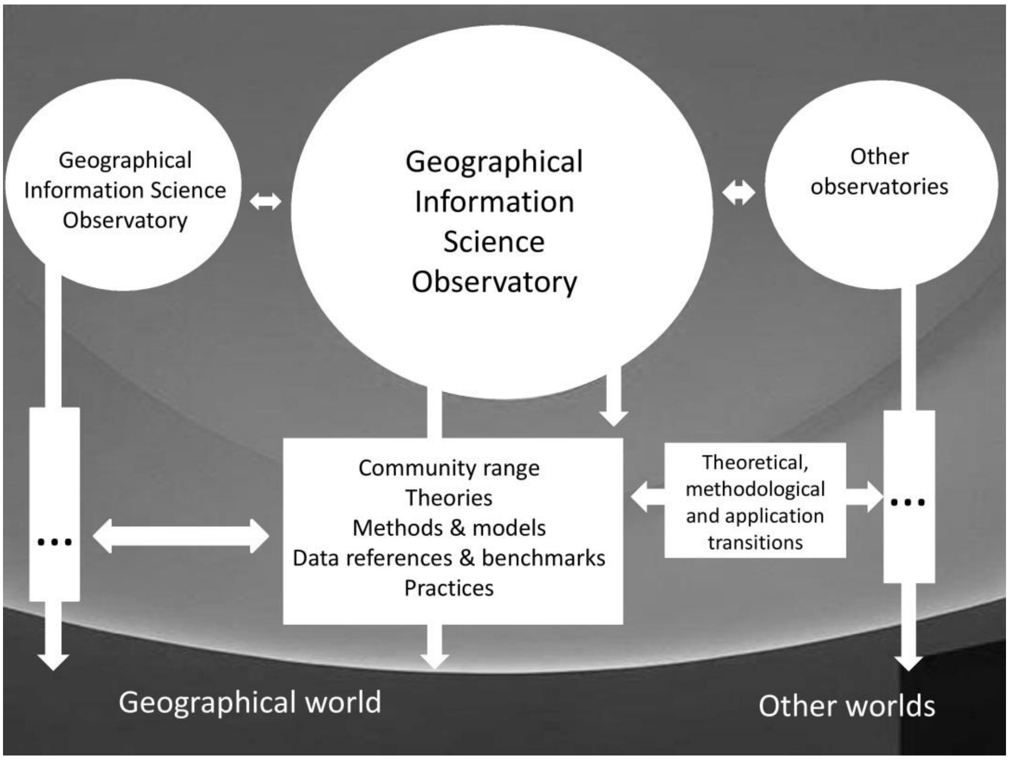

Figure 1: Observation, observatories, transitions and geographical information science.

Without the ambition of providing an exhaustive or bounded observation framework that will be far beyond our objectives, we propose to classify these observations and possible transitions in several complementary dimensions:

- **Observation of the scope and extent of the geographical information science community:** What can we objectively learn from the observation of the practices of geographical information science? Does this bring a better understanding of the underlying spatio-temporal phenomena? The scope and perimeter of a scientific community, as well as its evolution, are essential indices to its observation. GIScience can be considered as a rapid evolving science, and one that progressively emerged from an initial cartographical and system component focus to now being recognized as an authentic science (Goodchild 1992), although this has not been without some debate (Reitsma 2013). This qualitative evolution came with a considerable increase of its production and visibility, this being confirmed by a constant augmentation of several indices: regular increase and impact of geographical information science journals, establishment of several conferences at the international level (e.g., COSIT, GIScience, ACM SIGSPATIAL), emergence of several strong regional communities (e.g., in China). Scientometric indices can provide quantitative evaluations of the respective roles of these GIS conferences and prominent authors (Keßler et al. 2012) while the spatio-temporal distribution and scientific production of GIS research communities can be studied using some inference mechanisms (Agrawal et al. 2006). Indeed, several exogenous factors contributed to the establishment of GIScience as an authentic discipline, such as the increased availability of geographical information and the growing impact of environmental and urban issues from global to local scales.

- **Explicit and prospective observation of the scientific domains in support of geographical information science:** Alongside the development of GIScience, evaluations arising from exhaustive surveys can qualify the impact of other disciplines. This has been for example applied to study the specific contributions of different scientific domains to the field of temporal GIS (e.g., Siabato et al. 2018). One can also mention, for instance, the initial contribution of cartography and qualitative spatial reasoning in the development of GIScience, and from another point of view the one of spatial databases in the development of GI systems to mention a few examples. Prospective projections on future developments of geographical information science, i.e., research challenges, also provide some indications on the evolution of the field as well as the contribution of different scientific domains and technics (e.g., Claramunt and Stewart 2015).

- **Methodological and practical observations:** Geographical information science is nowadays grounded on sound methodological foundations and principles that have been progressively well-established, including conceptual data models, spatial analysis and visualization methods, and technics to mention a few (Goodchild 2010). What is much less well-understood is the context of use of these methods and data models for many real-world applications, including cross-disciplinary scientific research. In particular, we have little observational data on the relationships between practitioners' knowledge of GIScience's methodological foundations and how they are using GIS software, systems, and workflows in practice based on this knowledge.

- **Data references and benchmarks:** Several disciplines have long benefited from data benchmarks that acted as references for testing data processes and algorithms. The emblematic "Lena" image widely used in signal processing gives a good example of long standing reference that has been widely used for implementing and testing some machine learning and feature recognition algorithms. Closer to GIScience, experimental developments developed by space syntax studies have been often based on benchmark datasets such as the village of Gassin in the South of France, or more recently very large trajectory datasets as given by the GeoLife project in the city of Beijing (Zheng et al. 2010). Data performance contests have been organized in the context of specialized international conferences such as the regularly organized ACM SIGSPATIAL cup (e.g., http://sigspatial2018.sigspatial.org/giscup2018/). Such data performance benchmarks allow for an evaluation of algorithm performances and quality, as well data structures appropriate or not to the efficient storage and manipulation of very large geographical datasets (Samet 1990). Yet, there still exists much room in GIScience for improvement in this regard; a recent evaluation of papers published in the Association of Geographic Information Laboratories in Europe (AGILE) conference series showed extremely poor data support for reproducibility of the research contained in the papers (Nust et al. 2018). A recent noteworthy initiative developed by a consortium of scientists and organizations established open data and code principles for scientific data accessibility, interoperability and reusability (Wilkinson et al., 2016). These principles have been recently retained by the International Journal of Geographical Information Science, authors are now asked when publishing their papers to provide additional information on data and code reusability.

- **Territorial practices:** In relationship with geographical information infrastructures another objective is to develop long-term observation frameworks specifically oriented to territorial practices. The idea is to evaluate the range of interactions and practices between geographical information repositories, the geographical phenomena under scrutiny, and the different urban and environmental studies, actors and decision-makers involved (Sinnott 2015). These practices deeply depend on the context, experiences, and the situations within which they are developed and used (Gahegan and Pike 2006).

The second idea we would like to explore, illustrated by the figure above, is the one of transition identified according to its theoretical, methodological and application dimensions, and this at the interface of several observatories at the crossroad of different scientific communities:

- **Theoretical transitions:** Geographical information science lies at the crossroads or convergence of several scientific domains and greatly benefits from them. An illustrative example is given by the long-standing contribution of the 2nd law of thermodynamics towards the principles of entropy and diversity as developed by the information theory (Shannon 1948) to recent extensions to the concept of spatial entropy to study the distribution and diversity of some patterns in space and time (Batty 1974, Claramunt 2012) and in return to applications of these measures of spatial entropy to show thermal patterns at the micro spatial scale (Knechtel et al. 2017). In fact, the inherent complexity of space and time, as those clearly appear in the modeling and analysis of geographical information and phenomena bring new research challenges and opportunities, often creating a place for specific theoretical and methodological enrichment and novelties done within the scope of geographical information science, but that can be extended to other fields. A preliminary and practical attempt to evaluate the impact of research contributions and the relative introversion of a given scientific domain is to cross-check journal citations from and to different disciplines as suggested by Laffan (2010) but applied to human and physical geography in relation with a series of cognate disciplines such as information science. One can study citation counts from specific fundamental contributions, and specifically the scientific domains involved as revealed by the publication sources. For instance, the fundamental contribution to the modeling of point-set topological relations, as originally initiated from geographical information science (Egenhofer and Fransoza 1991), has progressively led towards extensions towards different non-geographical domains such as multimedia and image processing (Li et al. 1997, Vazirgiannis 1998), brain understanding and neuroinformatics (Bota et al. 2005), and architectural design (Akinci et al. 2002). While originally oriented to temporal reasoning and manipulation of semi-intervals (Freksa 1992), this generalisation of Allen's interval-based reasoning approach has since had much more and larger implications in the domain of qualitative spatial reasoning than the initial temporal frame, this being a quite unusual case of transitions to a different reasoning environment. As a relatively young science, and also much narrower than many other domains, it is probably very likely that geographical information science is far more of an importer of ideas, theories and methodological developments than an exporter to other sciences, but this surely a subject left for further exploration.

- **Methodological appropriations and enrichment:** In addition to respective theoretical contributions, geographical information science can also enrich in return other scientific domains as shown by conceptual spatial information design contributions to environmental and urban applications (Warmer and Kleppe 1998, Parent et al. 2006), and generalization and application of these approaches to related scientific domains such as architecture and urban design.
- **Transitions and application extensions:** The machines, programs, and algorithms behind and in support of the development of geographical information science and systems draw from a large set of technologies and technics. The recent profusion of mobile sensors from GPS to small autonomous devices, either in outdoor or indoor environments, as well as the emergence of social networks as new information diffusion media, generate a new set of application opportunities and novel challenges and perspectives that enlarge the scope and boundaries of geographical information science from global to very local scales. This also leads to the emergence of booming application domains very much related to geographical information science: a good example being smart cities.

This concept of transition or knowledge transfer, whatever the dimensions considered, leads us to introduce a difference between **strong transitions** and **smooth transitions**. We define a smooth transition as either a theoretical, methodological or technological transition from a source science towards a target science without any noticeable impact in return to the source science. When there is an impact in return we will consider it as a strong transition. Let us give two representative examples. Graph theory and topology have largely contributed to the development of fundamental principles of geographical information models, without any significant impact and to the best of our knowledge in return to these scientific domains. On the contrary, spatial and temporal extensions to conventional conceptual data design methods have contributed in return by providing novel spatio-temporal abstractions now used in other disciplines.

An implicit objective in having a better picture of these knowledge transfers is not only to have a better understanding of our domain as such and how it is inspired by other domains and possibly how we inspire others, but also to foster scientific reutilization of some of the theories, methods, and computational algorithms behind geographical information science. Indeed we should presuppose that we have different domains, and that we should develop mechanisms to observe how knowledge can be transferred across them (Humphreys 2018). While early scientists were often navigating between different fundamental and applied disciplines, contemporary scientists are most often domain-specific, making knowledge transfer between different areas much more difficult to observe.

IV DISCUSSION

The further development of geographical information science observatories raises a series of key methodological and practical challenges still to address:

- Governance and organization rules should be established to ensure information security and transparency as well as compliance issues. Implementing GIScience observatories will require development and implementation of appropriate light governance instruments to coordinate the different contributors and uses. Specific procedures should be designed and developed to support the instruments to manage all users and observers' interactions, with the final aim of promoting participation and diffusion.

- Data and metadata should be collected, at different levels, using appropriate mechanisms, from objects to relations in space and time, from methods to advanced processes, projects, users, applications, etc. This surely requires the design of a sort of meta-model of a geographical information science observatory in order to identify and collect the different concepts that are common across all domains. This is a key issue to formally unify as much as possible the different notions, methods, projects, data, and abstractions used and applied by different scientists.

- Theoretical and methodological transitions should be inferred and identified using, probably in a first attempt, some experimental approaches such as the ones suggested in this paper. Observing and identifying such practices and transitions is surely not a straightforward issue to achieve. One-to-one transfers between scientists are probably easier to identify, while generalization of such transitions is a longer term objective. This implies the observation of a series of specific cases such as the ones mentioned in this paper in order to categorize the different routes to and from geographical information science.

- Recommender functionalities should be implemented to help scientists to discover methods and algorithms they might not have used otherwise and facilitate learning processes, and to explore other geographical projects and datasets. Very likely Web-based recommendation principles and engines widely developed over the past few years can provide appropriate mechanisms to identify common or novel practices when interacting with geographical information data and geographical information science (Resnick 1997). There are here surely many opportunities to design and implement novel interactive facilities over the Web to inspire GIS practitioners and scientists.

- Explicit and implicit relevance feedback and mechanisms to achieve them should be developed in order to provide a clear evaluation of the added value of a geographical information science observatory. Specific metrics, ranking functions, and qualitative feedback should be ensured using appropriate instrumentation. The idea behind this is to observe user behaviors under different contexts and application areas and the way they interact with geographical information infrastructures and repositories.

- Clearly web infrastructures should play a privileged role in the development of geographical information science observatory, by providing an actual live web of interactions and interface facilities. External links with other data sources and specialized scientific social networks should be implemented. In fact, the concept of GIScience observatory is not only a methodological and instrumented framework but also a dynamic concept that should provide discussion and social-based forums to share ideas and future theoretical developments and pathways to other sciences and disciplines.

A geographical information science observatory should constitute a sort of exchange platform that will incentivize researchers and users to share ideas, methods, and overall pluridisciplinary collaborations. Such a community also generates an important source of information by itself. Reference implementations and success stories are indeed required to make the whole concept not only a nice tool and abstraction, but a practical and feasible solution.

V CONCLUSION

To conclude, in the era of big data and at an age of constant acceleration of science and technologies, it has become indispensable to develop novel observational frameworks for geographical information science, which will give us a place of reflection and thinking on the theories, methods, practices, and technological artifacts used and applied. Such an intellectual approach, probably opportunistic in the sense of Stanley (2016), will be useful to provide to geographical information science a higher level of maturity and better hindsight on its potential societal impact, mandatory for the implementation of performing education processes, as well as, finally, a better integration of geographical information science into the international scientific community at large. This should also favor interdisciplinary interactions between different communities and practitioners as the whole concept of scientific observatory is per essence not limited to a single discipline, this also possibly favoring the emergence of transdisciplinary sciences. Finally, the conceptualization and development of geographical information science observatories will require the participation of a large range of social and engineering sciences, experts and practitioners, to refine the preliminary observation principles and methods sketched in this tentative essay.

References

Adams B and Gahegan M. (2016). We need to rethink how we describe and organize spatial in formation. instrumenting and observing the community of users to improve data description and discovery. In *GEOProcessing: The Eighth International Conference on Advanced Geographic Information Systems, Applications, and Services*, pp. 131–136.

Adams B., Gahegan M., Gupta P. and Hosking R. (2014). Geographic information observatories for supporting science. In *Proceedings of the Workshop on Geographic Information Observatories*, CEUR Proceedings 1273, pp. 32–39.

Agrawal, P., Bera R., and Claramunt C. (2006). A social and spatial network approach to the investigation of research communities over the world wide web. In *Proceedings of the 4th International Conference on Geographic Information Science*, Springer-Verlag LNCS 4197, pp. 1–17.

Akinci B., Fischer M., Kunz J. and Levitt R. (2002). Representing work spaces generically in construction method models. *Journal of Construction Engineering and Management*, 128(4), 96–305.

Al-Khalili, J. (2011), *The House of Wisdom: How Arabic Science Saved Ancient Knowledge and Gave Us the Renaissance*, New York: Penguin Press.

Batty M. (1974). Spatial entropy. Geographical Analysis, 6(1), 1–31.

Bota M., Dong H-W. and Swanson L. W. (2005). Brain architecture management system. *Neuroinformatics*, 3(1), 15–47.

Box G. (1976). Science and statistics. *Journal of the American Statistical Association*, 71(356),791–799.

Bruun H., Hukkinen J., Huutoniemi K. and Klein J. T (2005). *Promoting Interdisciplinary Research. The Case of the Academy of Finland*. Academy of Finland, Helsinki.

Chisholm H. (1911). Brahe, Tycho. *Encyclopædia Britannica*. 4 (11th ed.). Cambridge University Press. p. 377.

Claramunt C. (2012). Towards a spatio-temporal form of entropy. In *ER Workshops*, Springer LNCS, pp. 221-230.

Claramunt C. and Stewart K. (2015). Special issue on spatio-temporal theories and models for environmental, urban and social sciences: where do we stand? *Spatial Computation and Cognition*, 15(2), 61–67.

Dogan M. (2001). Specialization and recombination of specialities in the social sciences. In N. J. Smelser and P B. Baltes (eds.), *International Encyclopedia of the Social and Behavioral Sciences*, vol. 2., Elsevier.

Egenohfer M. and Fransoza R. D. (1991). Point-set topological spatial relations. *International Journal of Geographical Information Systems*, 5(2), 161–174.

Freksa C. (1992). Temporal reasoning on semi-intervals. *Artificial Intelligence*, 54(1), 199–227.

Gahegan M. and Pike W. (2006). A situated knowledge representation of geographical information. *Transactions in GIS*, 20(5), 727–749.

Garstin W. A. (2013). A note on Islamic astronomy. *Empire Survey Reviews*, 11(85), 306–309.

Georis-Creuseveau J., Claramunt C. and Gourmelon F. (2017). A modelling framework for the study of spatial data infrastructures applied to coastal management and planning. *International Journal of Geographical Information Science*, 31(1), 122–138.

Goodchild M. (1992). Geographical information science. *International Journal of Geographical Information Systems*, 6(1), 31–45.

Goodchild M. (2010). Twenty years of progress: GIScience in 2010. *Journal of Spatial Information Science*, 1(1), 3–20.

Gould M., Craglia M., Goodchild M. F., Annoni A., Camara G., Kuhn W., Mark D., Masser I., Maguire D., Liang S. and Parsons E. (2008). Next-generation digital earth: A position paper from the Vespucci initiative for the advancement of geographic information science. *International Journal of Spatial Data Infrastructures Research*, 3, 146–167.

Hey T. and Trefethen A. E. (2005). Cyberinfrastructure for e-science. *Science*, 308(5723), 817–821.

Humphreys P. (2018). Knowledge transfer across scientific disciplines. *Studies in History and Philosophy of Science Part A*, 1–8.

Janowicz, K., Adams B., McKenzie G. and Kauppinen T. (2014). Towards geographic information observatories. In *Proceedings of the Workshop on Geographic Information Observatories*, CEUR Proceedings 1273, pp. 1–5.

Keßler C., Janowicz K. and Kauppinen T. (2012). Spatial@linkedsience - exploring the research field of giscience with linked data. In *International Conference of Geographical Information Science*, Springer LNCS, pp. 102–115.

Klein J. T. (1990). *Interdisciplinarity. History, Theory and Practice*. Wayne State University Press.

Knechtel J. and Sinanoglu O. (2017). On mitigation of side-channel attacks in 3D ICs: Decorrelating thermal patterns from power and activity. In *Proceedings of 54th ACM/EDAC/IEEE Design Automation Conference (DAC)*, pp. 1–6.

Laffan S. W. (2010). The citation relationships between journals of geography and cognate discipline. *Geographical Journal*, 48(2), 166–180.

Li J. Z., Ozsu T. and Szafron D. (1997). Modelling of moving objects in a video database. In *ICMCS* 1997, pp. 336–343.

Matthew J. A. and Herbert D. T. (2004). Unity of geography. prospects for the discipline. In J. A. Matthew and D. T. Herbert, editors, *Unifying Geography*. Common Heritage, Shared Future. Routledge.

McKenzie G., Janowicz K., Gao S. Yang J.-A. and Hu Y. (2015). POI pulse: A multi-granular, semantic signature–based information observatory for the interactive visualization of big geosocial data. *Cartographica: The International Journal for Geographic Information and Geovisualization*, 50(2), 71–85.

Miller H. J. (2017). Geographic information observatories and opportunistic GIScience. *Progress in Human Geography*, 41(4), 489–500.

Nüst D., Granell C., Hofer B., Konkol M., Ostermann F. O., Sileryte R. and Cerutti V. (2018). Reproducible research and GIScience: an evaluation using AGILE conference papers. *PeerJ*, 6(e5072).

Østreng W. (2007). Crossing scientific boundaries by way of disciplines. In *Complexity, Interdisciplinary Communications*, Centre for Advanced Study, CAS, Oslo, 11-14.

Parent C., Spaccapietra S. and Zimányi E. (2006). *Conceptual Modeling for Traditional and Spatio-temporal Applications – the MADS Approach*. Springer.

Reitsma F. (2013). Revisiting the ‘is GIScience a science?’ debate (or quite possibly scientific gerrymandering). *International Journal of Geographical Information Science*, 27(2), 211–221.

Resnick P. and Varian H. R. (1997). Recommender systems. *Communications of the ACM*, 40(3), 56–59.

Ribes D. and Lee C. P. (2010). Sociotechnical studies of cyberinfrastructure and e-research: Current themes and future trajectories. *Computer Supported Cooperative Work (CSCW)*, 19(3–4), 231–244.

Samet H. (1990). *The Design and Analysis of Spatial Data Structures*. Addison-Wesley.

Shannon C. E. (1948). A mathematical theory of communication. *The Bell System Technical Journal*, 27:379–423, 623–656.

Siabato W., Claramunt C., Ilarri S. and Manso-Callejo M.-Á. (2018). A survey of modelling trends in temporal GIS. *ACM Computing Surveys*, 51(2), 30:1–30:41.

Sinnott R. O., Bayliss C., Bromage A., Galang G., Grazioli G., Greenwood P., Macaulay A., Morandini L., Nogoorani G., Nino-Ruiz M., Pettit C., Tomko M., Sarwar M., Stimson R., Voorsluys, and Widjaja W. (2015). The Australia urban research gateway. *Concurrency and Computation: Practice and Experience*, 27(2), 358–375.

Stanley M. (2016). Why should physicists study history? *Physics Today*, 69(7):38.

Vazirgiannis M., Theodoridis Y. and Sellis T. (1998). Spatio-temporal composition and indexing for large multimedia applications. *Multimedia System*, 6(4), 284–298.

Warmer J. B. and Kleppe A. G. (1998). *The Object Constraint Language: Precise Modeling with UML*. Addison-Wesley Object Technology Series.

Wilkinson M. D., Dumontier M., Aalbersberg I. J., Appleton, G. et al. (2016). The FAIR Guiding Principles for Scientific Data Management and Stewardship. Scientific Data 3.

Yang C., Raskin R., Goodchild M. and M. Gahegan (2010). Geospatial cyberinfrastructure: past, present and future. *Computers, Environment and Urban Systems*, 34(4), 264–277.

Zheng Y., Xie X. and Ma W. (2010). GeoLife: A collaborative social networking service among user, location and trajectory. *IEEE Data Eng. Bulletin*, 33(2), 32–40.