Large Language Model Empowered City-wide Delivery Demand Joint Estimation and Prediction

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Cross-city transfer

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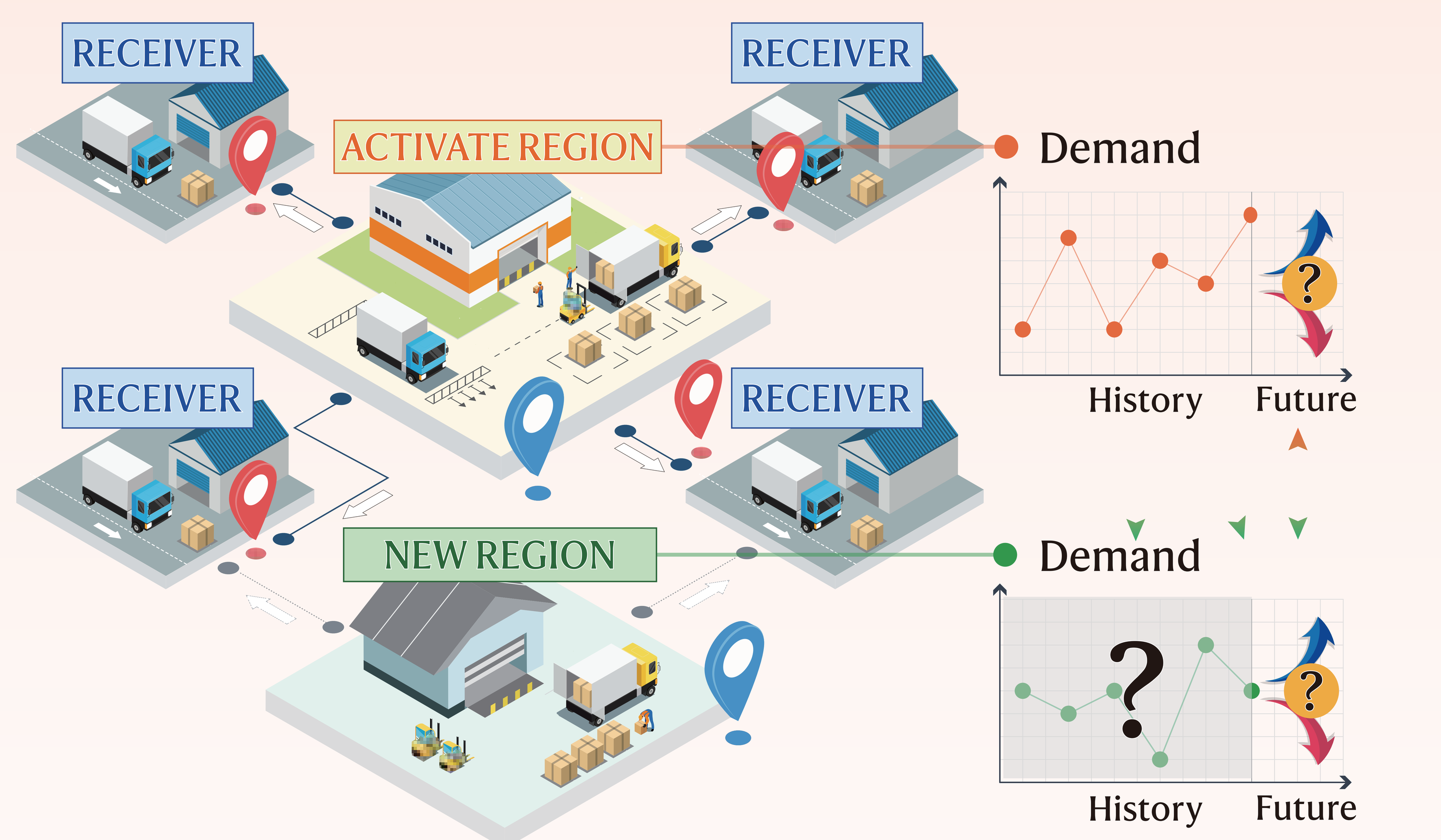
0 City-wide Delivery Demand Joint Estimation and Prediction

- We highlight the significance of **location-based modeling** in delivery demand joint estimation and prediction and develop a scheme for **extracting geolocation knowledge from LLMs**;
- We present a method for integrating the geolocation encoding into **graph-based deep learning** architectures and **elicit the cross-city tranferability** of the backbone model.

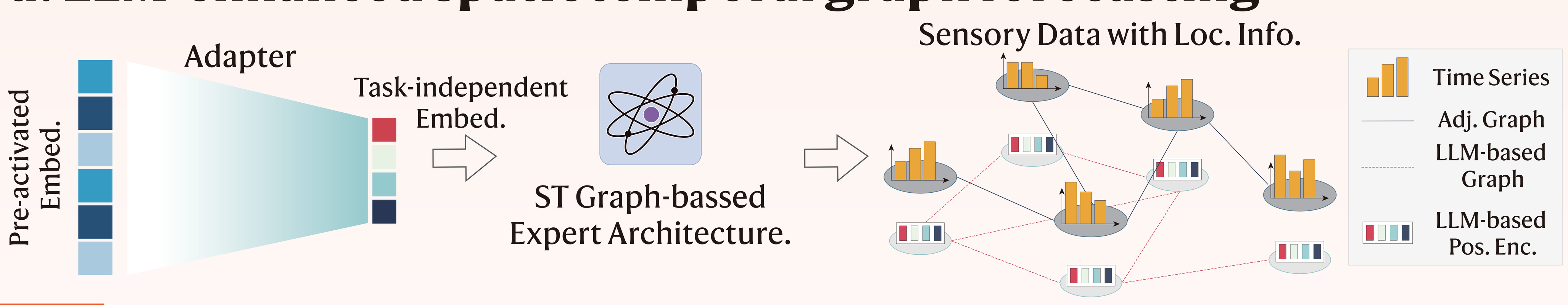
1 Knowledge-driven Geolocation Encoding Extraction from Pretrained LLMs

a. City-wide delivery demand joint estimation and prediction



c. LLM-based geolocation knowledge extraction

d. LLM-enhanced spatiotemporal graph forecasting



b. Constructing geospatial prompt from open map data

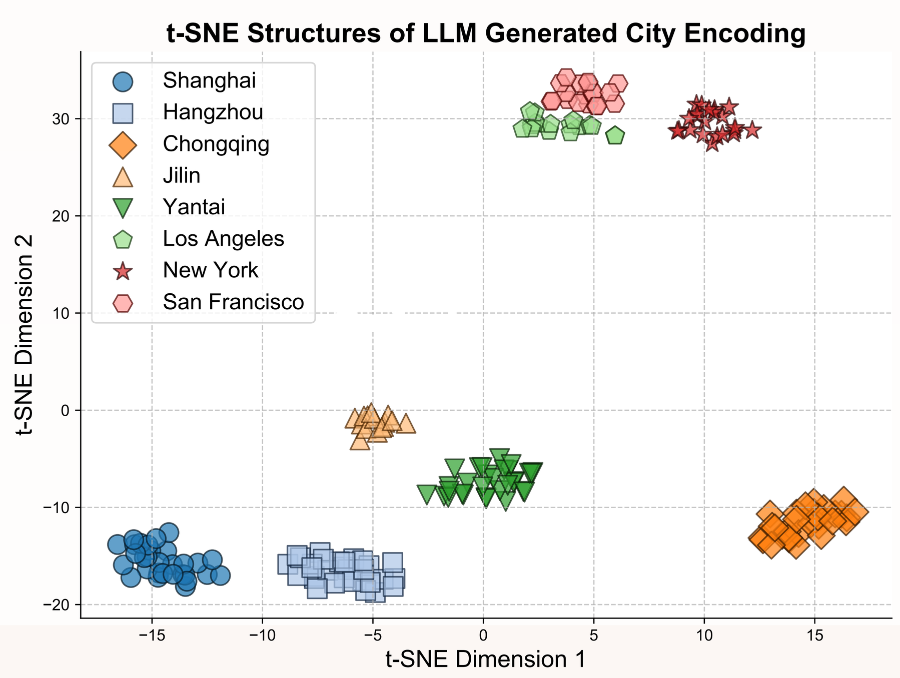
Open Map Data

Geospatial Prompt

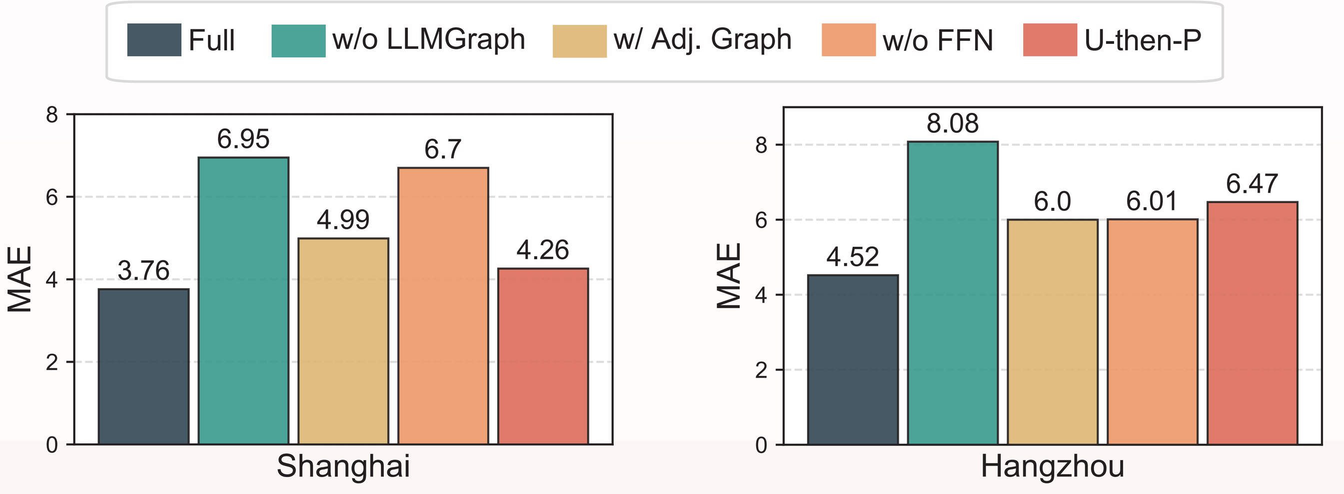
Identify the geospatial information (Urban Environment) of the given coordinate
(29.48968, 106.46992)
Address:
Jiugongmiao Street, Dadukou District, Chongqing, China
Nearby Places (POIs):
0.9 km South-East: Dadukou District
1.2 km South-East: Baqiao Town
2.2 km East: Yuejin Street
3.0 km North-West: Erlang Restaurant
3.4 km South: Chunhui Road Street
3.4 km North: Shiqiaopu Depot
3.7 km North-East: Zaoqi Village
3.7 km North-West: Zhangjiawan District

Query Coordinate
Retrieved address
Nearby POIs
Geographic distance

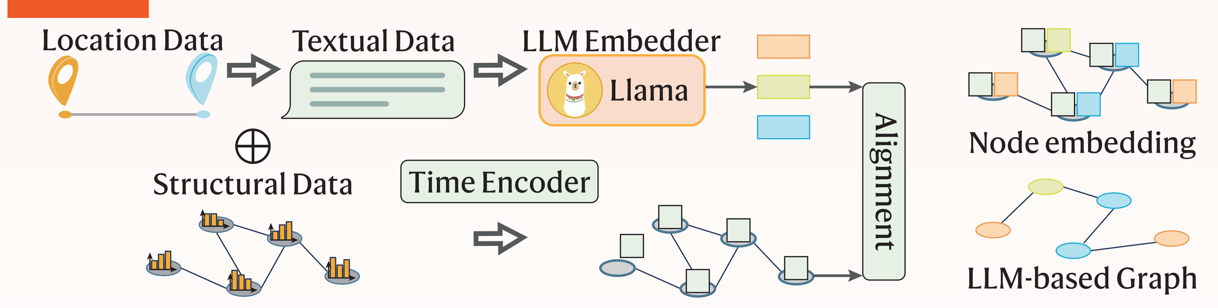
Latent Structures of LLM-enc



Ablation Study



2 Preserving the Transferability across Cities



Geolocation encoding by decoding LLMs

$$\widehat{\mathbf{W}}_{\text{prob}} = \arg\min_{\mathbf{W}_{\text{prob}}} \|\mathbf{E} - \mathbf{H}_{\text{LLM}}\mathbf{W}_{\text{prob}}\|_F^2 + \lambda\|\mathbf{W}_{\text{prob}}\|_F^2$$
$$= (\mathbf{H}_{\text{LLM}}^{\mathsf{T}}\mathbf{H}_{\text{LLM}} + \lambda\mathbf{I})^{-1}\mathbf{H}_{\text{LLM}}^{\mathsf{T}}\mathbf{E},$$
$$\mathbf{v}_{g,\phi_i} = \texttt{LeakyReLU}(\mathbf{D}^{(\ell)}\mathbf{v}_{\phi_i}),$$
$$e^{i\rightleftarrows j} = \langle \mathbf{v}_{g,\phi_i}, \mathbf{v}_{g,\phi_j}\rangle,\ \mathcal{E} = \{e^{i\rightleftarrows j} | \forall i, j \in 1, \dots, \bar{N}\},$$

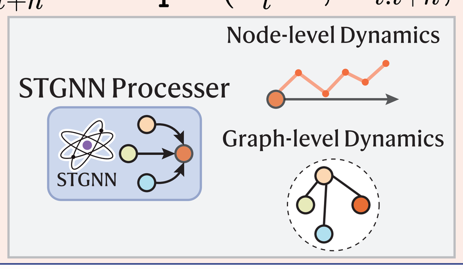
Region-specific and region-wide modeling in a unified representation

Individual components to approximate the joint distribution

$$p^i_{\theta,\{\phi_i\}}(\mathbf{x}^i_{t+h} | \mathbf{X}^i_{t-W:t}, \mathbf{U}_{t-W:t+h}, \mathbf{v}_{\phi_i}) \approx p^i(\mathbf{x}^i_{t+h} | \mathcal{X}_{<t}, \mathbf{U}_{\le t+h}, \mathbf{V}),\ \forall i \in \{1, \dots, \bar{N}\},$$

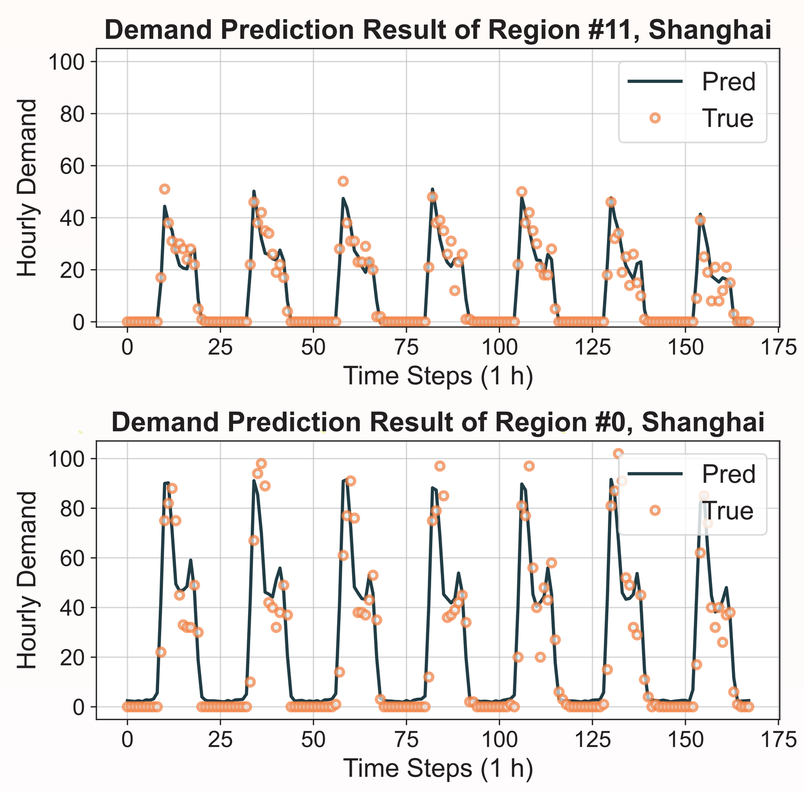
Hybrid collective-individual modeling considering transferability

$$\mathbf{h}_t^{i,(0)} = \texttt{TempEnc}(\mathbf{X}^{i,(0)}_{t-W:t}, \mathbf{U}_{t-W:t}, \mathbf{v}_{\phi_i}),$$
$$\mathbf{h}_t^{i,(\ell+1)} = \psi^{(\ell)}\left(\mathbf{h}_t^{i,(\ell)}, \texttt{Aggr}_{j\in\mathcal{N}(i)}\{\rho^{(\ell)}(\mathbf{h}_t^{i,(\ell)}, \mathbf{h}_t^{j,(\ell)}, e^{i\leftarrow j})\}\right)_{\ell=0}^{L-1},$$
$$\hat{\mathbf{x}}^i_{t+h} = \texttt{Output}(\mathbf{h}_t^{i,(L)}, \mathbf{U}_{t:t+h}, \mathbf{v}_{\phi_i}),\ \forall h \in [1, H],$$



Individual modeling
⊕
Collective modeling

Prediction under Sparse Data



Cross-city Transferability

Models	IMPEL (Ours)		MTGNN		IGNNK		STGCN		GRIN	
Source ↦ Target	MAE	RMSE	MAE	RMSE	MAE	RMSE	MAE	RMSE	MAE	RMSE
Shanghai ↦ Hangzhou	**3.35**	**6.42**	4.07	7.32	5.64	9.00	5.55	9.31	3.75	7.33
Shanghai ↦ Chongqing	**2.26**	**4.44**	2.62	4.89	3.25	5.22	2.91	4.91	2.51	4.86
Shanghai ↦ Yantai	**2.21**	**4.14**	2.52	4.68	3.47	5.66	2.79	4.77	2.56	4.87
Hangzhou ↦ Shanghai	**2.90**	**6.20**	3.12	6.38	3.04	6.26	3.09	6.54	3.11	6.53
Hangzhou ↦ Chongqing	**2.10**	**4.25**	2.21	4.37	2.21	4.32	2.17	4.37	2.20	4.47
Hangzhou ↦ Yantai	**2.13**	**4.08**	2.26	4.33	2.23	4.17	2.21	4.28	2.34	4.69

HIGHLIGHTS

- A new solution to the joint demand estimation and prediction problem;
- A novel knowledge-driven scheme for extracting informative geolocation encoding;
- Cross-city transferabiliy is encouraged to address the "cold-start" scenario.

TAKEAWAYS

- Location-based geospatial information serves as important covariates for traffic (delivery) demand estimation;
- Our encoding method is generic and applicable to various architectures, consistently improving their performances.

TOPS

Mobility AI Lab

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- Spatiotemporal Data
- Smart Transportation
- Urban Science
- Large Language Models

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