Self-supervised Learning of Trajectory Data

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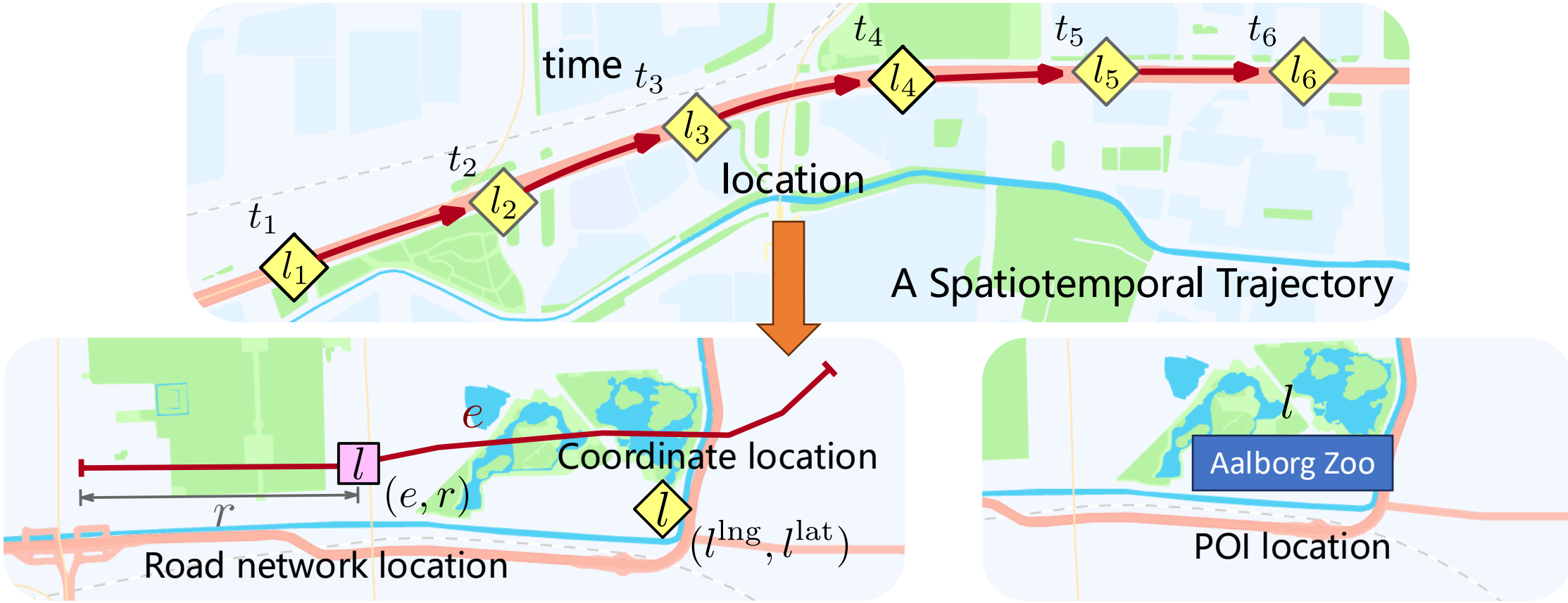
Menu

Menu

Definition of Trajectory Data

➢A type of spatiotemporal structure

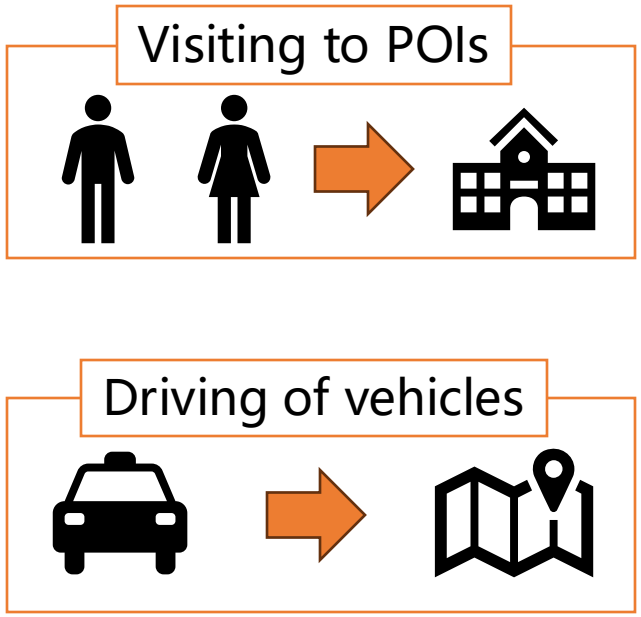
- Sequences of (location, time) pairs
- Records the movement behavior of objects or individuals



Source of Trajectory Data

➢Recordings of movements

- Individuals and location-based services
- Vehicle and in-car GPS systems
- Vessel and AIS (automatic identification system)



Generate

```
[user]  [check-in time]          [latitude]      [longitude]     [location id]
196514  2010-07-24T13:45:06Z     53.3648119      -2.2723465833   145064
196514  2010-07-24T13:44:58Z     53.360511233    -2.276369017    1275991
196514  2010-07-24T13:44:46Z     53.3653895945   -2.2754087046   376497
196514  2010-07-24T13:44:38Z     53.3663709833   -2.2700764333   98503
196514  2010-07-24T13:44:26Z     53.3674087524   -2.2783813477   1043431
196514  2010-07-24T13:44:08Z     53.3675663377   -2.278631763    881734
196514  2010-07-24T13:43:18Z     53.3679640626   -2.2792943689   207763
196514  2010-07-24T13:41:10Z     53.364905       -2.270824       1042822
```

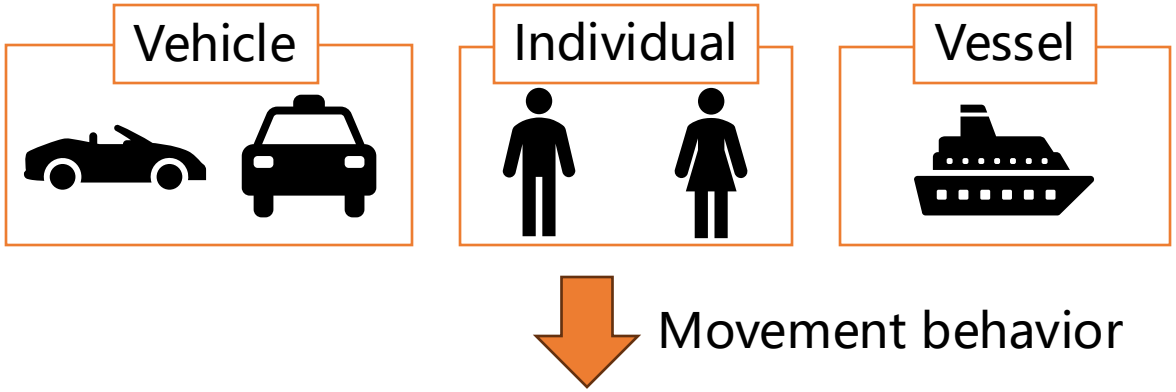
Trajectory Data

	signal_id	day_num	vehicle_id	trip_id	time_stamp	latitude	longitude	speed
1	1	190.511826148	10	2400	0	42.2782011111	-83.7484502778	33.7599983215
2	2	190.511826148	10	2400	100	42.2782011111	-83.7484502778	33.7599983215
3	3	190.511826148	10	2400	1000	42.2782011111	-83.7484502778	31.5599994659
4	4	190.511826148	10	2400	1100	42.2782011111	-83.7484502778	31.5599994659
5	5	190.511826148	10	2400	1700	42.2782011111	-83.7484502778	31.5599994659
6	6	190.511826148	10	2400	2100	42.2782011111	-83.7484502778	29.4099998474
7	7	190.511826148	10	2400	2200	42.2782011111	-83.7484502778	29.4099998474
8	8	190.511826148	10	2400	2500	42.2784791667	-83.7483075	29.4099998474

Information in Trajectory Data

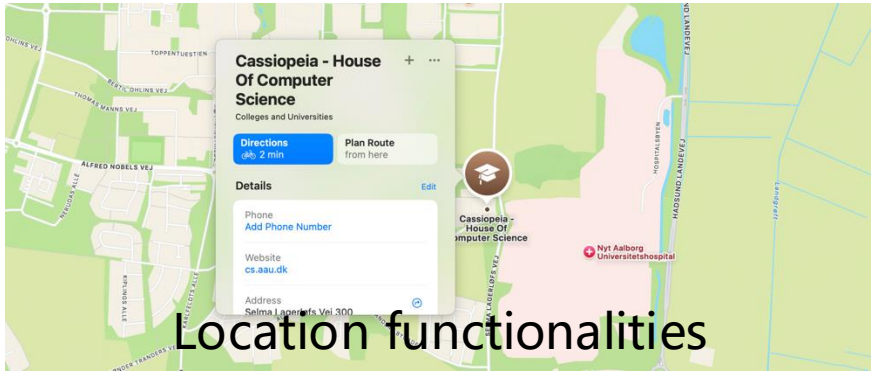
➢Various aspects of spatiotemporal information

- Basic movement information
- Inherent information, such as functionalities of locations and traffic conditions

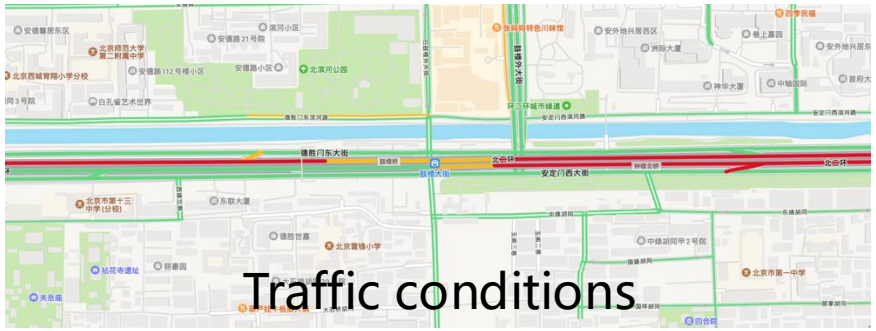


Trajectory Data

Spatiotemporal Information



Location functionalities



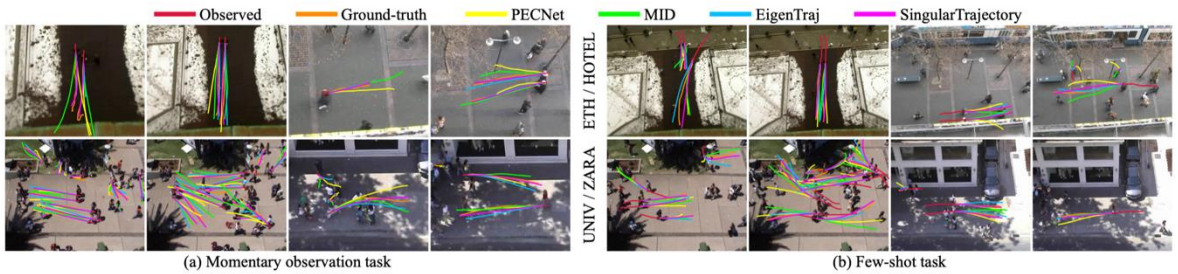
Traffic conditions

Utilization of Trajectory Data

➢A variety of spatiotemporal analysis tasks

- Analysis of movement behavior
- Analysis of location functionalities
- Analysis of traffic conditions

Pedestrian Prediction



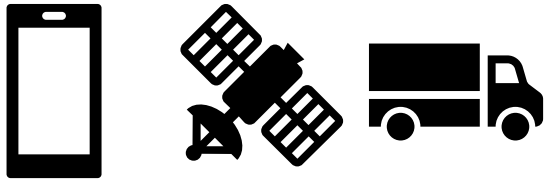
Routing and ETA

Location classification

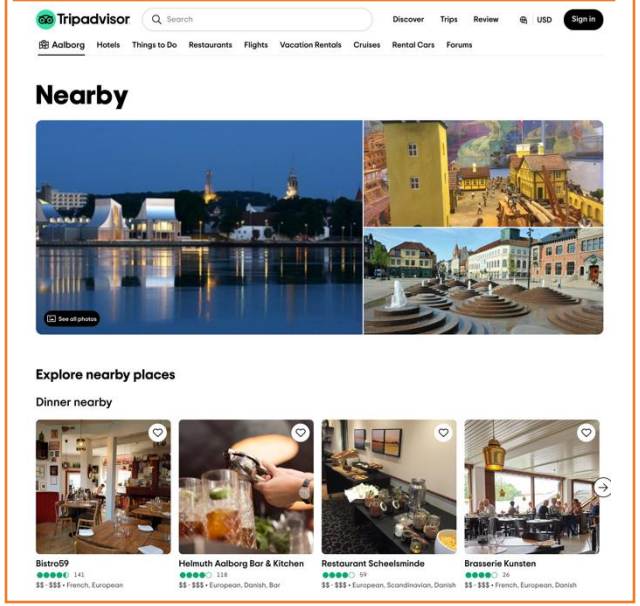
Trajectory Data Modeling

- Wide availability and board utilization – both feasible and important

Trajectory Records



Location-based Systems



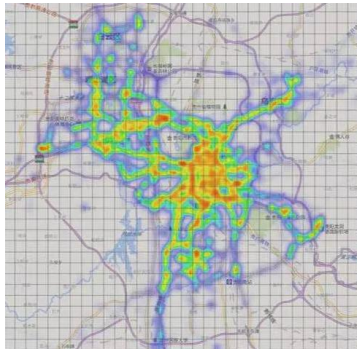
Produce

Trajectory Data

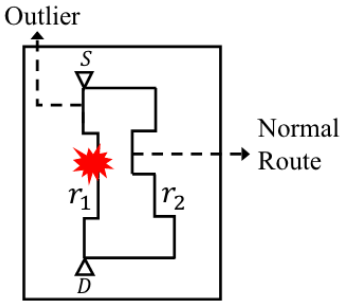
Support

Spatiotemporal Analysis

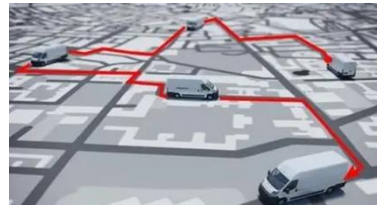
Flow Prediction



Anomaly Detection



Routing



Menu

1 **Background**

Sources, Information, and Utilization of Trajectory Data

2 **Problem**

Machine Learning of Trajectory Data

3 **Methodology**

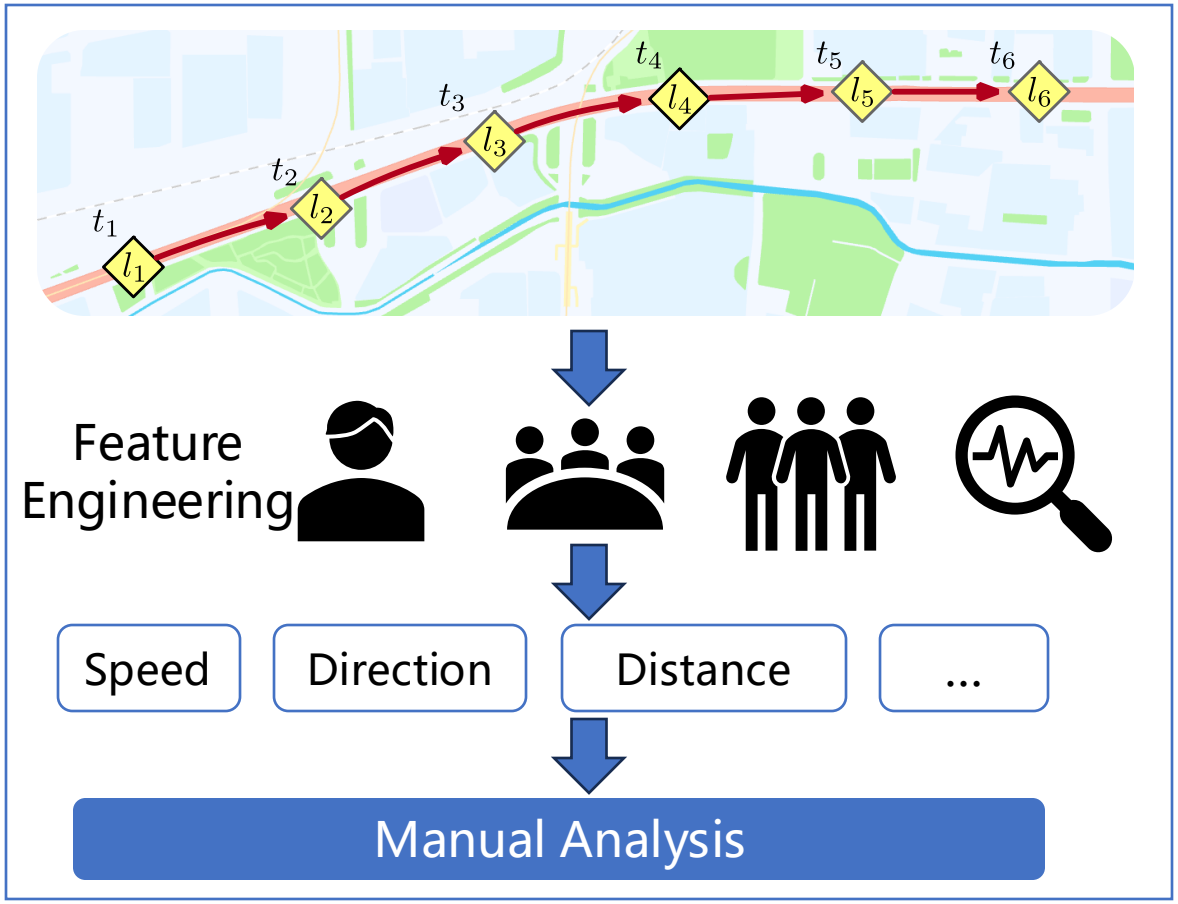
Implementation of SSL on Trajectory Data

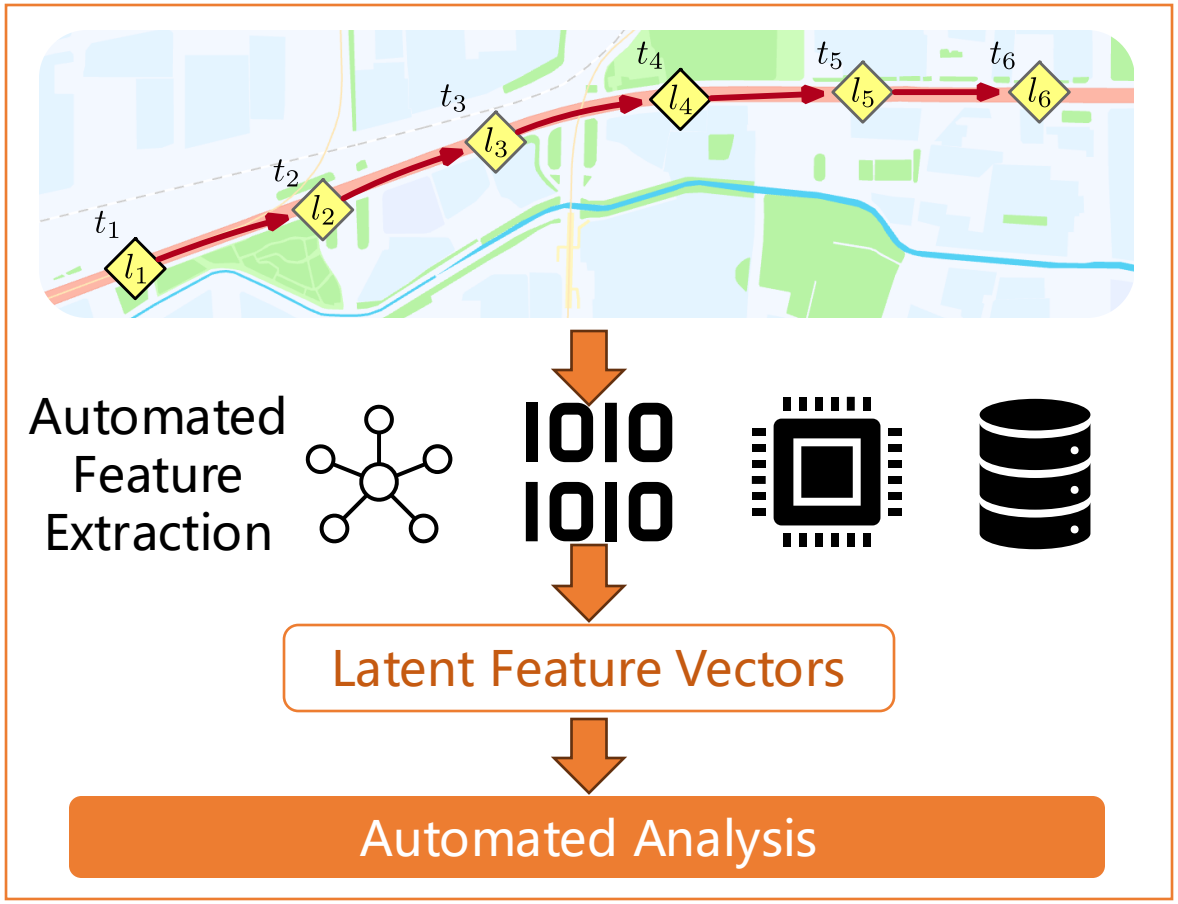
4 **Outlook**

Future of Self-Supervised Learning on Trajectory Data

Machine Learning (ML) of Trajectory Data

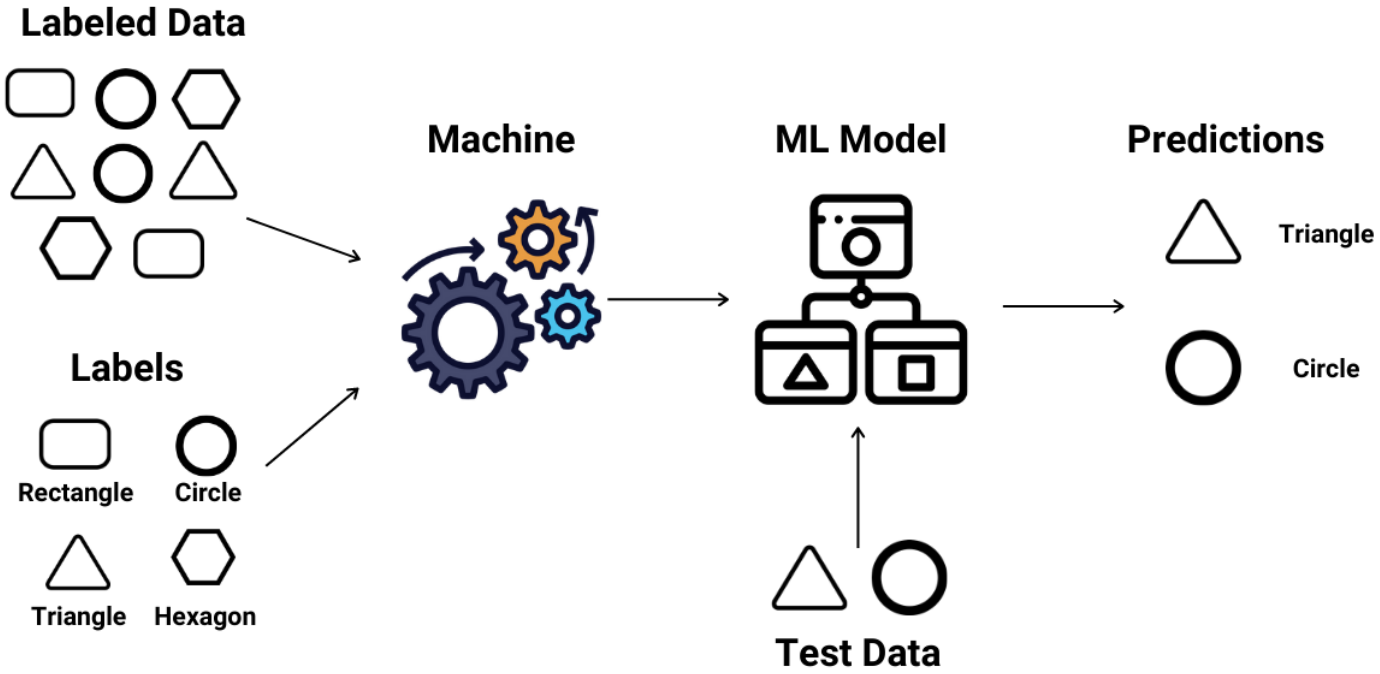
- Capable of automatically extracting rich information from trajectory data and performing spatiotemporal analysis
- Performance of ML methods depends greatly on the quality of supervision

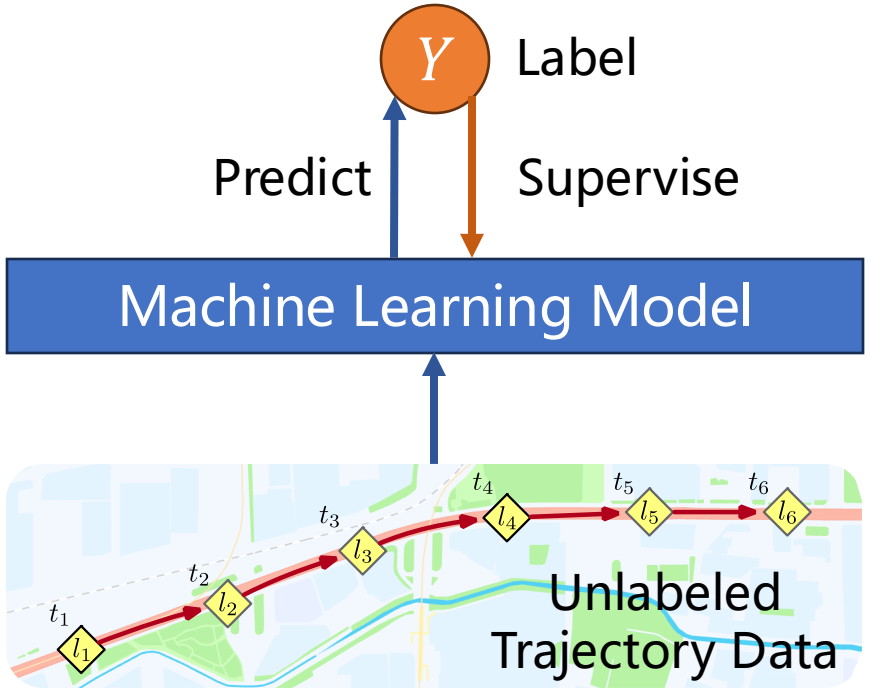




Supervised Learning

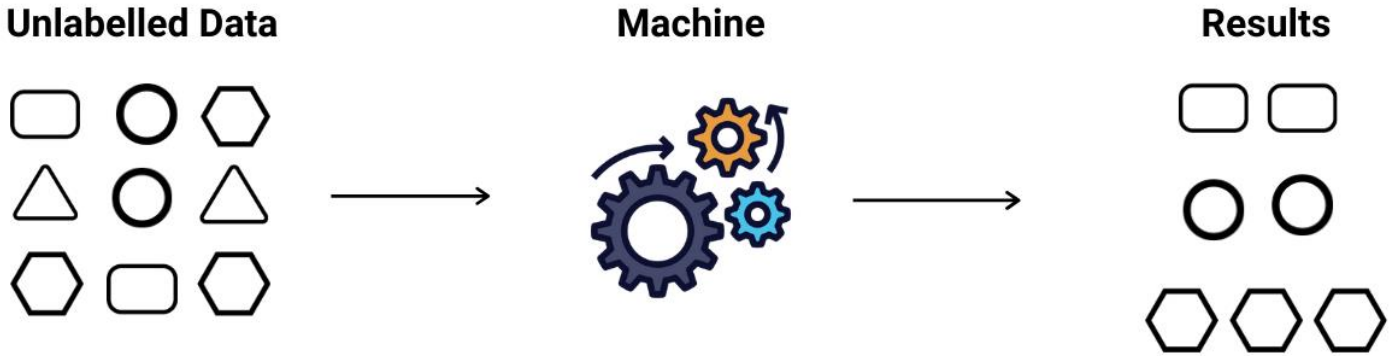
- Directly supervises ML methods with labels for a specific analysis task
- Limited by the availability and quality of labels, poor in task transferability

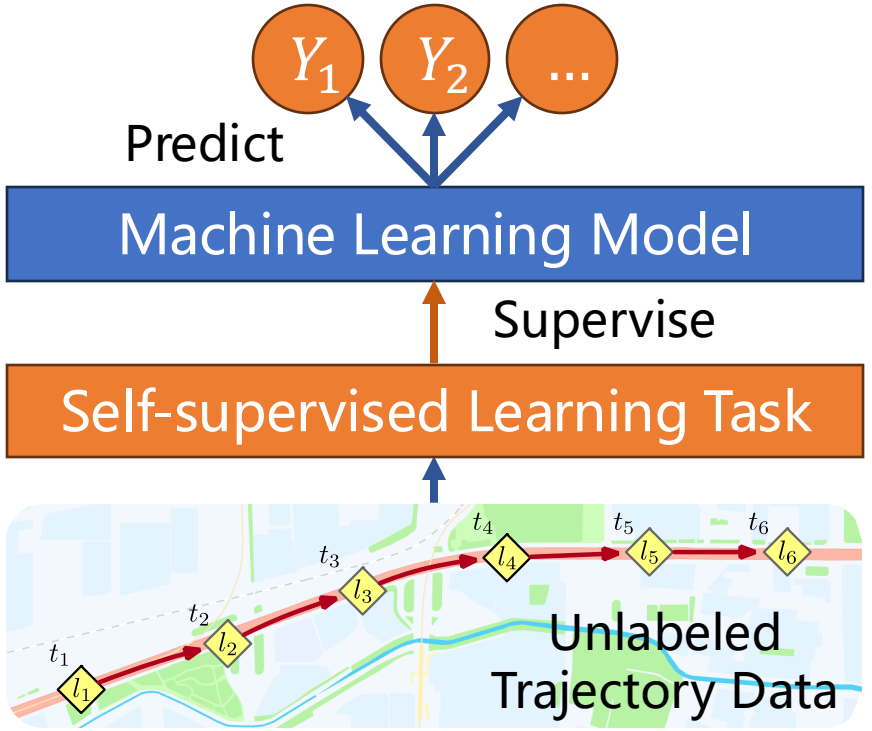




Self-supervised Learning (SSL)

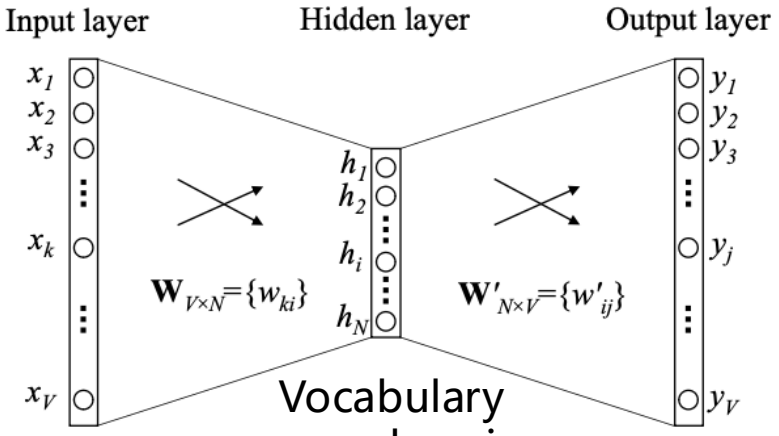
- Supervises ML methods by constructing supervision from unlabeled data
- Higher data availability, capable of performing a variety of tasks



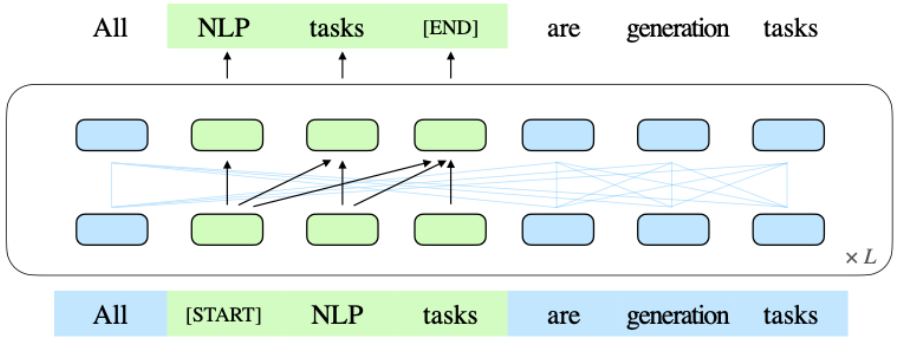


SSL in Popular Domains

- SSL has shown promising performance in domains like natural language processing (NLP) and computer vision (CV)



Vocabulary comprehension



Natural language comprehension

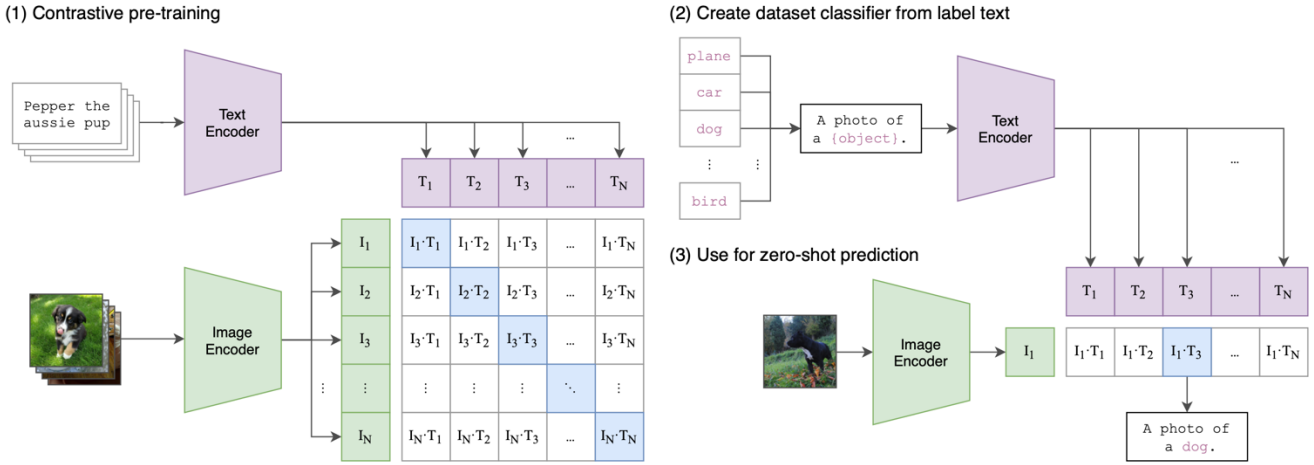


Image comprehension

SSL of Trajectory Data

What information to extract with SSL?

How to extract the information with SSL?

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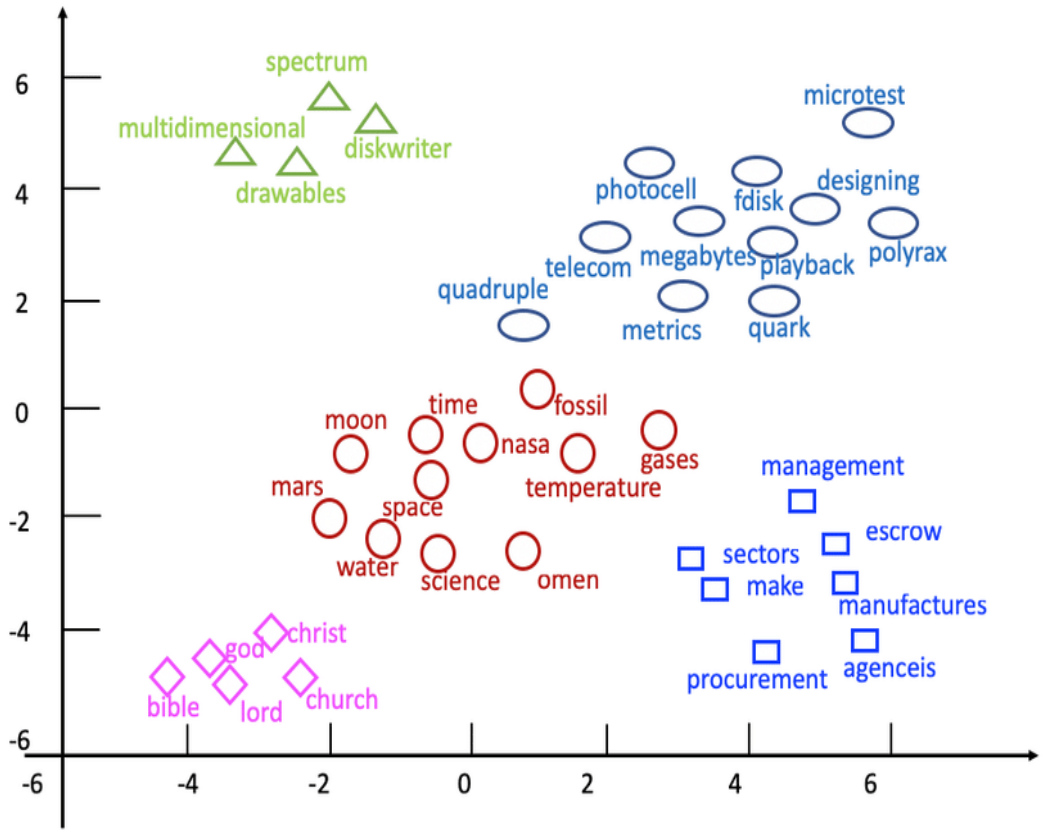
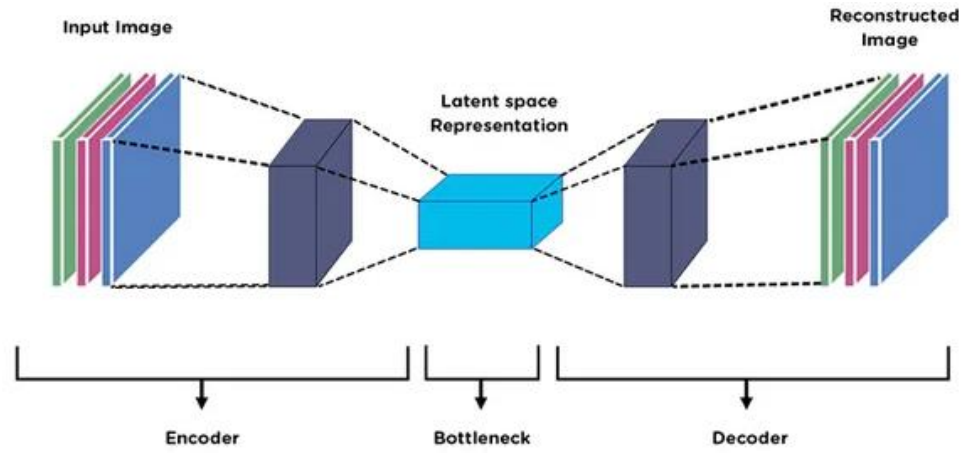
Future of Self-Supervised Learning on Trajectory Data

Popular SSL Frameworks

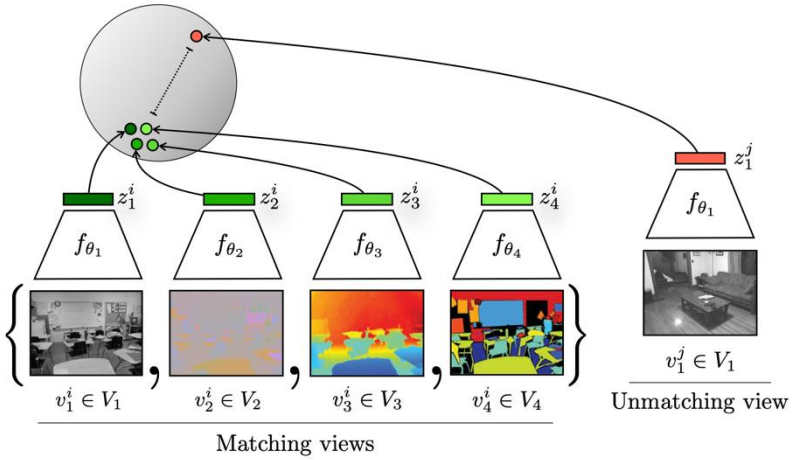
Word Embedding



Auto-encoding



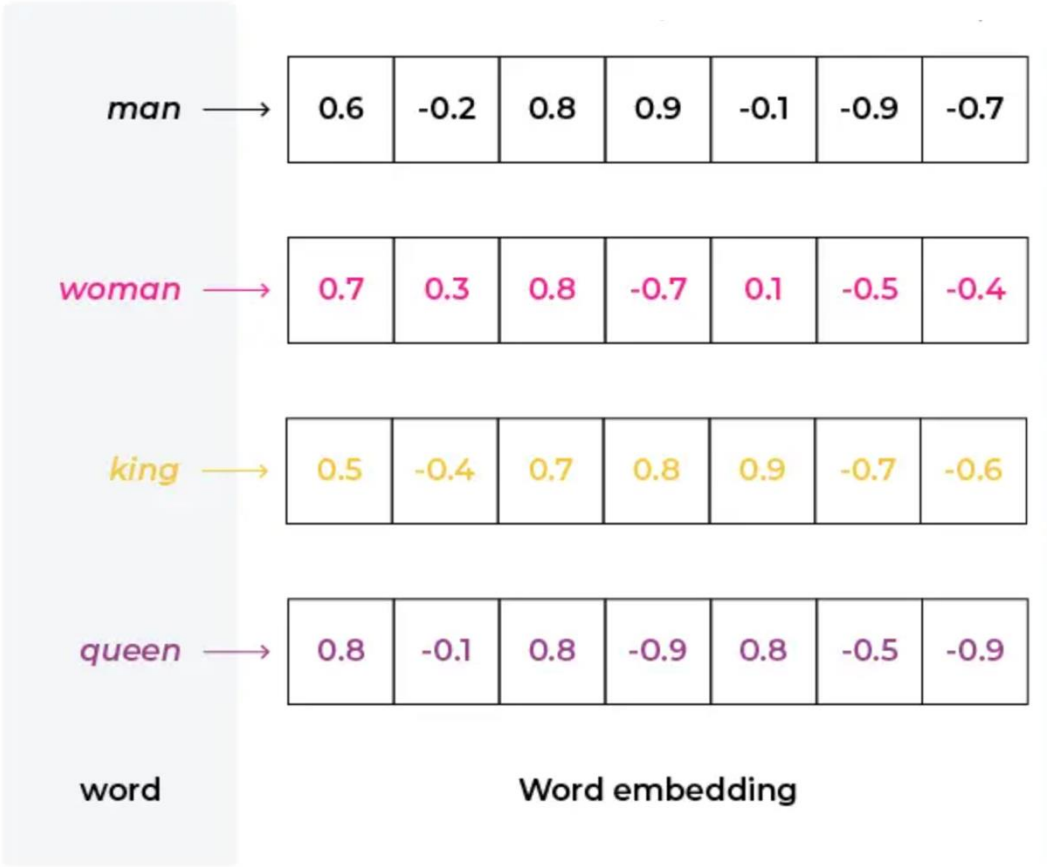
Contrastive Learning

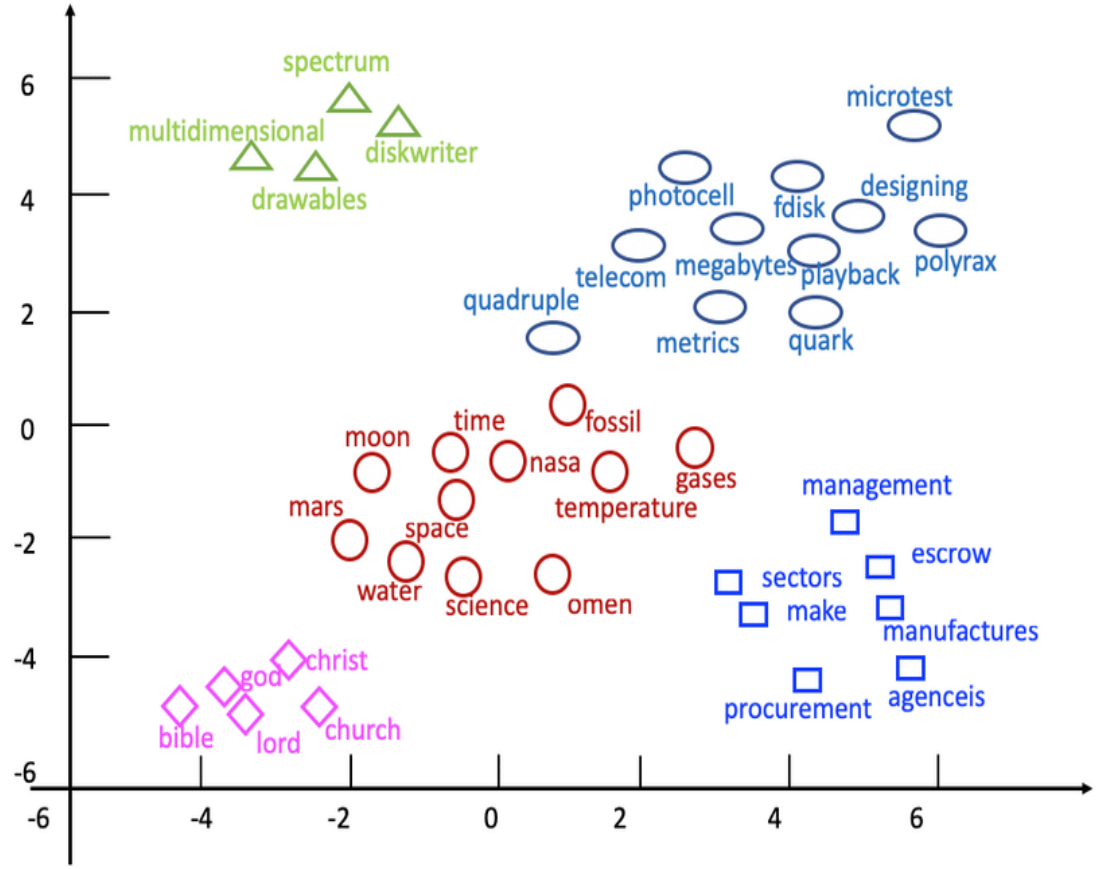


Word Embedding-Based Methods

➢Background: Word Embedding

- Maps words into fixed-dimensional embedding space, where the positions of words correspond to their semantic meanings

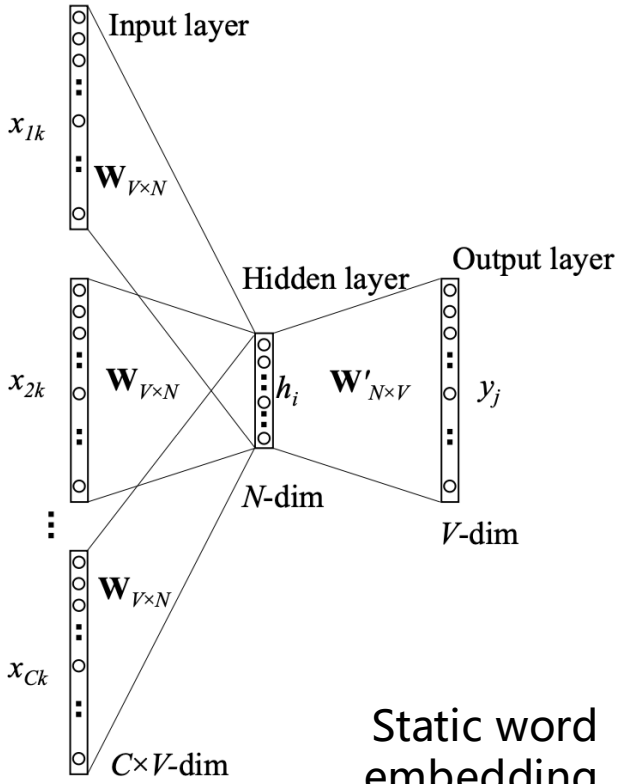




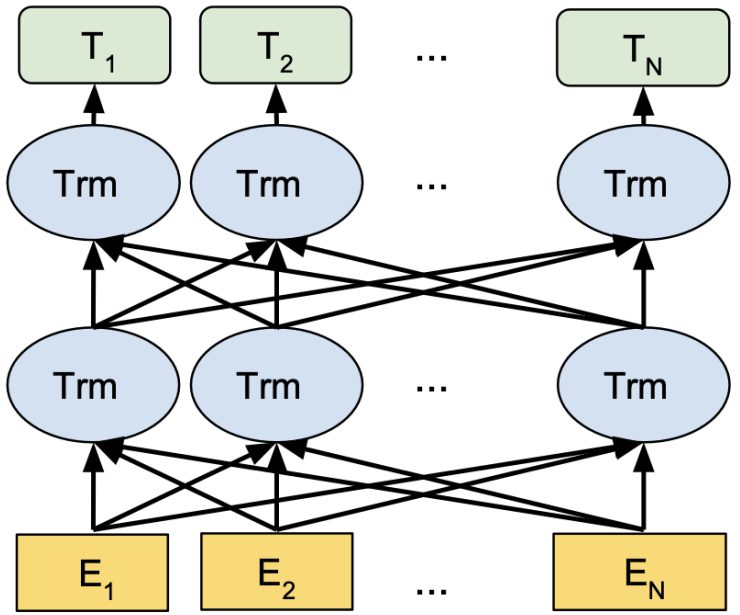
Word Embedding-Based Methods

➢Background: Word Embedding

- Static word embedding: Assigns one embedding vector to each word
- Contextual word embedding: Dynamically calculates embedding vectors based on words' contexts



Static word embedding



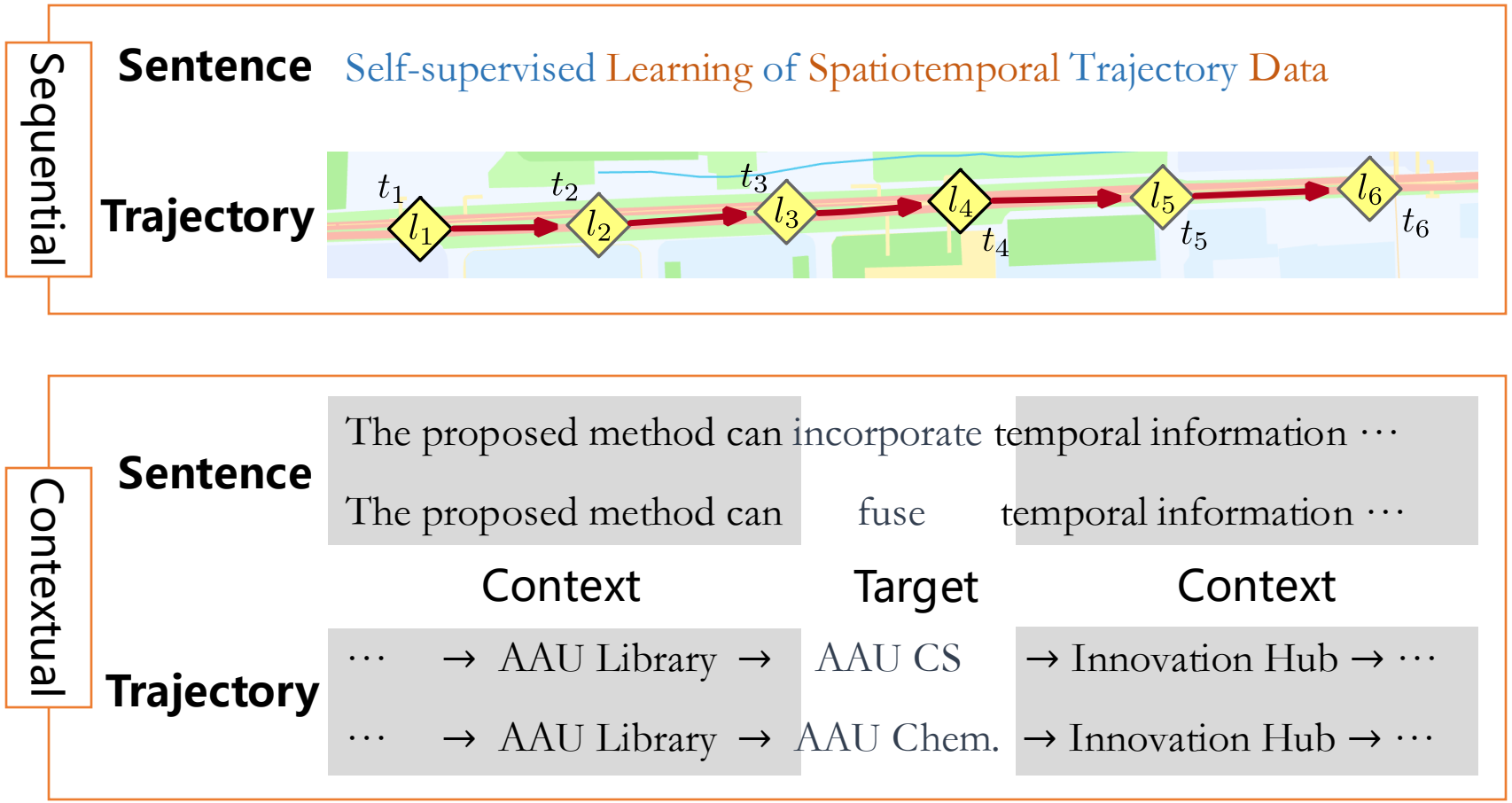
Contextual word embedding

- T. Mikolov, K. Chen, G. Corrado, and J. Dean, "Efficient Estimation of Word Representations in Vector Space." in ICLR 2013.
- J. Devlin, M.-W. Chang, K. Lee, and K. Toutanova, "BERT: Pre-training of Deep Bidirectional Transformers for Language Understanding." in NAACL-HLT 2019.

Word Embedding-Based Methods

➢Migration: Trajectories and Sentences

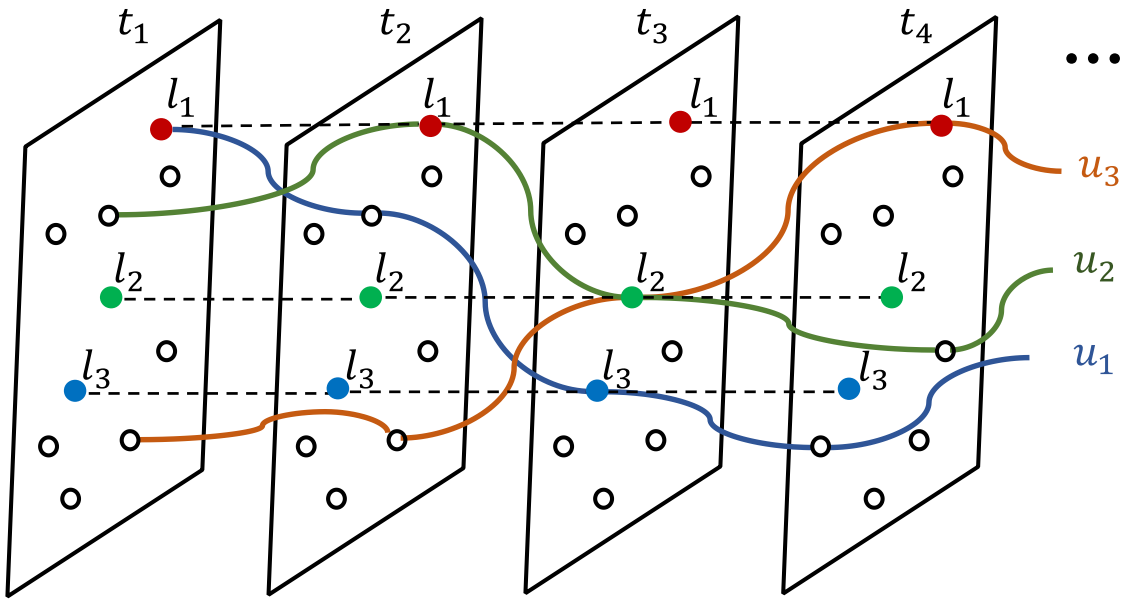
- Similarities: Both are sequences, both possess contextual correlations



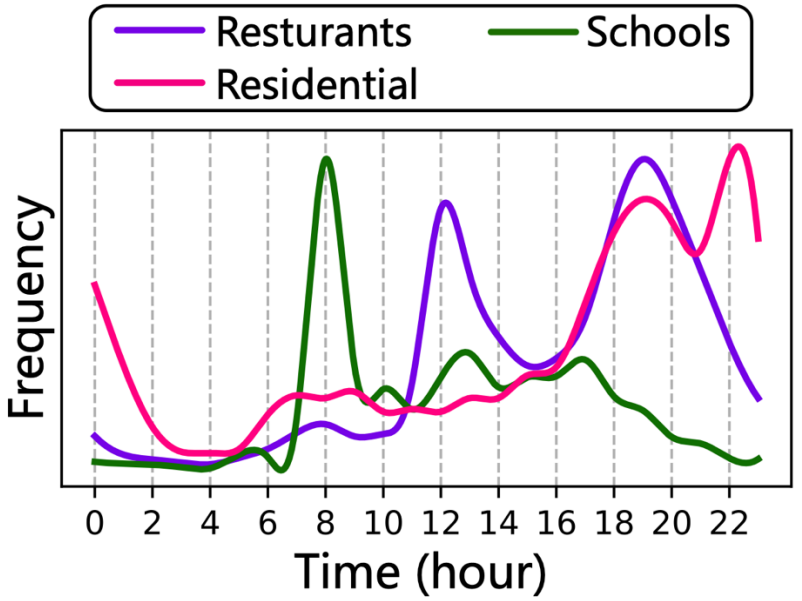
Word Embedding-Based Methods

➢Migration: Trajectories and Sentences

- Uniqueness: Trajectories contains spatiotemporal features and information



Temporal Features

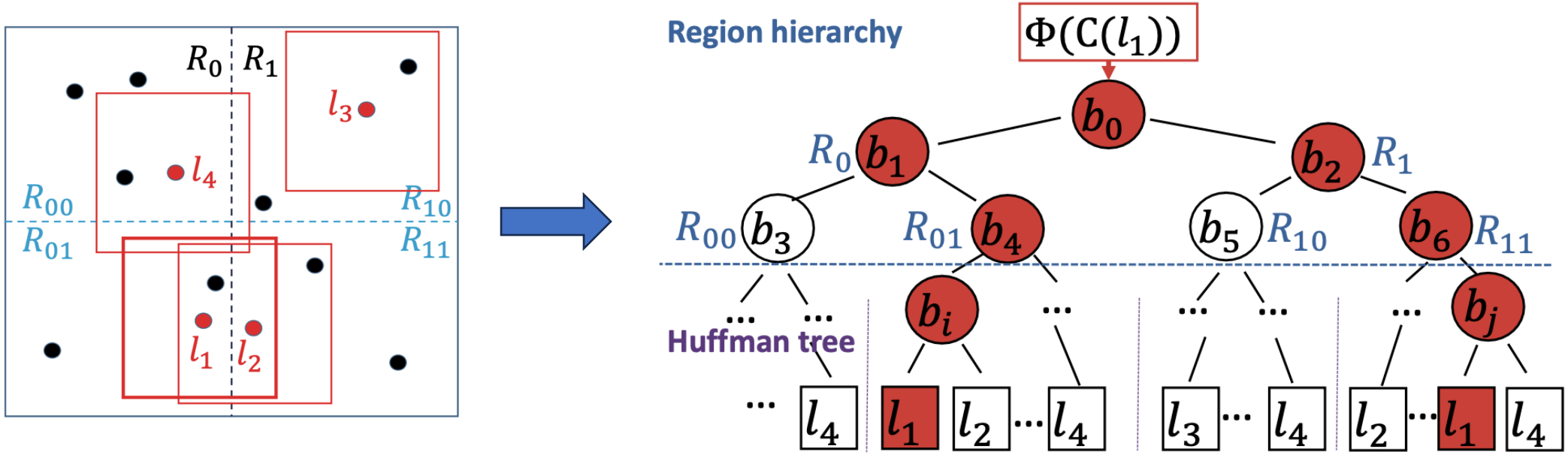


Temporal Information

Word Embedding-Based Methods

➢Example of existing methods: POI2Vec

- Splits the space using a hierarchical grid, capturing spatial correlations between locations



Hierarchical Grid

Huffman tree with spatial correlations

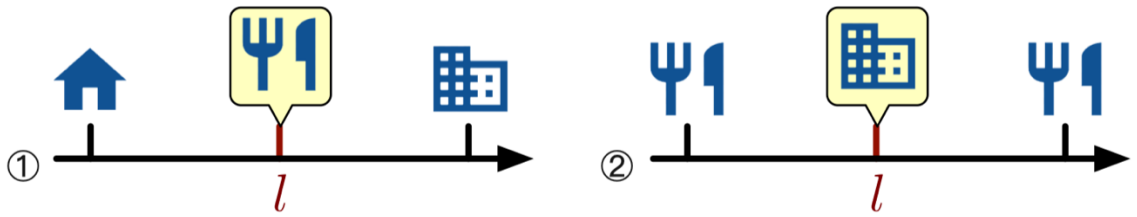
Feng S, Cong G, An B, et al. POI2Vec: Geographical latent representation for predicting future visitors[C]//Proceedings of the AAAI Conference on Artificial Intelligence. 2017, 31(1).

Word Embedding-Based Methods

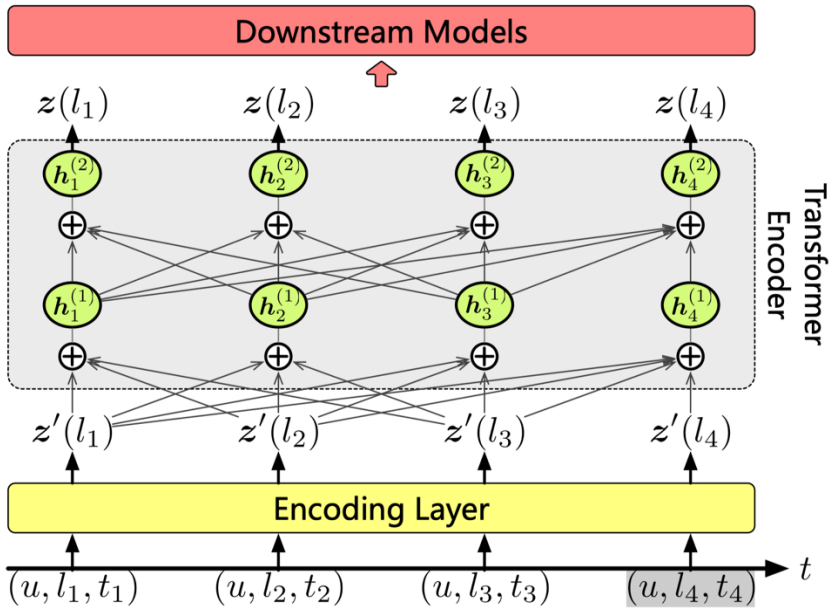
➢Example of existing methods: CTLE

- Dynamically calculates embedding vectors for locations based on the specific contexts (trajectories) they are in

$$\boldsymbol{z}_l = f(l, C(l))$$



Basic idea of CTLE



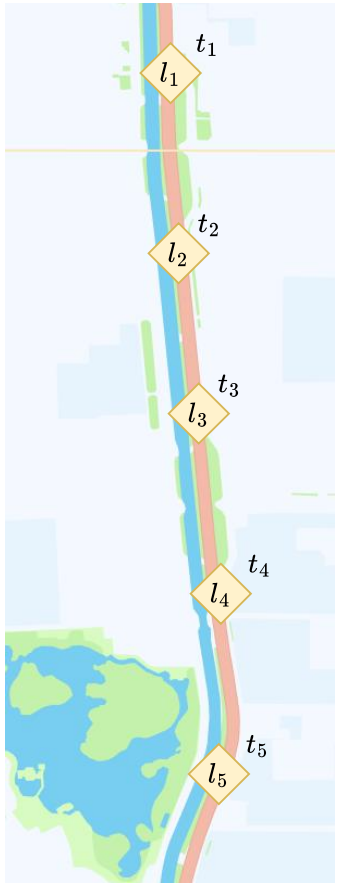
Embedding vector calculation

Yan Lin, Huaiyu Wan, et al. Pre-training Context and Time Aware Location Embeddings from Spatial-Temporal Trajectories for User Next Location Prediction. *The 35th AAAI Conference on Artificial Intelligence* (AAAI), 2021, 35(5), 4241-4248.

Word Embedding-Based Methods

➢Conclusion

- Migrating word embedding techniques to self-supervised learning of trajectory data



Trajectory Data

Word Embedding

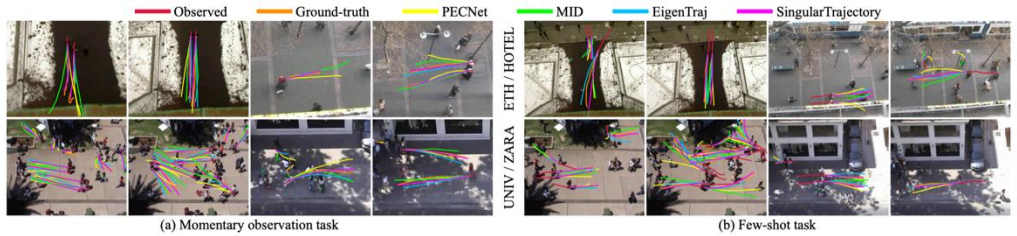
Incorporate spatiotemporal information

Trajectory Representations

Aggregate

Location Representations

Trajectory Analysis

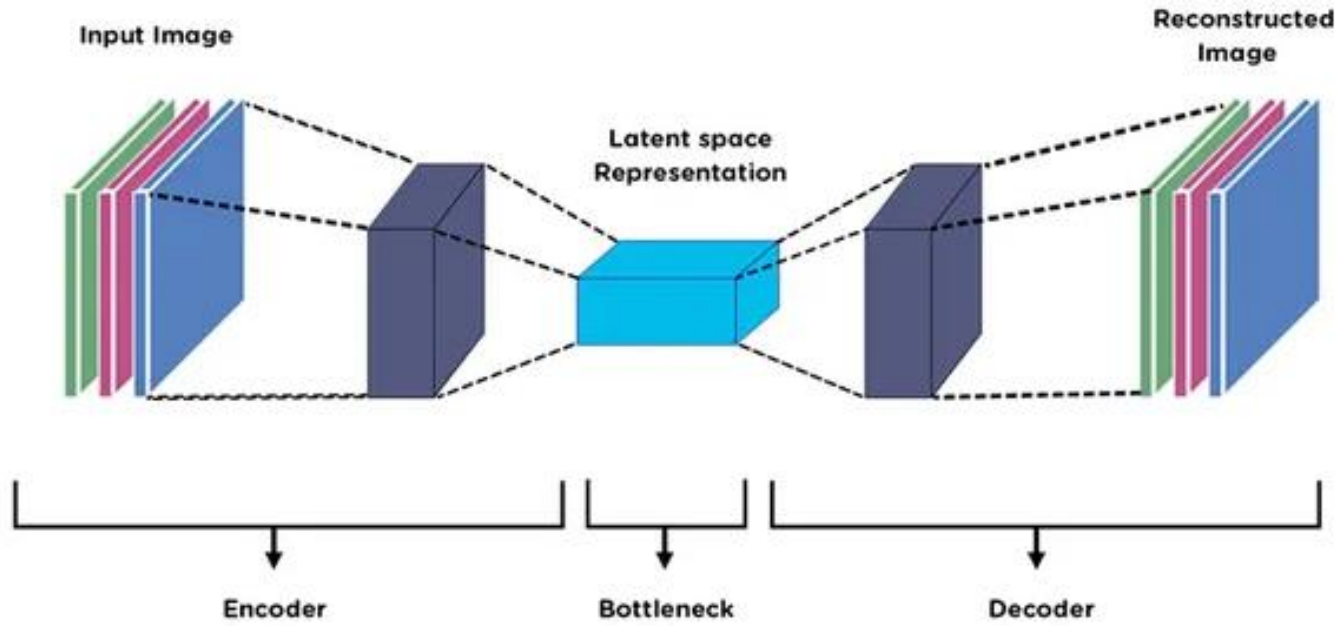


Location Analysis

Auto-Encoding-Based Methods

➢Background: Auto-Encoding (AE)

- A pair of encoder and decoder: the encoder compresses raw features into embedding vectors, and the decoder reconstructs raw features from the embedding vectors.
- Compresses essential information contained in raw features into the embedding vectors

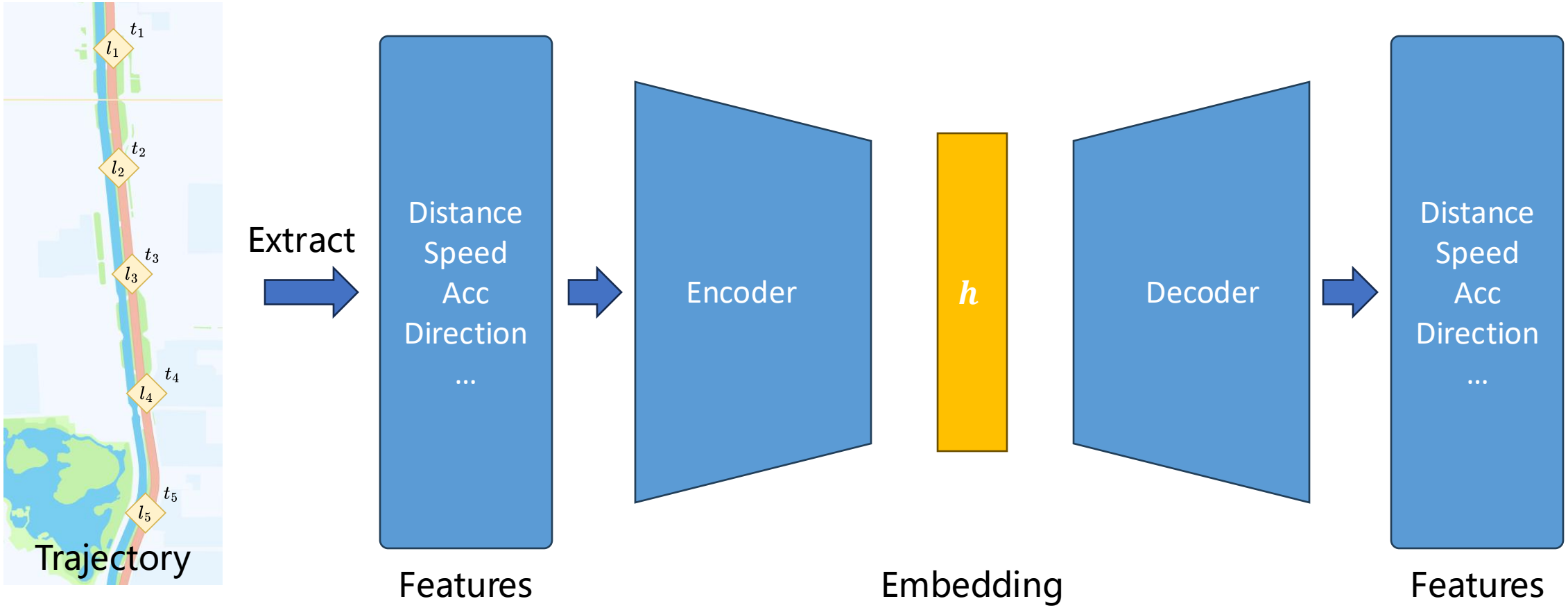


Hinton G E, Salakhutdinov R R. Reducing the dimensionality of data with neural networks[J]. science, 2006, 313(5786): 504-507.

Auto-Encoding-Based Methods

➢Adaptation: Features are the key

- Compressed information in the embedding vectors largely depends on the input features
- The key is the features of trajectory data provided to the AE framework

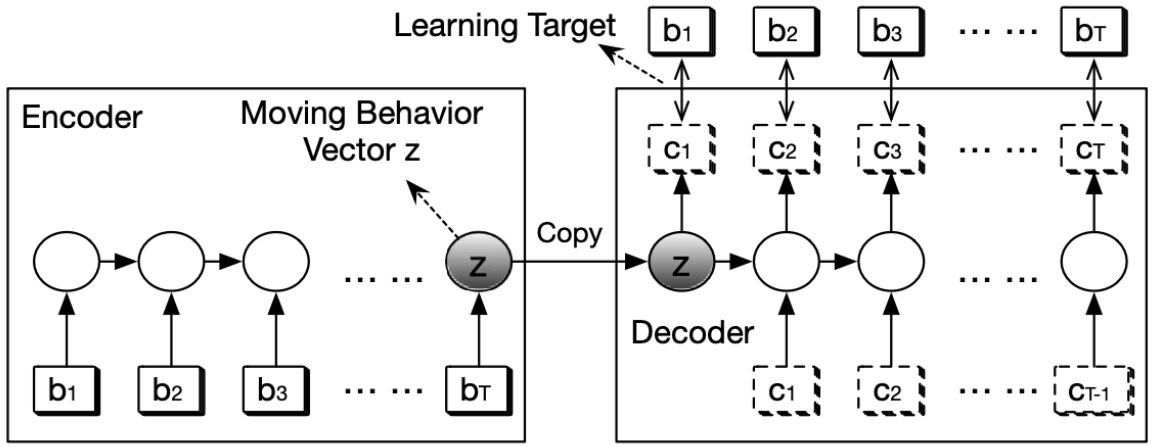


Auto-Encoding-Based Methods

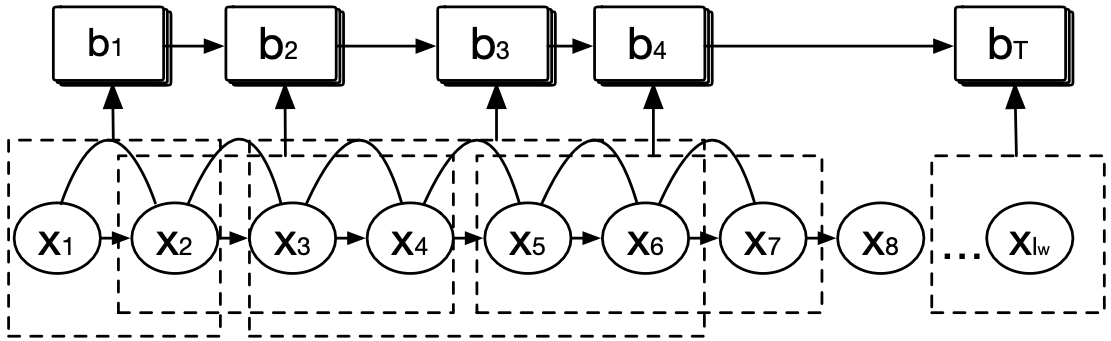
➢Example of existing methods: Traj2Vec

- Uses a sliding-window to prepare high-order features like movement distance, acceleration, and heading directions

Auto-encoder based on RNN



Feature extraction based on sliding-window

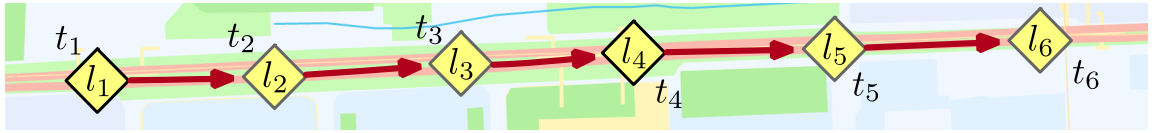


Yao D, Zhang C, Zhu Z, et al. Trajectory clustering via deep representation learning[C]//2017 international joint conference on neural networks (IJCNN). IEEE, 2017: 3880-3887.

Auto-Encoding-Based Methods

➢Conclusion

- Adapting the auto-encoding framework for self-supervised learning of trajectory data



Extract

Trajectory Features

Encoder

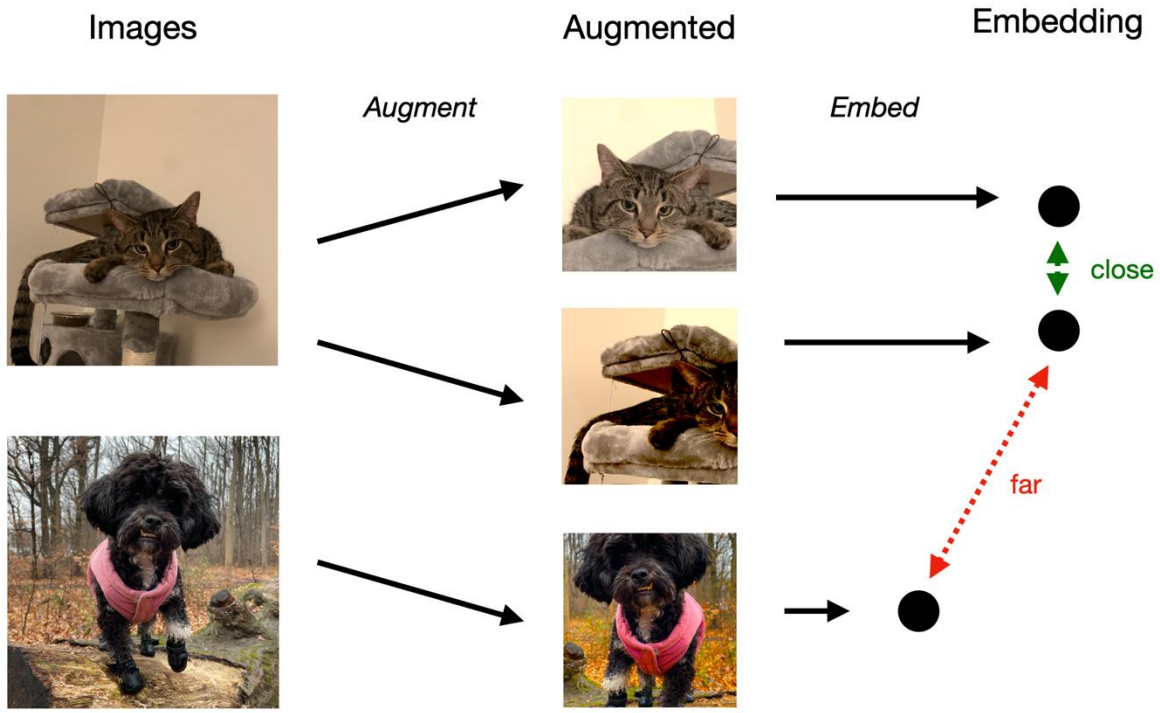
Trajectory Representations

Decoder

Contrastive Learning-Based Methods

➢Background: Contrastive Learning (CL)

- Creates multiple views of the data, with views of same item having similar embeddings and views of different items having dissimilar embeddings
- Extracts high-level semantic meanings that are independent of views

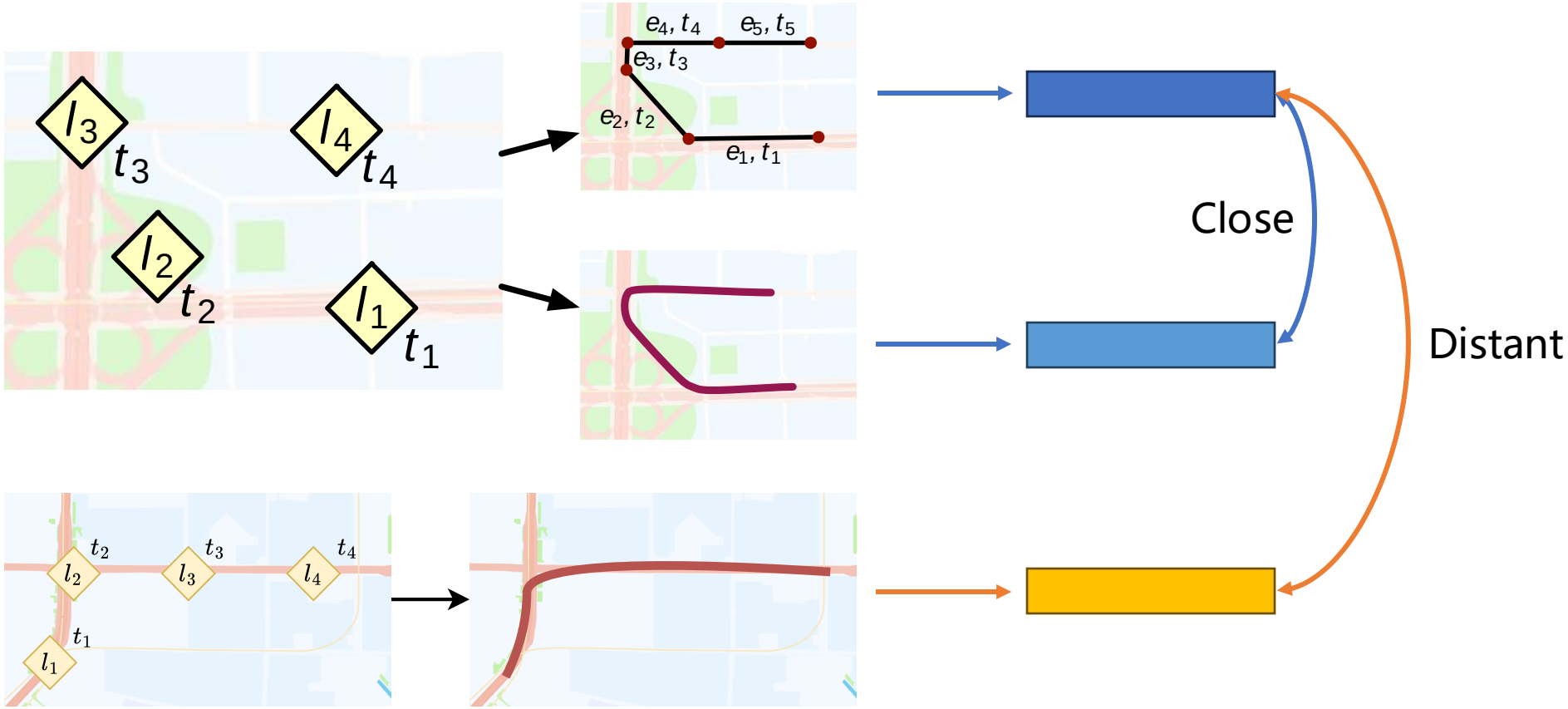


Chen T, Kornblith S, Norouzi M, et al. A simple framework for contrastive learning of visual representations[C]//International conference on machine learning. PMLR, 2020: 1597-1607.

Contrastive Learning-Based Methods

➢Adaptation: Trajectory View Construction

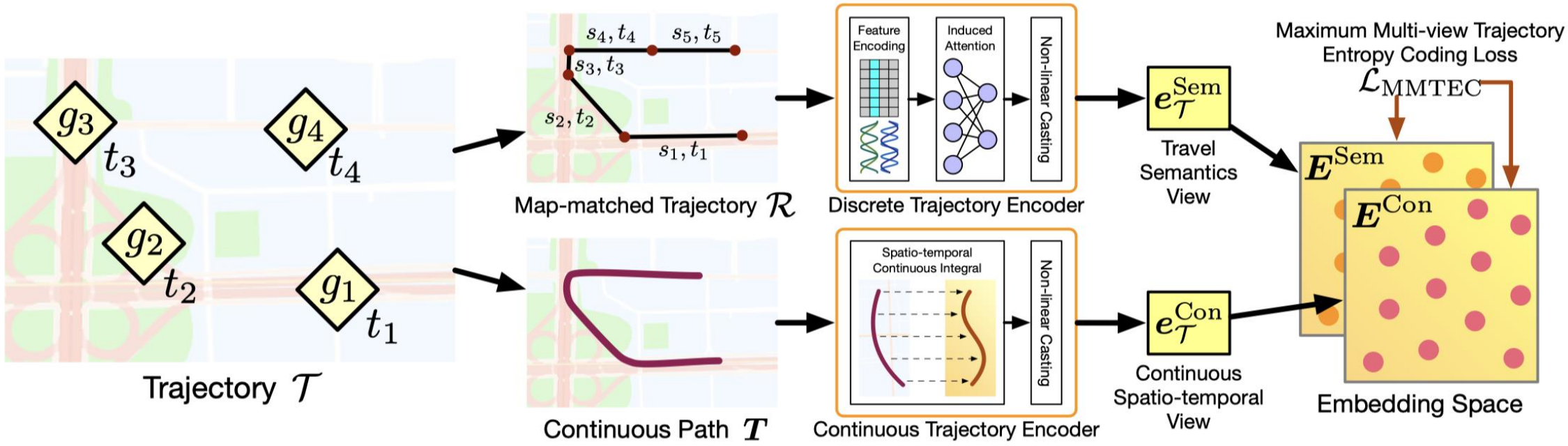
- The key is how to construct multiple views of trajectory data



Contrastive Learning-Based Methods

➢Example of existing methods: MMTEC

- Creates two views for each trajectory
  - map-matching the trajectory as a discrete view
  - using spline interpolation to create a continuous view

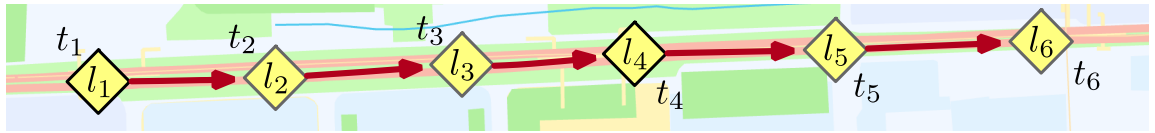


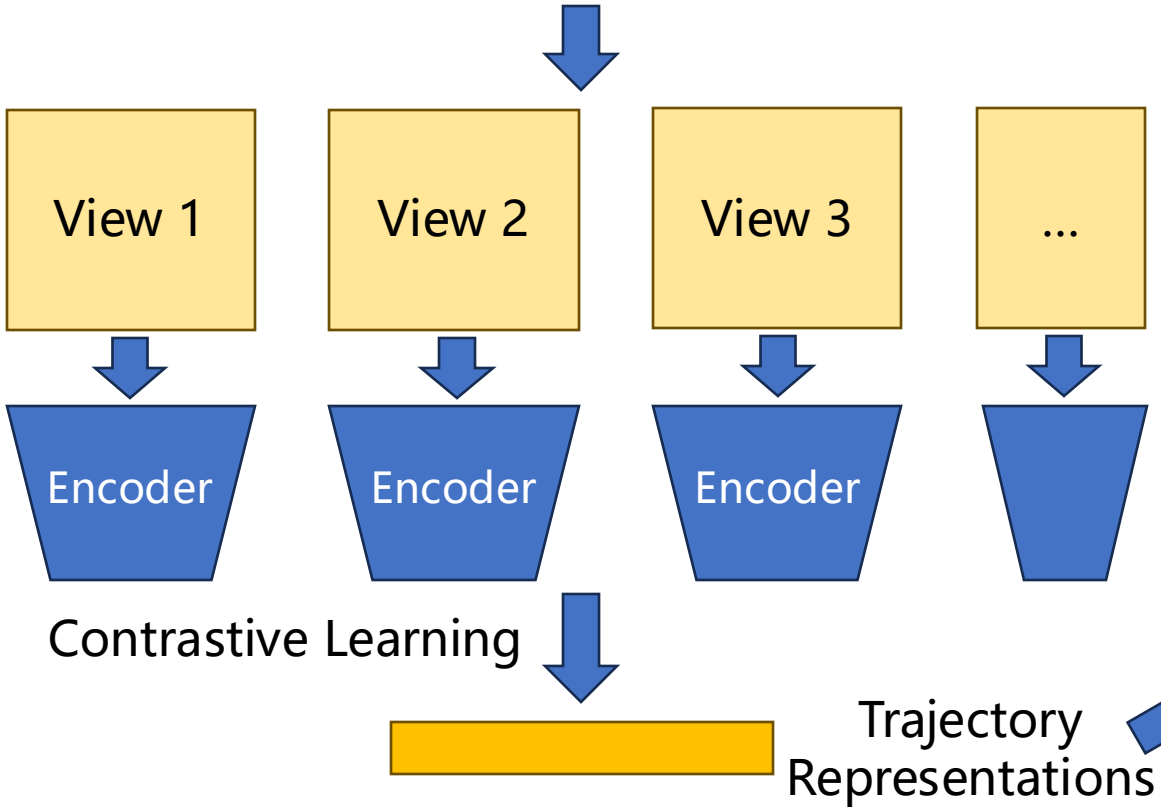
Yan Lin, Huaiyu Wan, et al. Pre-training General Trajectory Embeddings with Maximum Multi-view Entropy Coding. *IEEE Transactions on Knowledge and Data Engineering* (TKDE), 2024.

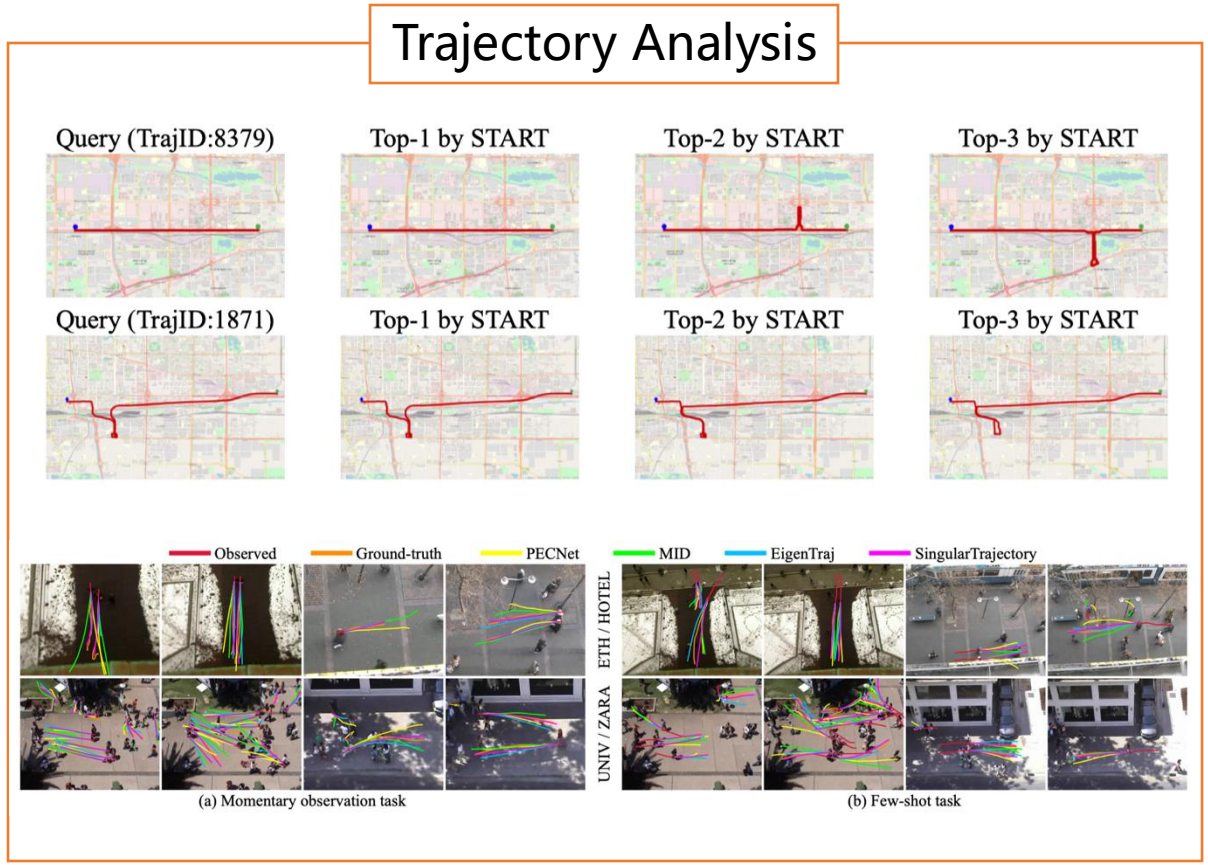
Contrastive Learning-Based Methods

➢Conclusion

- Adapting the contrastive learning framework for self-supervised learning of trajectory data







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Future of Self-Supervised Learning on Trajectory Data

SSL in NLP and CV

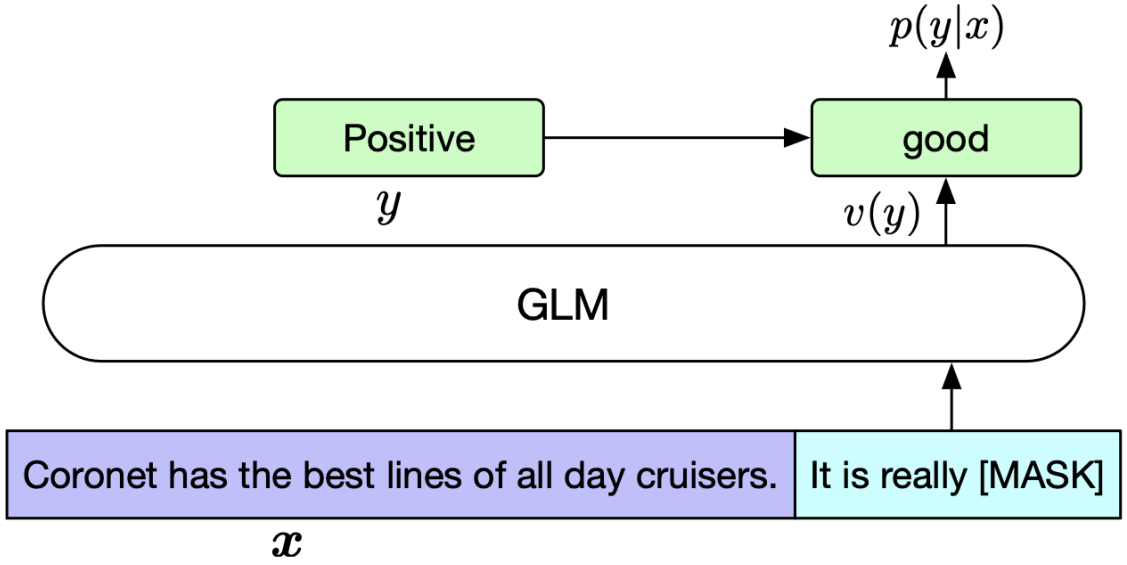
➢Amazing data and task transferability

- Large-scale dataset
- Inherent shared semantic information across domains
- Most tasks can be described with natural language prompts

Natural language processing (NLP) is an interdisciplinary subfield of computer science and information retrieval. It is primarily concerned with giving computers the ability to support and manipulate human language. ...

Natural language processing (NLP) is the ability of a computer program to understand human language as it's spoken and written -- referred to as natural language. It's a component of artificial intelligence (AI).

Shared semantic information

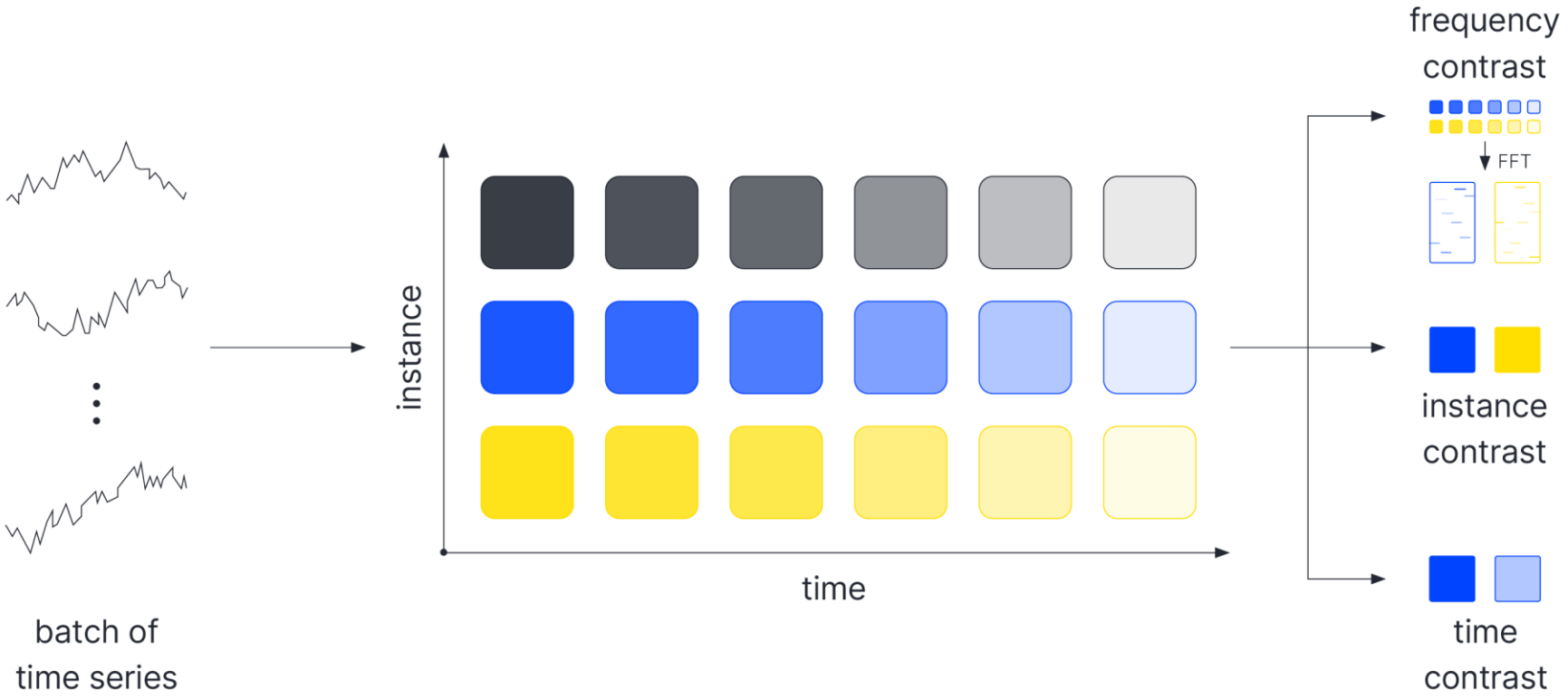


Natural language prompts

SSL of Time Series Data

➢Good data and task transferability

- Inherent shared semantic information across domains
- Most tasks can be formulated as generation of time series

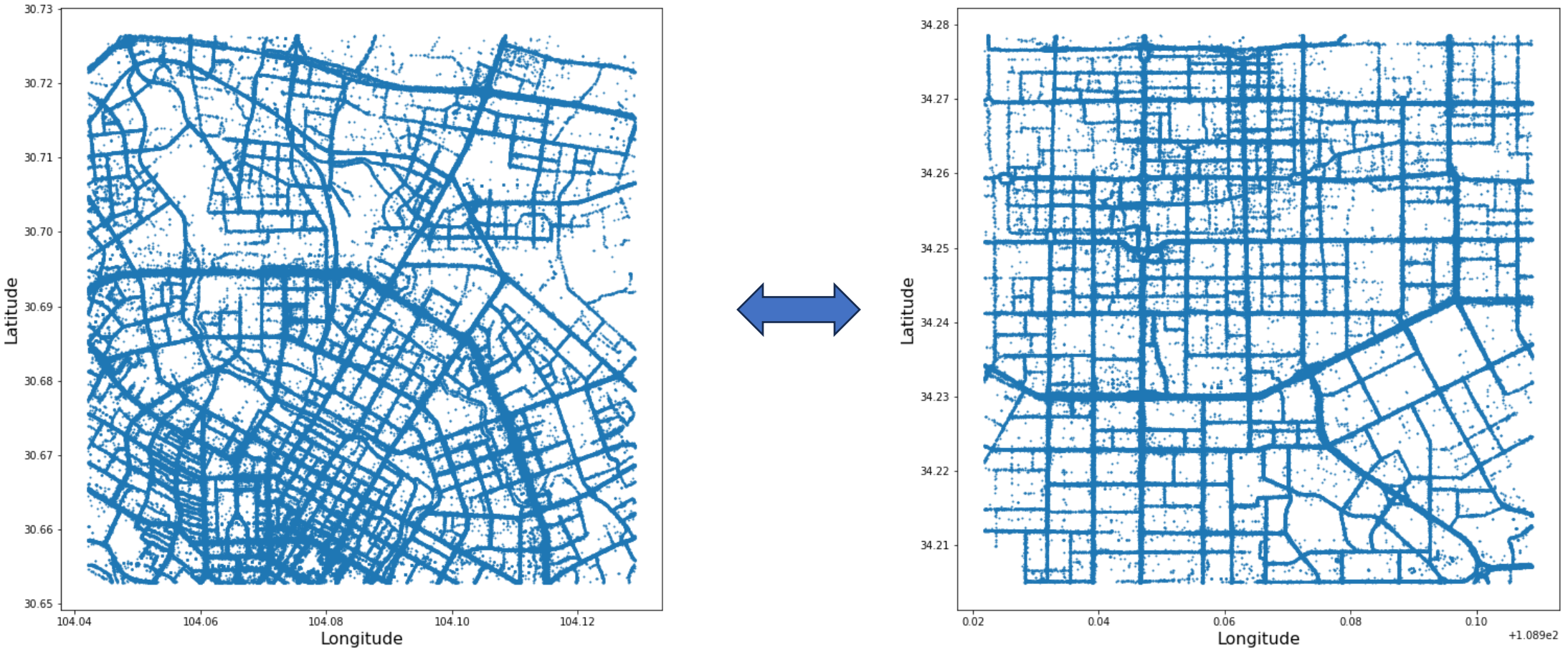


Contrastive learning of time series

SSL of Trajectory Data

➢Poor data transferability

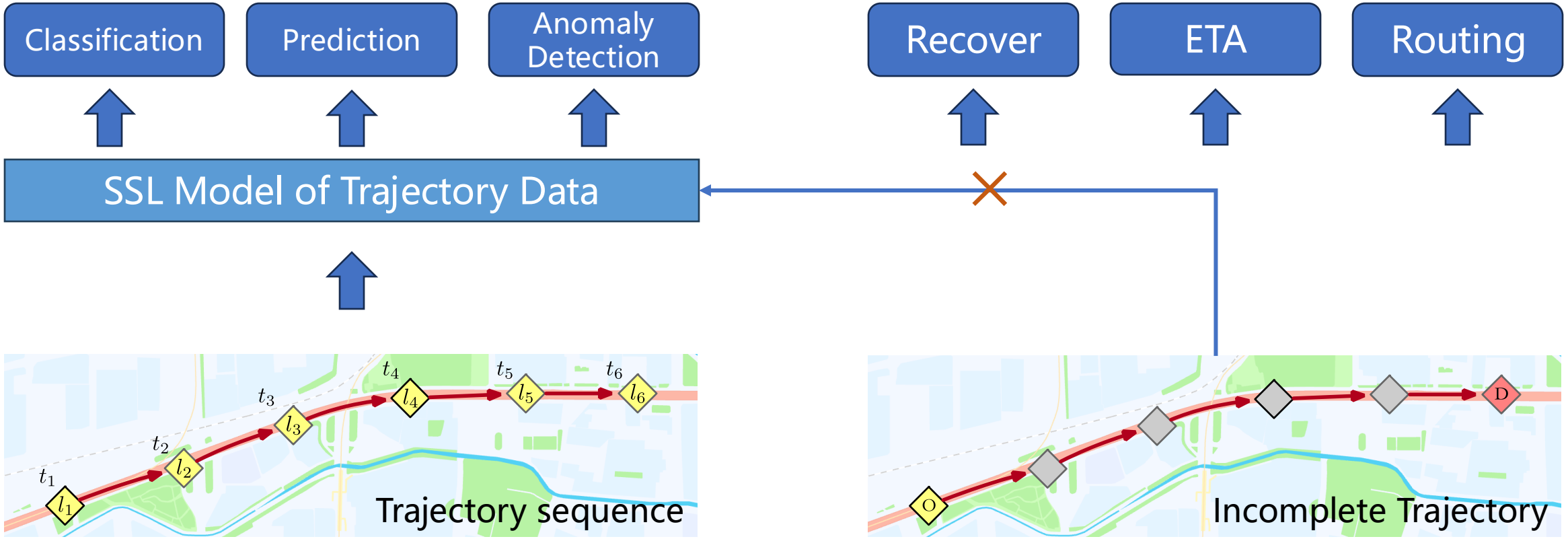
- How to learn the knowledge (transferable) rather than the features (non-transferable)?



SSL of Trajectory Data

➢Flawed task transferability

- How to generalize the input/output schema across different tasks?



Thank You!