geographies

Editorial

Perspectives on Advanced Technologies in Spatial Data Collection and Analysis

Hartwig H. Hochmair [1,*], Gerhard Navratil [2] and Haosheng Huang [3]

1 Geomatics Sciences, Fort Lauderdale Research and Education Center, University of Florida, Davie, FL 33314, USA
2 Department of Geodesy and Geoinformation, Technical University of Vienna, 1040 Vienna, Austria; gerhard.navratil@geo.tuwien.ac.at
3 Department of Geography, Ghent University, 9000 Ghent, Belgium; haosheng.huang@ugent.be
* Correspondence: hhhochmair@ufl.edu

Citation: Hochmair, H.H.; Navratil, G.; Huang, H. Perspectives on Advanced Technologies in Spatial Data Collection and Analysis. *Geographies* **2023**, *3*, 709–713. https://doi.org/10.3390/geographies3040037

Received: 18 October 2023
Accepted: 27 October 2023
Published: 2 November 2023

1. Introduction

The motivation to organize this Special Issue originated from the observation of rapid changes taking place in the domain of geographical information science and systems over the past few decades. For example, 20 years ago, GNSS was only known to a few experts, whereas today, it is commonly used to track humans, animals, and unmanned devices with unparalleled precision, availability, and reliability. Web 2.0, smart devices, new generations of earth observation satellites, and dramatically increasing computing power have enabled new insights into our world and society and also triggered novel applications. Some examples of developments that pushed progress are:

- The idea of volunteered geographic information (VGI) [1], which was initially applied to the collection of geometries and labels for maps and a routable street graph, later on led to numerous other application fields such as tourism and travel recommendation systems and analysis [2]; biodiversity modeling [3]; travel pattern analysis [4]; detection, monitoring and the management of natural disasters [5], sentiment analysis [6], and environmental monitoring [7].
- Wearable devices for the collection of physiological data in relation to human emotions [8] have, for example, been used to identify locations of increased stress levels for cyclists in road networks in order to identify urban planning deficiencies [9].
- The deployment of social media and networking apps has enabled the rapid dissemination of geographic information and the detection of natural and man-made events [10], monitoring outbreaks of pandemics [11], providing insights into public opinion [12], traffic forecasting and real-time traffic incident detection [13], and tracking people's whereabouts and movements [14].
- GIS cloud computing enables computations and the sharing of services to be performed in web-based environments instead of local desktop systems and has been used in application areas such as land valuation [15]. Efficient Spatial Data Infrastructure (SDI), including standards, protocols, policies, and guidelines on geospatial data capture, production, and distribution, is a crucial component for sharing a large volume of data over the web and, thus, GIS cloud computing [16].
- Novel types of mobile networks and communication techniques facilitate the seamless interaction of small devices, which provides the foundation and increases the popularity of the Internet of Things (IoT) [17]. These integrated sensors (measuring, e.g., pressure, positions, distances, light, chemicals, radiation, rain, or soil parameters) play a vital role in enabling smart city systems [18] and monitoring our living environments, e.g., regarding indoor air quality [19].
- Recent approaches to GeoAI integrate GIS with AI techniques, such as Artificial Neural Networks (ANNs), deep learning, or large language foundation models [20]. Different

types of foundation models, once enhanced with spatial knowledge, e.g., through geospatial knowledge graphs, can lead toward spatially explicit GeoAI models for specific domains, such as urban geography [21].
- Blockchain is a distributed ledger technology that enables secure and transparent transactions within a peer-to-peer network of computers, where any updates to the data are immediately propagated throughout the network [22]. It can be used to create a decentralized system for managing spatial data that ensures integrity and the authenticity of geospatial data [23], e.g., in web-based public participatory GIS [24] or the management of IoT devices [25].

Each of these technologies demands new approaches or adaptations to existing approaches to make use of the strengths and mitigate weaknesses. With this Special Issue, we aimed to collect manuscripts that showcased these changes for a wide range of topics.

2. New Data Analysis Techniques and Datasets

Recent years have seen significant advances in the collection of spatial or spatiotemporal data from various devices and platforms, including high-resolution remote sensing platforms such as Unmanned Aerial Vehicles (UAVs) [26], environmental sensor networks [27], location-tracking devices [28], human-wearable biometrics sensors [29], smartphone sensing [30], Connected Vehicle Infrastructure [31], or IoT devices [32]. Data are contributed by governmental agencies, public institutions, NGOs, industry, and the general public, who collect and share crowdsourced data, including VGI, and participate in citizen science projects [33,34]. The provision of these different devices and platforms has led to a massive amount of new data, which can be divided into two main categories, namely earth observation data and human behavior data [35].

Earth observation data (environment sensing) capture the status of the Earth's physical environment, mainly using satellites, UAVs, on-ground monitoring devices, and environmental sensors. Typical examples of such data include remote sensing imagery from satellites or UAVs, Lidar data, environmental sensor network data (e.g., for monitoring the water and air quality), street-level images (e.g., from Google Streetview or Mapillary) captured by moving vehicles, and crowdsourced environmental data. Several studies included in this Special Issue [36–39] explicitly focus on these datasets and their analysis, including aerial photos, drone images, rain gauges, and rainfall-measuring mission satellite observations.

On the other hand, human behavior data (social sensing) focuses on human and social environments and records various human behavioral and social activities, such as human mobility, social interactions, social–economic activities, and city dynamics. Mobile phone network data, GNSS data, social media data, social–economic statistic data (e.g., from surveys), crowdsourced behavioral data, LBS usage/log data, smart card travel data, and camera imagery data are notable examples of such data. Some papers in this Special Issue [40,41] present novel web-based applications and data quality analyses based on such data, including health outcomes and healthcare data as well as tweets. Survey data can provide insight into factors that should be considered in urban planning and decision making, which are illustrated in another contribution of this Special Issue for agent-based cellular automata modeling [42].

This Special Issue invites contributions from several topics, including (but not limited to) geospatial open-source software; the analysis of big data, sensor and network data; text mining; GeoAI; and geovisual analytics. The content of papers published in this Special Issue falls to some extent into the topics summarized in Table 1.

Table 1. Topics covered by papers published in this Special Issue.

Analysis Type	Theme	SI Topic	Ref.
Deep Learning	Pavement condition evaluation using aerial imagery	AI	[10]
Measuring image processing time	OpenDroneMap performance analysis	Open-source software	[11]
Time series analysis	Assess rainfall persistence from CHIRPS satellite observations	Innovative data collection platforms	[12]
3D simulation	Assess rockfall hazards using 3D models and aerial photos	Advanced geospatial technologies	[13]
Web map development	Web-GIS Tool for community health	Open-source software	[14]
Pre/post-statistical comparison	Assess the effects of Twitter's app policy changes on data sharing	Big data	[15]
Questionnaire analysis	Choice of actor variables in agent-based cellular automata modeling	Location-based questions	[16]

3. Future Directions

While geospatial artificial intelligence (GeoAI) is not covered in particular papers in this Special Issue, this topic experienced recently significant attention within the geoscience research community through the release of massive pre-trained AI models, including large language models (LLMs), such as ChatGPT, Bard, BERT or Claude [43]. The rapid enhancement of these models provides novel opportunities for future geospatial research. For example, until recently, the integration of image information with LLMs to map enhancement tasks using generative AI had to be conducted separately using LLMs and Vision Foundation Models [44]. However, updated versions of ChatGPT and Bard can already answer image (e.g., map)-related questions and, therefore, conduct joint reasoning from vision and language, using Multimodal Foundation Models. Recent studies demonstrate another trend in the GeoAI research area, namely the fusion of geo-knowledge into Generative Pre-Trained LLMs to improve the quality of spatial analysis tasks [45]. On a different note, currently released open datasets, such as the Overture Places dataset with millions of points of interest around the globe [46], provide new opportunities for analysis and data integration with other data sources in numerous geo-applications. This list of evolving topics is therefore included in the follow-up Special Issue (https://www.mdpi.com/journal/geographies/special_issues/VN77IP0N1D, accessed on 17 October 2023), with the goal of enhancing previous findings [47–50] from papers published in related Special Issues and meetings, such as the ACM SIGSPATIAL GeoAI workshop series.

Author Contributions: All authors contributed equally to the conceptualization and writing of this editorial. All authors have read and agreed to the published version of the manuscript.

Acknowledgments: We want to express our congratulations to the authors of the papers of this Special Issue for their scientific contributions; to the anonymous referees whose key help made it possible to improve the contents of these papers; and finally, to the editorial staff of *Geographies* for their excellent assistance in producing this Special Issue.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Goodchild, M.F. Citizens as Voluntary Sensors: Spatial Data Infrastructure in the World of Web 2.0 (Editorial). *Int. J. Spat. Data Infrastruct. Res.* **2007**, *2*, 24–32.
2. Kirilenko, A.P.; Ma, S.; Stepchenkova, S.O.; Su, L.; Waddell, T.F. Detecting Early Signs of Overtourism: Bringing Together Indicators of Tourism Development with Data Fusion. *J. Travel Res.* **2023**, *62*, 382–398. [CrossRef]
3. Callaghan, C.T.; Ozeroff, I.; Hitchcock, C.; Chandler, M. Capitalizing on opportunistic citizen science data to monitor urban biodiversity: A multi-taxa framework. *Biol. Conserv.* **2020**, *251*, 108753. [CrossRef]
4. Schirck-Matthews, A.; Hochmair, H.H.; Paulus, G.; Strelnikova, D. Comparison of Cycling Path Characteristics in South Florida and North Holland among Three GPS Fitness Tracker Apps. *Int. J. Sustain. Transp.* **2022**, *16*, 804–819. [CrossRef]
5. Havas, C.; Resch, B. Portability of semantic and spatial–temporal machine learning methods to analyse social media for near-real-time disaster monitoring. *Nat. Hazards* **2021**, *108*, 2939–2969. [CrossRef]
6. Jain, P.K.; Pamul, R.; Srivastava, G. A systematic literature review on machine learning applications for consumer sentiment analysis using online reviews. *Comput. Sci. Rev.* **2021**, *41*, 100413. [CrossRef]
7. Ghermandi, A.; Sinclair, M. Passive crowdsourcing of social media in environmental research: A systematic map. *Glob. Environ. Chang.* **2019**, *55*, 36–47. [CrossRef]
8. Dzedzickis, A.; Kaklauskas, A.; Bucinskas, V. Human Emotion Recognition: Review of Sensors and Methods. *Sensors* **2020**, *20*, 592. [CrossRef]
9. Zeile, P.; Resch, B.; Loidl, M.; Petutschnig, A.; Dörrzapf, L. Urban Emotions and Cycling Experience—Enriching Traffic Planning for Cyclists with Human Sensor Data. *GI_Forum* **2016**, *1*, 204–216. [CrossRef]
10. Hasan, M.; Orgun, M.A.; Schwitter, R. A survey on real-time event detection from the Twitter data stream. *J. Inf. Sci.* **2018**, *44*, 443–463. [CrossRef]
11. Tang, L.; Bie, B.; Park, S.-E.; Zhi, D. Social media and outbreaks of emerging infectious diseases: A systematic review of literature. *Am. J. Infect. Control* **2018**, *46*, 962–972. [CrossRef]
12. Gorodnichenko, Y.; Pham, T.; Talavera, O. Social media, sentiment and public opinions: Evidence from #Brexit and #USElection. *Eur. Econ. Rev.* **2021**, *136*, 103772.
13. Gu, Y.; Qian, Z.; Chen, F. From Twitter to detector: Real-time traffic incident detection using social media data. *Transp. Res. Part C Emerg. Technol.* **2016**, *67*, 321–342. [CrossRef]
14. Zhong, C.; Morphet, R.; Yoshida, M. Twitter mobility dynamics during the COVID-19 pandemic: A case study of London. *PLoS ONE* **2023**, *18*, e0284902. [CrossRef]
15. Mete, M.O.; Yomralioglu, T. Implementation of serverless cloud GIS platform for land valuation. *Int. J. Digit. Earth* **2021**, *14*, 836–850. [CrossRef]
16. Tripathi, A.K.; Agrawal, S.; Gupta, R.D. Cloud enabled SDI architecture: A review. *Earth Sci. Inform.* **2020**, *13*, 211–231. [CrossRef]
17. Jamshed, M.A.; Ali, K.; Abbasi, Q.H.; Imran, M.A.; Ur-Rehman, M. Challenges, Applications, and Future of Wireless Sensors in Internet of Things: A Review. *IEEE Sens. J.* **2022**, *22*, 5482–5494. [CrossRef]
18. Kim, T.-h.; Ramos, C.; Mohammed, S. Smart City and IoT. *Future Gener. Comput. Syst.* **2017**, *76*, 159–162. [CrossRef]
19. Marques, G.; Pitarma, R. Monitoring Health Factors in Indoor Living Environments Using Internet of Things. In *World Conference on Information Systems and Technologies*; Rocha, Á., Correia, A.M., Adeli, H., Reis, L.P., Costanzo, S., Eds.; Springer: Cham, Switzerland, 2017; pp. 785–794.
20. Mai, G.; Huang, W.; Sun, J.; Song, S.; Mishra, D.; Liu, N.; Gao, S.; Liu, T.; Cong, G.; Hu, Y.; et al. On the opportunities and challenges of foundation models for geospatial artificial intelligence. *arXiv* **2023**, arXiv:2304.06798.
21. Liu, P.; Biljecki, F. A review of spatially-explicit GeoAI applications in Urban Geography. *Int. J. Appl. Earth Obs. Geoinf.* **2022**, *112*, 102936. [CrossRef]
22. Shen, C.; Pena-Mora, F. Blockchain for Cities—A Systematic Literature Review. *IEEE Access* **2018**, *6*, 76787–76819. [CrossRef]
23. Wu, Y.; Dai, H.-N.; Wang, H.; Choo, K.-K.R. Blockchain-Based Privacy Preservation for 5G-Enabled Drone Communications. *IEEE Netw.* **2021**, *35*, 50–56. [CrossRef]
24. Farnaghi, M.; Mansourian, A. Blockchain, an enabling technology for transparent and accountable decentralized public participatory GIS. *Cities* **2020**, *105*, 102850. [CrossRef]
25. Huh, S.; Cho, S.; Kim, S. Managing IoT devices using blockchain platform. In Proceedings of the 19th International Conference on Advanced Communication Technology (ICACT), PyeongChang, Republic of Korea, 19–22 February 2017; pp. 464–467.
26. Aasen, H.; Honkavaara, E.; Lucieer, A.; Zarco-Tejada, P.J. Quantitative Remote Sensing at Ultra-High Resolution with UAV Spectroscopy: A Review of Sensor Technology, Measurement Procedures, and Data Correction Workflows. *Remote Sens.* **2018**, *10*, 1091. [CrossRef]
27. Kandris, D.; Nakas, C.; Vomvas, D.; Koulouras, G. Applications of Wireless Sensor Networks: An Up-to-Date Survey. *Appl. Syst. Innov.* **2020**, *4*, 14. [CrossRef]
28. Becker, J.K.; Li, D.; Starobinski, D. Tracking Anonymized Bluetooth Devices. *Proc. Priv. Enhancing Technol.* **2019**, *3*, 50–65. [CrossRef]
29. Blasco, J.; Chen, T.M.; Tapiador, J.; Peris-Lopez, P. A Survey of Wearable Biometric Recognition Systems. *ACM Comput. Surv.* **2016**, *49*, 43. [CrossRef]

30. Harari, G.M.; Müller, S.R.; Aung, M.S.H.; Rentfrow, P.J. Smartphone sensing methods for studying behavior in everyday life. *Curr. Opin. Behav. Sci.* **2017**, *18*, 83–90. [CrossRef]
31. Lim, K.L.; Whitehead, J.; Jia, D.; Zheng, Z. State of data platforms for connected vehicles and infrastructures. *Commun. Transp. Res.* **2021**, *1*, 100013. [CrossRef]
32. Gupta, B.B.; Quamara, M. An overview of Internet of Things (IoT): Architectural aspects, challenges, and protocols. *Concurr. Comput. Pract. Exp.* **2020**, *32*, e4946. [CrossRef]
33. See, L.; Mooney, P.; Foody, G.; Bastin, L.; Comber, A.; Estima, J.; Fritz, S.; Kerle, N.; Jiang, B.; Laakso, M.; et al. Crowdsourcing, Citizen Science or Volunteered Geographic Information? The Current State of Crowdsourced Geographic Information. *ISPRS Int. J. Geo-Inf.* **2016**, *5*, 64. [CrossRef]
34. Lukyanenko, R.; Wiggins, A.; Rosser, H.K. Citizen Science: An Information Quality Research Frontier. *Inf. Syst. Front.* **2020**, *22*, 961–983. [CrossRef]
35. Huang, H.; Yao, X.A.; Krisp, J.M.; Jiang, B. Analytics of location-based big data for smart cities: Opportunities, challenges, and future directions. *Comput. Environ. Urban Syst.* **2021**, *90*, 101712. [CrossRef]
36. Han, S.; Chung, I.-H.; Jiang, Y.; Uwakweh, B. PCIer: Pavement Condition Evaluation Using Aerial Imagery and Deep Learning. *Geographies* **2023**, *3*, 132–142. [CrossRef]
37. Gbagir, A.-M.G.; Ek, K.; Colpaert, A. OpenDroneMap: Multi-Platform Performance Analysis. *Geographies* **2023**, *3*, 446–458. [CrossRef]
38. Avalon Cullen, C.; Al Suhili, R. Assessing Rainfall Variability in Jamaica Using CHIRPS: Techniques and Measures for Persistence, Long and Short-Term Trends. *Geographies* **2023**, *3*, 375–397. [CrossRef]
39. Al-Shaar, M.; Gérard, P.-C.; Faour, G.; Al-Shaar, W.; Adjizian-Gérard, J. Comparison of Earthquake and Moisture Effects on Rockfall-Runouts Using 3D Models and Orthorectified Aerial Photos. *Geographies* **2023**, *3*, 110–129. [CrossRef]
40. Geyer, N.R.; Lengerich, E.J. LionVu: A Data-Driven Geographical Web-GIS Tool for Community Health and Decision-Making in a Catchment Area. *Geographies* **2023**, *3*, 286–302. [CrossRef]
41. Cao, J.; Hochmair, H.H.; Basheeh, F. The effect of Twitter app policy changes on the sharing of spatial information through Twitter users. *Geographies* **2022**, *2*, 549–562. [CrossRef]
42. Searle, G.; Wang, S.; Batty, M.; Liu, Y. The Choice of Actor Variables in Agent-Based Cellular Automata Modelling Using Survey Data. *Geographies* **2022**, *2*, 145–160. [CrossRef]
43. Han, X.; Zhang, Z.; Ding, N.; Gu, Y.; Liu, X.; Huo, Y.; Qiu, J.; Yao, Y.; Zhang, A.; Zhang, L.; et al. Pre-trained models: Past, present and future. *AI Open* **2021**, *2*, 225–250. [CrossRef]
44. Juhász, L.; Mooney, P.; Hochmair, H.H.; Guan, B. ChatGPT as a mapping assistant: A novel method to enrich maps with generative AI and content derived from street-level photographs. In Proceedings of the Fourth Spatial Data Science Symposium, Online, 5 September 2023.
45. Hu, Y.; Mai, G.; Cundy, C.; Choi, K.; Lao, N.; Liu, W.; Lakhanpal, G.; Zhou, R.Z.; Joseph, K. Geo-knowledge-guided GPT models improve the extraction of location descriptions from disaster-related social media messages. *Int. J. Geogr. Inf. Sci.* **2023**, *37*, 2289–2318. [CrossRef]
46. Marcel, W. Overture Places Quality Analysis. Available online: https://observablehq.com/d/9847c08c46f56ed6 (accessed on 16 October 2023).
47. Mai, G.; Hu, Y.; Gao, S.; Cai, L.; Martins, B.; Scholz, J.; Gao, J.; Janowicz, K. Symbolic and subsymbolic GeoAI: Geospatial knowledge graphs and spatially explicit machine learning. *Trans. GIS* **2022**, *26*, 3118–3124. [CrossRef]
48. Lunga, D.; Hu, Y.; Newsam, S.; Gao, S.; Martins, B.; Yang, L.; Deng, X. GeoAI at ACM SIGSPATIAL: The New Frontier of Geospatial Artificial Intelligence Research. *SIGSPATIAL Spec.* **2022**, *13*, 21–32. [CrossRef]
49. Gao, S.; Hu, Y.; Li, W.; Zou, L. Special issue on geospatial artificial intelligence. *GeoInformatica* **2023**, *27*, 133–136. [CrossRef]
50. Scheider, S.; Richter, K.-F. GeoAI. *KI—Künstliche Intell.* **2023**, *37*, 5–9. [CrossRef]