Forecasting Multi-Technology Convergence via Dual-Channel Spatial-Temporal Hypergraph Neural Networks: A Case Study of Intelligent Connected Vehicles

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Abstract

Technology convergence is a key driver of technology innovation, particularly in highly interdisciplinary fields such as intelligent connected vehicles (ICVs). Accurately forecasting these convergence trends is crucial for strategic R&D planning. However, existing predictive models predominantly rely on pairwise networks and thus fail to capture the complex, high-order interactions among three or more technologies. Furthermore, they often struggle to fuse explicit and implicit convergence signals, and lack robust mechanisms to handle temporal network evolution and the continuous emergence of novel technological nodes (the cold-start problem). To address these critical gaps, this study proposes a novel Dual-Channel Spatial-Temporal Hypergraph Neural Network (DC-STHGNN) to forecast multi-technology convergence, using ICVs as a case study. Using patent data from 2000 to 2024, we construct sequential dual-channel hypergraphs: a co-classification hypergraph that captures explicit inventive integration, and a co-citation hypergraph that maps implicit knowledge flows. The proposed architecture employs parallel Hypergraph Convolutional Networks (HGCNs) with a dynamic node-level attention mechanism that can adaptively fuse multi-view features and handle missing nodes effectively. To capture temporal momentum, we introduce a Gated Recurrent Unit (GRU) module with temporal masking and neighborhood-based history inheritance. This design seamlessly integrates the dynamic evolution of established technologies with the cold-start initialization of emerging ones, formulating the forecasting task as an end-to-end hyperedge link prediction problem. Experimental results on the ICV dataset show that the DC-STHGNN significantly outperforms state-of-the-art baseline models on key metrics such as AUC-ROC and AUPRC. Ablation studies confirm that integrating co-classification and co-citation features via dynamic attention achieves optimal predictive performance. Furthermore, the model successfully anticipates high-probability future technology convergence opportunities in the ICV sector, highlighting the accelerating integration of AI-driven perception, V2X communication, and smart vehicle control systems. This study advances the methodological frontier of technology forecasting by effectively modeling evolving, high-order network interactions. In practice, it provides policymakers and corporate managers with actionable, data-driven intelligence to help them identify latent opportunities and navigate the rapidly converging technological landscape.

Keywords

Technology Convergence, Hypergraph Neural Network, Link Prediction, Spatial-Temporal Evolution,
Intelligent Connected Vehicles, Patent Analysis