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Foreword

The exponential growth of geospatial data —from GPS traces and remote sensing to social media check-ins — has enabled modern machine learning models to perform geospatial analysis at an unprecedented scale. However, detecting anomalies in this wealth of data — events that significantly deviate from expected patterns — presents unique challenges. Most of the existing work in geospatial data analysis relies on supervised machine learning using labeled datasets. Anomalies, by nature, are rare and unpredictable, making such data scarce. Consequently, anomaly detection research calls for new strategies that can identify rare and unexpected events based on patterns and distributions within the data itself in an unsupervised fashion.

Anomaly detection in geo-spatial data that pertains to humans is particularly complex because what may seem like "noise" to one observer could be a critical "signal" to another. Human mobility patterns exhibit periodicity (e.g., time-of-day and seasonal cycles), are shaped by numerous factors (e.g., social behavior, weather, urban infrastructure), and evolve over time as new constructions emerge and demographics shift. Understanding these behaviors and detecting underlying anomalies is crucial across various domains. A sudden shift in mobility may indicate the early onset of infectious diseases, while deviations in animal movements could signal environmental distress. In urban environments, traffic anomalies provide invaluable insights for planners, and irregularities in remote sensing data can help detect natural disasters faster than traditional reporting mechanisms.

Effectively capturing and analyzing these complex, evolving behaviors demand novel methodologies that enable understanding of individual and collective geospatial behaviors and how they are influenced by endogenous (e.g., social norms) and exogenous (e.g., infrastructure or environmental changes) factors. Developing these methods is essential to ensure timely and accurate detection of anomalies across a range of critical applications, from public health to environmental monitoring and urban management.

The 2nd ACM SIGSPATIAL Int. Workshop on Geospatial Anomaly Detection (GeoAnomalies'25), held in Minneapolis, Minnesota, brought together researchers exploring new frontiers in detecting, explaining, and simulating anomalies across spatial, temporal, semantic, and physical dimensions. As human mobility, environmental sensing, and autonomous systems generate ever-richer streams of spatio-temporal data, the detection of rare, irregular, or suspicious patterns has become central to ensuring safety, resilience, and interpretability in complex systems. The six papers in this volume reflect the diversity and maturity of this emerging field — ranging from unsupervised detection in scientific sensor data, to causally grounded anomaly generation, to large-scale semantic and behavioral representations of human mobility.

Unsupervised and Physics-Informed Anomaly Detection

At the foundations of anomaly detection, *Scarscelli et al.*'s **"Anomalies in the Depths: Evaluating Unsupervised Anomaly Detection on Real-World Unlabelled Data"** presents a case study in the marine domain, analyzing sensor data collected from autonomous ocean gliders in the Central Tropical Atlantic. The work addresses the fundamental challenge of evaluating unsupervised anomaly detection methods in the absence of ground-truth labels. Using a variational recurrent autoencoder with convolutional preprocessing and bidirectional LSTM encoding, the authors derive anomaly scores from reconstruction errors and validate them through expert knowledge and geospatial clustering. Their findings emphasize the importance of domain-informed evaluation strategies for real-world, heterogeneous, and unlabeled scientific data streams — an issue equally central to Earth observation and mobility analysis.

A complementary line of work by *Sharma et al.* explores the integration of physical constraints into data-driven modeling. Their paper **“Towards Physics-informed Diffusion for Anomaly Detection in Trajectories”** introduces a physics-informed diffusion probabilistic model (Pi-DPM) that identifies GPS-spoofed trajectories violating kinematic laws. By combining encoder–decoder architectures with physical attributes such as acceleration and rate of turn, the model enforces motion feasibility and enhances detection accuracy in both maritime and urban domains. The approach exemplifies a growing interest in physics-grounded learning for interpretable and trustworthy geo-AI systems, bridging the gap between machine-learning flexibility and physical realism.

Causally and Behaviorally Grounded Anomaly Generation

Understanding *why* anomalies occur, rather than merely detecting them, is a recurring theme in this year’s proceedings. *Kim and Züfle*’s **“Grounded Anomalies: Towards Causally Grounded Kinematic Anomaly Generation”** offers a conceptual framework for simulating anomalies with explicit causal grounding. Moving beyond arbitrary data augmentation, the authors argue that anomaly detection gains value when embedded in a causal reasoning chain, from detection to explanation, prediction, and prescription. Drawing inspiration from John Snow’s 1854 cholera map, the paper articulates an algebraic model for generating kinematic anomalies in driving, walking, and bicycling contexts that reflect specific causal mechanisms such as fatigue, distraction, or environmental stressors. This vision establishes a bridge between anomaly detection and counterfactual reasoning, highlighting the potential of synthetic yet *causally meaningful* data to train explainable anomaly models. In the behavioral realm, *Xie et al.*’s **“BeSTAD: Behavior-Aware Spatio-Temporal Anomaly Detection for Human Mobility Data”** proposes an unsupervised framework that models individual-level mobility behavior through multi-scale spatial semantics and temporal clustering. By leveraging H3 hexagonal cells enriched with OpenStreetMap features, the method constructs personalized behavior clusters and detects deviations via cross-period comparisons. This “behavior-aware” design captures not only spatial or kinematic irregularities but also semantic inconsistencies — such as a person frequenting venue inconsistent with their habitual roles or schedules. BeSTAD exemplifies a paradigm shift from global anomaly detection to individualized modeling of *patterns of life*, with direct implications for public safety, epidemiology, and urban analytics.

Semantic and Collective Perspectives on Anomalous Mobility

While BeSTAD focuses on the individual, *Hosseini Sereshgi et al.*’s **“Semantic Anomaly Detection in Human Trajectories: Preserving Behavioral Patterns Through Calendar Representations”** captures multi-temporal human routines through *calendar-based* visual and textual encodings. By transforming spatio-temporal traces into weekly “behavioral calendars,” the authors enable vision-language models to recognize deviations in both semantic and temporal dimensions. Experiments on real (GeoLife) and simulated (Patterns of Life, NumoSim) datasets demonstrate that such representations retain crucial periodic structures that conventional models often lose. This approach underscores the workshop’s growing emphasis on explainability and human-interpretable anomaly detection — aligning data science techniques with intuitive cognitive metaphors such as calendars and routines.

At the collective level, *An et al.*’s **“Towards Recurring Co-traveling Pattern Detection: A Summary of Results”** investigates the detection of recurring co-traveling groups in trajectory and location-trace data. The proposed RCPD algorithms formalize an interest measure for recurring co-traveling patterns, enabling early pruning through anti-monotonicity and efficient discovery of group mobility structures. Beyond algorithmic contributions, the authors position recurring co-traveling detection as a baseline for anomaly detection — deviations from normal co-traveling groups naturally signal irregular or suspicious activity. The framework also supports synthetic data validation and transportation planning, linking anomaly detection to broader societal applications.

Reflections and Outlook

Together, these six papers demonstrate the conceptual and methodological breadth of the GeoAnomalies community. They extend anomaly detection beyond conventional statistical definitions — embedding it within causal reasoning, physical constraints, semantic structures, and behavioral routines. Across diverse domains, from oceanographic sensing to urban mobility, the research presented here advances the central mission of GeoAnomalies: to make anomalies *interpretable, actionable, and causally explainable* within complex spatio-temporal systems.

As anomaly detection becomes increasingly central to safety-critical and data-rich environments, the GeoAnomalies workshop continues to serve as a focal point for interdisciplinary collaboration — uniting geospatial data science, AI, physics, and human behavior modeling. The contributions in this volume exemplify this synthesis and chart an exciting trajectory for future research on understanding, predicting, and preventing anomalies in the spatial world.

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