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GeoAI and Human Geography

The Dawn of a New Spatial Intelligence Era

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Preface

Geospatial artificial intelligence (GeoAI), the rapidly evolving fusion of geospatial technologies and artificial intelligence, is reshaping the way researchers and practitioners grapple with questions central to human geography. The potential of this interdisciplinary field is both transformative and expansive, offering novel ways to understand the social, economic, political, cultural, and spatial dimensions of our everyday environments. By integrating advanced computing with place-based knowledge, GeoAI allows us to identify patterns and relationships that traditional methods often miss, and it prompts us to rethink core geographic concepts of scale, distance, and spatial interaction.

This volume, *GeoAI and Human Geography*, encompasses 28 chapters that illustrate how these innovations unfold across a broad spectrum of themes. Early chapters introduce the essential frameworks of human geography in the context of the GeoAI era, from the evolution of geographic thought to the theoretical pillars that link artificial intelligence with geographical inquiry. Subsequent chapters describe major methodological breakthroughs—from explainable AI in spatial analysis to the use of natural language processing for interpreting textual data, to human-centered computer vision for urban sensing, to advances in social network analysis and high-performance computing for large-scale geospatial problems. These contributions showcase the technological strides that are redefining how data is gathered, processed, and ultimately interpreted.

Another large portion of this book focuses on traditional branches of human geography—cultural, economic, political, health, tourism, cartography, transport, and urban studies—illustrating how each area is adopting GeoAI tools to enrich understanding and generate new insights. Whether exploring the intersection of economic activity and digital geographies, contextualizing food environments with advanced analytics, or weaving spatial intelligence into transport planning and urban development, these chapters demonstrate the versatility of GeoAI in addressing both longstanding and emerging research questions. They also reinforce the importance of integrating local context, critical perspectives, and diverse data sources, ensuring that the technological dimension remains rooted in real-world social and environmental concerns.

As the book moves toward its conclusion, readers encounter chapters that envision future trajectories. These contributions delve into topics such as identifying gentrification by synthesizing physical and socioeconomic data, probing the spatial biases of generative AI models, fostering ethical and sustainable approaches to geospatial decision-making, and examining the political dimensions that shape the production and application of spatial knowledge. Discussions on the digital divide, climate change adaptation, and cross-disciplinary research illustrate the expansive possibilities for applying GeoAI to pressing global challenges. The final chapters articulate a forward-looking stance on how GeoAI may continue to influence human geography, urging scholars, practitioners, and policymakers to harness its power responsibly and equitably.

Collectively, this book offers a comprehensive map of how GeoAI-based approaches are reshaping the knowledge horizons of human geography. Each chapter underscores the importance of maintaining a balanced perspective that respects both the rigor of computational methods and the complexities of social and cultural phenomena. We hope this work will inspire researchers, students, and professionals to collaborate more deeply across disciplinary boundaries, spark thoughtful conversations on the ethical and methodological intricacies of using AI for spatial inquiries, and foster innovative applications that enrich our understanding of people and places.

Finally, the editors would like to extend heartfelt thanks to all contributors who poured their expertise and creativity into these pages. In presenting this volume, we invite readers to explore the new frontiers of GeoAI and human geography, reflect on the novel insights emerging from data-driven analysis, and envision the collective responsibility we share for shaping an inclusive, sustainable, and thriving future.

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Contents

About the Editors

Xiao Huang is an Assistant Professor in the Department of Environmental Sciences at Emory University. His research expertise encompasses human–environment interaction, computational social sciences, urban informatics, disaster mapping and mitigation, GeoAI, and disaster remote sensing. Dr. Huang has contributed extensively to his field, authoring over 200 peer-reviewed journal articles and over 20 book chapters and playing a pivotal role in editing five books. He is among the world's top 2% scientists by Stanford/Elsevier's rankings. In his professional capacity, he serves as an Associate Editor for Computational Urban Science and is a member of the editorial boards of several prestigious journals. His research has garnered significant attention and received coverage in renowned media outlets, such as Nature News, NASA, NBC, and Fox. His work has attracted substantial funding from NSF, NASA, the Bill & Melinda Gates Foundation, the National Academies, and the Centers for Medicare and Medicaid Services.

Siqin Wang is an Associate Professor (Teaching) of Spatial Sciences at the Spatial Sciences Institute within the Dornsife College of Letters, Arts and Sciences at the University of Southern California. Her research interests are in GIScience, spatiotemporal big data analytics, computational social science, digital health geography, human-centered GeoAI, human mobility and migration, smart cities, and human–climate interactions and she publishes extensively in these areas. She was named one of the 50 Rising Stars by Geospatial World in 2024. Her 2021 co-first-authored paper on human mobility and COVID-19 transmission received the 2022 Best Paper Award and the most Downloaded Paper from the Annals of GIS in 2023. Her professional roles include serving as the Associated Chair for the Spatial Data Lab affiliated with Harvard University and as Vice Chair of the Young Scientist Innovation Network for Digital Earth of the International Society for Digital Earth. Prior to joining the USC Spatial Sciences Institute, Dr. Wang was an Adjunct Senior Lecturer at the Royal Melbourne Institute of Technology, Australia, and as an Honorary Lecturer and Research Fellow at the University of Queensland, Australia. From April 2022 to July 2023, she also was a JSPS Research Fellow at the University of Tokyo, Japan, where she researched healthcare access and social vulnerability in post-COVID Japan.

John Wilson is Professor of Spatial Sciences and Sociology at the University of Southern California (USC), where he founded the Spatial Sciences Institute. He also holds appointments in USC's School of Architecture, the Keck School of Medicine, and the Viterbi School of Engineering. His research leverages GIS tools, fieldwork, and computer modeling to investigate the interplay among environmental systems, society, and human health. Dr. Wilson has published extensively, including edited volumes such as *Terrain Analysis: Principles and Applications*, the *Handbook of Geographic Information Science*, and *Environmental Applications of Digital Terrain Modeling*. His numerous honors include the UCGIS Lifetime Achievement in GIScience Education Award, his election as a Fellow of UCGIS, and a Lifetime Achievement Award from the International Society for Geomorphometry. He founded the journal *Transactions in GIS* and continues as its Editor-in-Chief. He has served on the editorial boards of several leading journals, was President of UCGIS, and leads the GIS&T Body of Knowledge 2.0 project. Formerly the Chair of USC's Department of Geography, he has also held visiting appointments at institutions worldwide.

Peter Kedron is a human geographer and GIScientist with expertise in economic geography, spatial analysis, and the design and evaluation of research. Dr. Kedron joined UCSB as an Associate Professor and member of the Center for Spatial Data Science after previously holding faculty positions at Arizona State University (2018–2023), Oklahoma State University (2016–2018), and Ryerson University (2012–2016). He earned his Ph.D. in Geography from the State University of New York at Buffalo, an MA in Economics from the University of Michigan, and B.A.s in Economics and Psychology from the State University of New York at Buffalo. His research develops and uses spatial analytical methods to explain geographic variation in social and ecological processes. Dr. Kedron's recent work focuses on the use of replication as a means of evaluating geographic research and on developing statistical approaches to improve the accumulation of evidence collected from different locations. To date, he has authored over 55 peer-reviewed articles, delivered over 100 conference presentations and public talks, and supervised over 20 graduate students and postdoctoral scholars.

Part I
Foundations of Human Geography and GeoAI

Chapter 1
Human Geography in the Era of Big Data and AI

Jonathan Corcoran, Siqin Wang, and Xiao Huang

Abstract This chapter explores the transformative impact of geospatial artificial intelligence (GeoAI) on human geography. GeoAI integrates artificial intelligence, geospatial big data, and high-performance computing to address complex spatial challenges. Tracing its evolution from early artificial intelligence (AI) applications in the 1980s to its formal introduction in 2018, the chapter highlights how advancements in AI, big data, and digital infrastructures have revolutionized geospatial analysis. It discusses the democratization of GeoAI through open-source tools, making advanced geospatial analysis accessible and fostering collaboration across diverse research communities. By interweaving tools and techniques, GeoAI enables researchers to unravel intricate socio-spatial complexities, leading to innovative applications in urban planning, cultural geography, and population studies. The chapter also examines future opportunities, such as enhanced decision-making, improved predictive capacities, and real-time monitoring. It discusses challenges including data quality, skill gaps, implementation costs, reproducibility concerns, and ethical issues like bias, privacy, and the rise of "deep fake geography." Emphasizing the need for responsible practices, the chapter underscores the importance of balancing innovation with ethical considerations to fully harness GeoAI's potential.

Keywords GeoAI · Human Geography · Big Data

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1.1 Introduction

Human geography has embraced the big data era with a growing diversity of studies spanning understanding city liveliness in developing countries (Liu et al., 2020) to quantifying conflict intensity (Levin et al., 2018) and understanding cultural ties through human mobility (Wu et al., 2016) to automating the extraction of features from historic maps (Duan et al., 2020) to name just a select few. Fuelled by the rapidly expanding and increasingly diverse landscape of spatially explicit data that is collected with greater frequency and resolution (Perez & Sengupta, 2024) underpinned by advancements in high-performance computing, the field is experiencing unprecedented growth. This momentum is further propelled by the efforts of dedicated research groups, the availability of open-source toolkits, and the support of various journal outlets, together shaping and sustaining its continued evolution.

The term *Geospatial artificial intelligence* or *GeoAI* refers to a fast-emerging field that "*integrates artificial intelligence, geospatial big data, and high-performance computing for geospatial problem solving*" (Li, 2022). Despite being more than 30 years in the making (Scheider and Richter, 2023) with studies back in the 1980s first detailing how spatial problems might be approached using artificial intelligence approaches (Smith, 1984; Couclelis, 1986; Openshaw, 1992), it has only been in the last five or so years that we have seen the birth then the growth of GeoAI across many subdomains that comprise human geography (Wang et al., 2024).

The origins of *Artificial Intelligence* can be traced back to the mid-twentieth century, when in the summer of 1956, a project titled "Artificial Intelligence" for a workshop was proposed to be held at Dartmouth, marking the birthplace of artificial intelligence (AI) (Negnevitsky, 2024). In their proposal, they defined artificial intelligence as "*the science and engineering of making intelligent machines*." They also claimed that every aspect of learning or any other feature of intelligence can in principle be so precisely described that a machine can be made to simulate it. It was the first time the term "Artificial Intelligence" was used, marking a new era in technological advancement (Cordeschi, 2007). Early AI research focused on symbolic reasoning and problem-solving, with significant contributions from Alan Turing, who proposed the concept of a universal machine capable of simulating any human intelligence (Brooks, 1999). The initial AI systems were designed to solve mathematical problems, play games like chess, and perform simple logical tasks. Despite early optimism, progress was slow due to limited computational power and the complexity of replicating human cognition.

The term "GeoAI" was formally introduced in 2018 during a workshop on "*Artificial Intelligence for Geospatial Data Analysis*" held at the International Conference on Geographic Information Science (GIScience), emerging from the convergence of advancements in AI and geospatial science (Gao, 2021). The concept of GeoAI, however, evolved over several years through the integration of AI with geospatial sciences and its relevant disciplines (e.g., physical geography, remote sensing, and environmental science). The development and application of AI techniques in geospatial analysis began earlier, but the explicit recognition and formalization of GeoAI as a distinct field gained prominence with the growing use of AI in processing and interpreting geospatial data (Couclelis, 2023). The foundation of GeoAI can be traced to the early use of AI in spatial analysis. In the late twentieth century, the development of geographic information systems (GIS) revolutionized the way geospatial data was collected, analyzed, and visualized.

As AI technologies progressed, they were increasingly and profoundly integrated with GIS to enhance spatial data analysis and predictive modeling. This integration gained momentum with the proliferation of big data, which provided extensive geospatial datasets and further fuelled the capabilities of AI models (Li & Hsu, 2022). The rise of big data, characterized by vast volumes, high velocity, and diverse types of spatial information, has provided GeoAI with unprecedented opportunities for enhanced analysis and decision-making. This integration began as geospatial technologies (e.g., GIS and remote sensing) started to handle increasingly large datasets, including satellite imagery, sensor data, social media feeds, mobile phone signal data, smart-card transportation, point of interests and crowdsourcing data more broadly (Huang et al., 2022, 2024). AI and machine learning algorithms, which thrive on large datasets, have been employed to extract patterns, trends, and insights from this expansive geospatial data. By leveraging big data, GeoAI can perform more intelligent spatial analyses to reveal the complex and sophisticated relationship among human (i.e., community and society) and environment (i.e., built and natural environment), such as real-time monitoring of people's response to environmental changes, predictive modelling of urban and population growth, and precise capturing human activities (Wang et al., 2024). This synergy enables more accurate and actionable insights, driving innovations in the subdomain of human geography and social science more broadly, such as urban geography, social geography, cultural geography, urban planning and health intervention. The continuous growth of big data and advancements in AI techniques are further propelling the capabilities and applications of GeoAI, making it a crucial tool for understanding and managing the dynamic aspects of our cities and societies.

1.2 The Expansion of GeoAI: Transforming Human Geography

1.2.1 Riding the Technological Wave: AI, Big Data, and Digital Infrastructures

GeoAI is founded on several key pillars that are essential for its development and success. The convergence of Artificial Intelligence (AI), big data, and robust technological infrastructures has ushered in a new era of geospatial analysis and application, profoundly transforming the field of geography. The unprecedented growth of data, fuelled by advancements in sensor technologies, satellite imagery, social media, and mobile devices, has provided a rich repository of spatial information (Huang et al., 2024). This wealth of data, often referred to as “big data,” presents both opportunities and challenges for geographers seeking to understand complex socio-spatial phenomena.

AI has become an essential tool in harnessing the potential of big data. Techniques such as deep learning, natural language processing, and computer vision enable the extraction of meaningful patterns and insights from vast and heterogeneous datasets. These advancements have made it possible to analyze and interpret spatial data at unprecedented scales and resolutions, offering new perspectives on traditional geographical questions (Janowicz et al., 2022). The integration of AI and big data is supported by advancements in computational infrastructures, such as cloud computing and high-performance computing. These infrastructures provide the necessary computational power and storage capacity to process and analyze large volumes of spatial data efficiently. Cloud platforms, like Google Earth Engine and Amazon Web Services, offer scalable solutions that democratize access to powerful geospatial analysis tools, enabling researchers from diverse backgrounds and institutions to collaborate and innovate. Furthermore, the development of sophisticated geospatial databases and data management systems has facilitated the organization, retrieval, and dissemination of spatial information. Spatial data infrastructures and geospatial data repositories, such as the ArcGIS Living Atlas of the World, Global Earth Observation System of Systems, and the Copernicus Open Access Hub, provide centralized access to diverse geospatial datasets, promoting data sharing and interoperability. These infrastructures are crucial for enabling the seamless integration of geospatial data from various sources, supporting comprehensive and multi-scale analyses.

The synergy between AI, big data, and technological infrastructures is expected to drive and continue driving significant advancements in human geography, particularly as the data and problems human geographers face become increasingly large, complex, and spatially intricate. This integration facilitates the ability to process and analyze vast amounts of spatial data efficiently, enabling geographers to gain deeper insights into complex socio-spatial phenomena.

1.2.2 Democratising GeoAI: The Open-Source Revolution

The open-source movement has fundamentally democratized the field of GeoAI, making advanced geospatial analysis accessible to a broader and more diverse audience. Historically, geospatial technologies were proprietary and expensive, limiting their use to well-funded institutions and organizations (Yang et al., 2010). The advent of open-source tools and platforms has significantly lowered these barriers, fostering a more inclusive and collaborative environment for geospatial research and applications. Platforms like GitHub have been instrumental in this transformation by providing a space for developers to share and collaborate on code, making it a hub for innovation in GeoAI. Open-source libraries, such as QGIS (Moyroud & Portet, 2018), GeoPandas (Jordahl et al., 2021), PySAL (Rey & Anselin, 2009), Rasterio (Gillies, 2019), and geemap (Wu, 2020), among many, have empowered researchers and practitioners to perform sophisticated geospatial analyses without costly software licenses. These tools have enabled tasks ranging from basic mapping and spatial data management to advanced spatial statistics and machine learning applications.

The impact of this democratization is profound. Researchers from institutions with limited resources can now access and utilize the same advanced tools as those from well-funded universities and corporations, leading to a more equitable distribution of knowledge and capability across the geospatial community. Moreover, the open-source movement has fostered a culture of collaboration and knowledge sharing. Online forums, workshops, and conferences dedicated to open-source geospatial tools have proliferated, creating spaces where users can exchange ideas, troubleshoot problems, and develop new applications. This collaborative ethos has accelerated the pace of innovation in GeoAI, as demonstrated during the COVID-19 pandemic, where the rapid development and deployment of open-source tools were crucial in tracking and analyzing the spread of the virus (Li et al., 2021; Brovelli & Coetzee, 2021; Malarvizhi et al., 2022).

Furthermore, the open-source movement has played a critical role in capacity building and education. Students and early-career professionals can gain hands-on experience with state-of-the-art geospatial technologies without financial constraints. This exposure enhances their technical skills and prepares them to contribute to the field of GeoAI with innovative solutions and diverse perspectives. The flexibility and adaptability of open-source GeoAI tools support interdisciplinary research, allowing for integration with various data sources and analytical frameworks to address complex socio-spatial issues.

1.2.3 Interweaving Tools and Techniques: Unravelling Socio-Spatial Complexities

GeoAI is inherently collaborative; its strength does not lie solely in individual tools and technologies but in the ability to integrate these elements, providing unique capabilities to address complex challenges. In an era characterized by intricate socio-spatial phenomena, the integrative nature of GeoAI enables researchers to achieve a more comprehensive and nuanced understanding of geographical issues (Wang et al., 2024). This approach is crucial for tackling the multifaceted nature of human geography, a domain previously untouched by the AI revolution. By leveraging the synergistic potential of AI and geospatial technologies, GeoAI transcends traditional boundaries, enabling more sophisticated analyses and solutions.

Geographers have capitalized on the opportunity to integrate the latest advancements in AI with geospatial data and spatial laws, developing innovative data-disciplinary collaboration, and accessibility, we can ensure that GeoAI serves as a catalyst for positive transformation within the discipline.

This convergence calls for a paradigm shift—a reimagining of how we conduct research, teach, and apply human geography in an increasingly data-rich world. It challenges us to move beyond traditional boundaries, fostering a culture of openness and adaptability. By integrating GeoAI thoughtfully and ethically, we can uncover new insights, validate and refine existing theories, and address pressing global issues with greater precision and empathy. The journey ahead is not without obstacles, but the likely rewards are profound. By working collectively to simplify complex technologies and bridge gaps between diverse communities of scholars and practitioners, we can lay the groundwork for a more dynamic and responsive human geography. This collaborative spirit will enable us to harness the full potential of GeoAI, ensuring it becomes a tool for empowerment rather than division.

Here, we affirm our commitment to a future where GeoAI enhances human geography in ways that are ethically sound, socially equitable, and intellectually enriching. The path forward is one of innovation grounded in responsibility—a journey that holds the promise of not only advancing our discipline but also contributing meaningfully to the broader quest for understanding and improving societal needs.

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Index

X. Huang et al. (eds.), *GeoAI and Human Geography*, Springer Geography,
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