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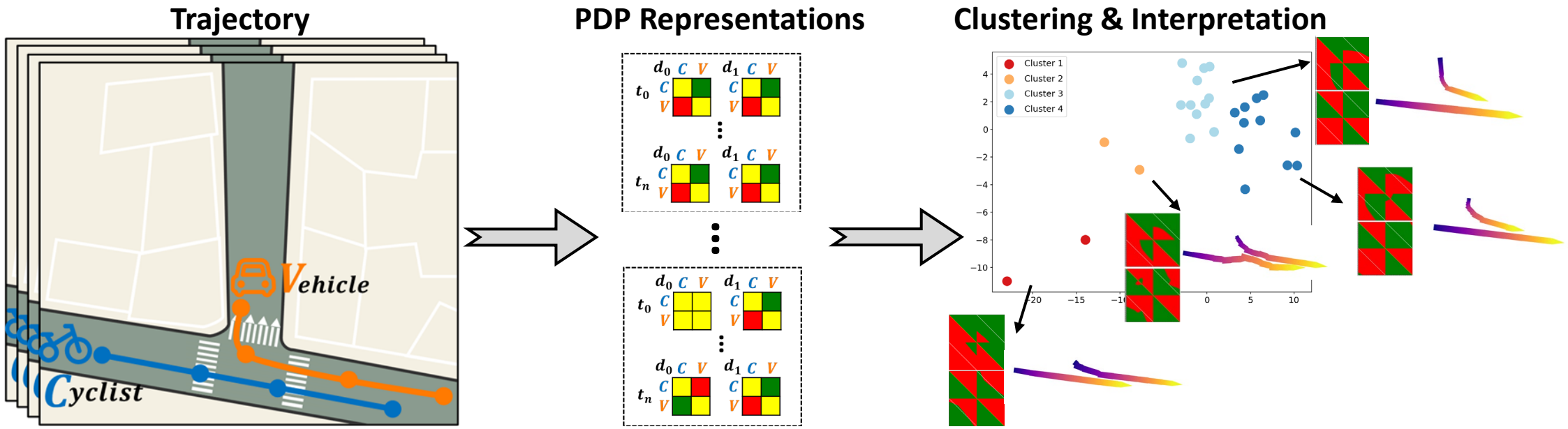
Department of Geography
GIS&T Research Group

GeoAI 2026



A Computational Framework for Clustering Vehicle-Cyclist Interactions in Urban Environments Using Qualitative Spatial Representations

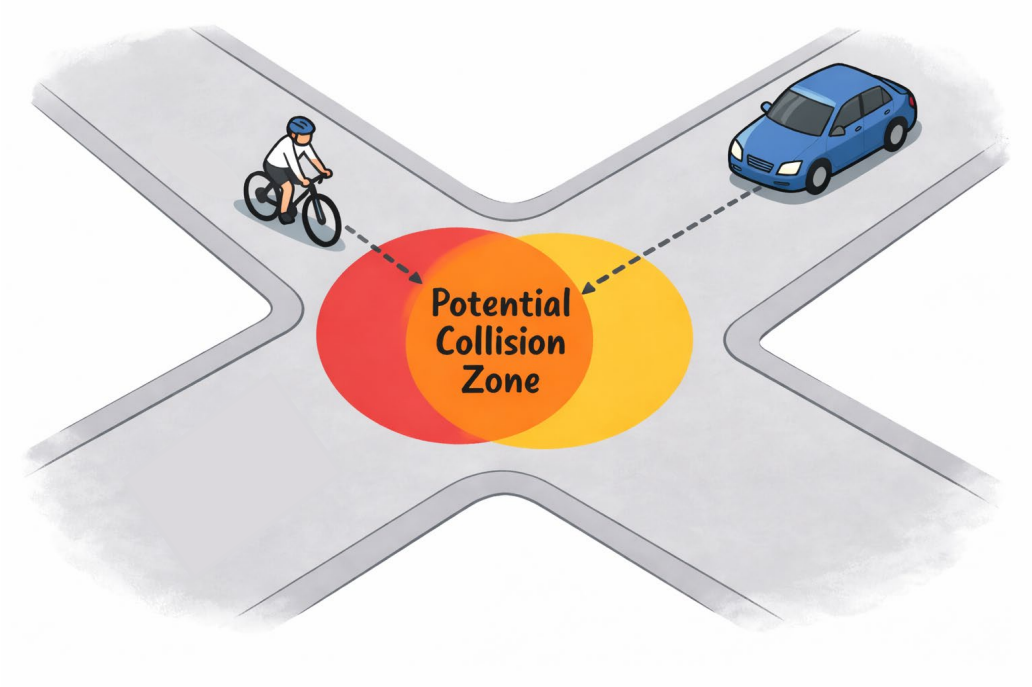
Reporter: Changbo Zhang (CB)

Co-authors: Lars De Sloover, Jana Verdoodt, Olivier Vermeulen, Bart Van Bossuyt, Samuel Van Ackere

Promoter: Prof. Nico Van de Weghe, Prof. Haosheng Huang

1 Background

Traffic Interaction: A situation where at **least two road users** can be influenced by the possibility that they are both **intending to occupy the same region** of space **at the same time** in the near future.



Implications for:

- Traffic efficiency
- Traffic safety
- AV design
- Street design and broader urban planning…

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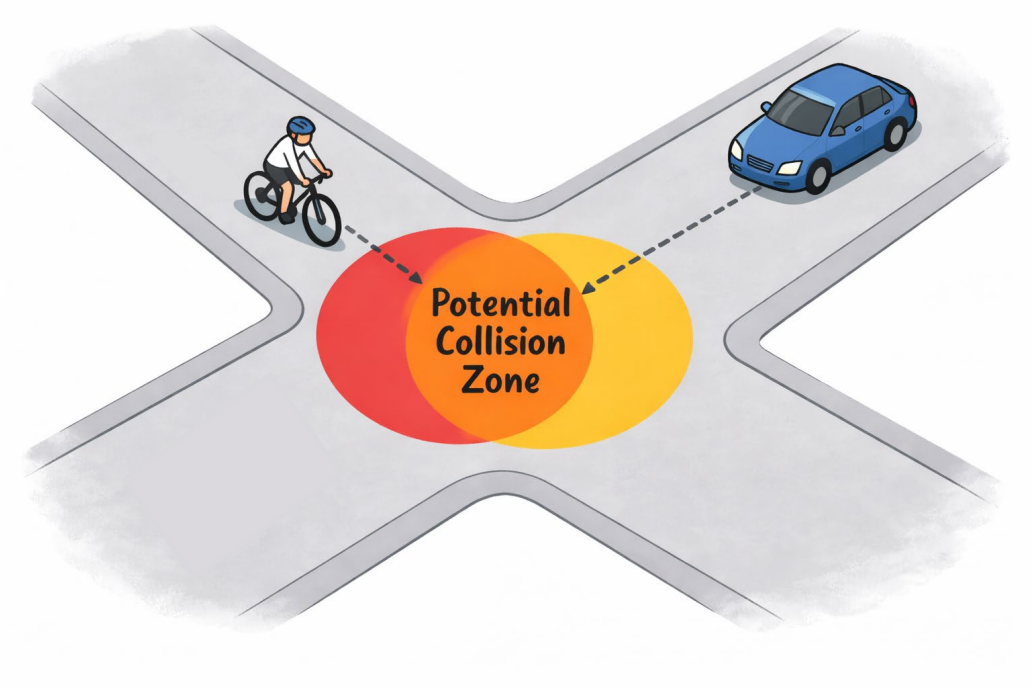
1 Background

Traffic Interaction: A situation where at **least two road users** can be influenced by the possibility that they are both **intending to occupy the same region** of space **at the same time** in the near future.



Restore

Cluster

- Pattern 1 (e.g. Vehicle yield)
- Pattern 2 (e.g. Cyclist yield)
- Pattern 3, 4, 5…

Further application
(Behavior prediction, Risk estimation…)

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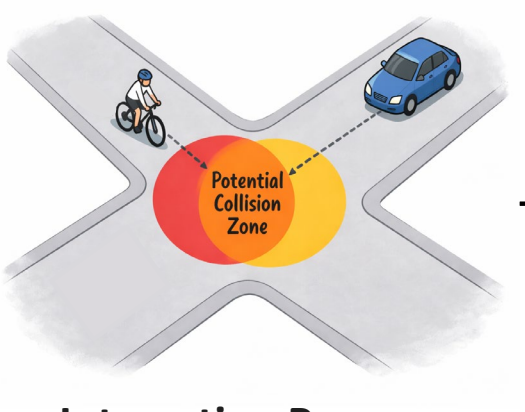
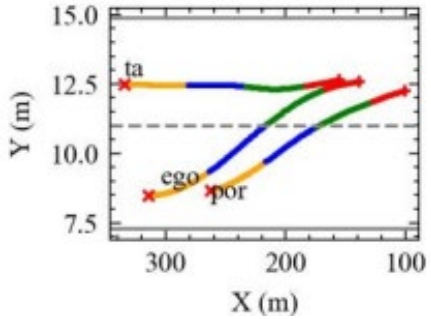
1 Background



Interaction Process

Decompose

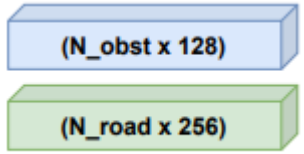
Statistical Methods



Primitives

Deep Learning Methods

Encode



Embeddings

Clustering

Research gaps:

- **Complex data input**
  - What if we only have xyt data?
- **Lack of interpretability**
  - Primitives are just interaction segments
  - Embeddings easily lead to ‘black box’

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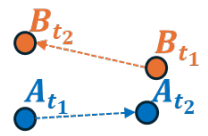
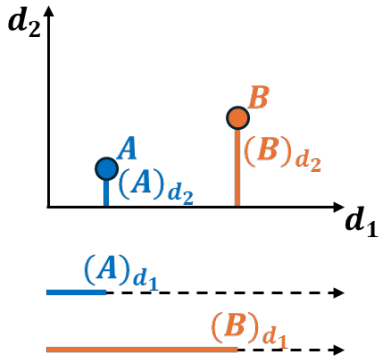
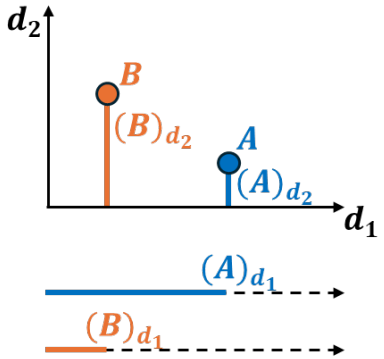
2 PDP Representation

PDP: A **qualitative method** to describe the temporal-spatial relationships of ***n* moving objects** based on their **precedence** in an ***m*-D space**

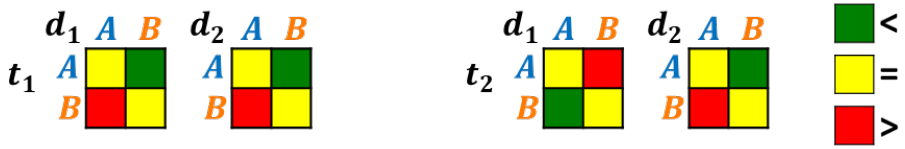
	Timestamp	
	t_1	t_2
POINT		
DESCRIPTOR		
PRECEDENCE	$t_1 \begin{cases} d_1 : A < B \\ d_2 : A < B \end{cases}$	$t_2 \begin{cases} d_1 : B < A \\ d_2 : A < B \end{cases}$

represent objects into points at given timestamps

identifies point's position along one or more dimensions

how points are ordered along these descriptors by using relation symbol (<,>,=)

PDP Inequality Matrix

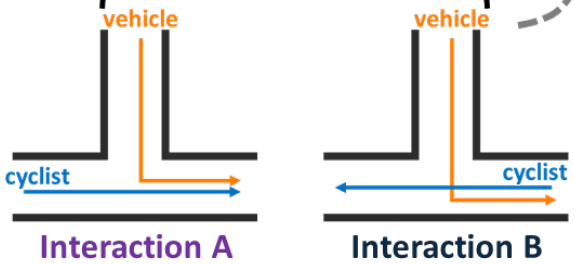


3 Experiment

Data Preparation

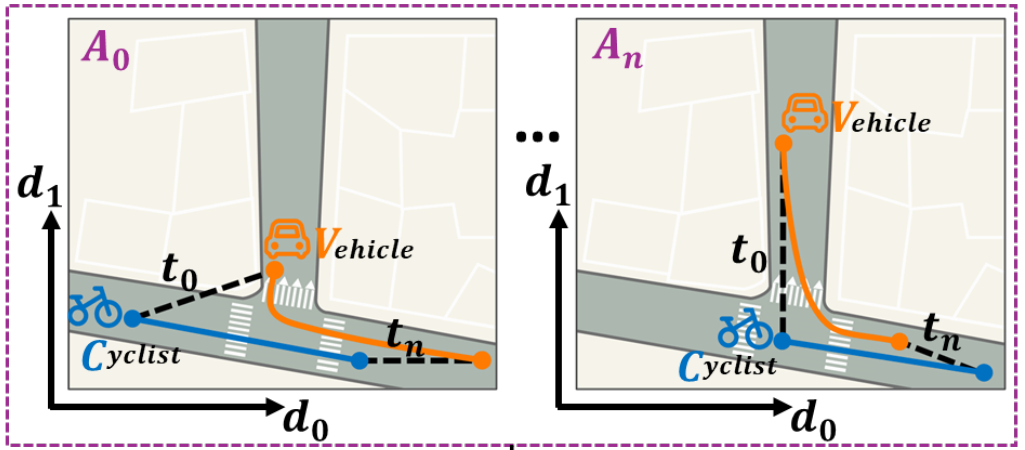
Trajectory data

Interaction extraction



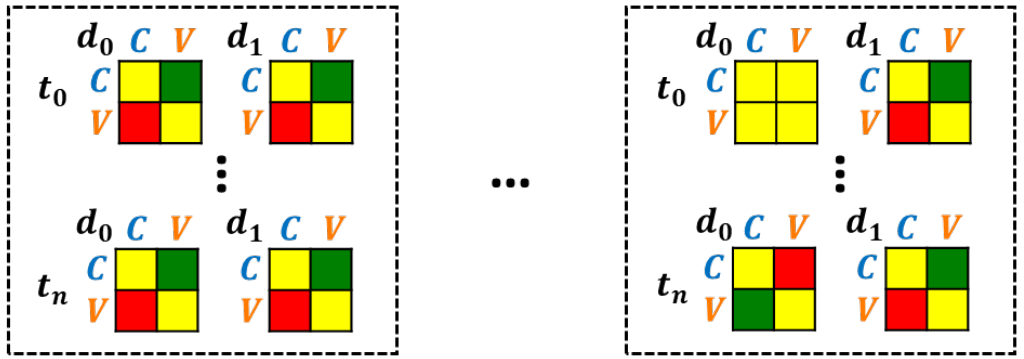
PDP Representation

Configurations of Interaction A



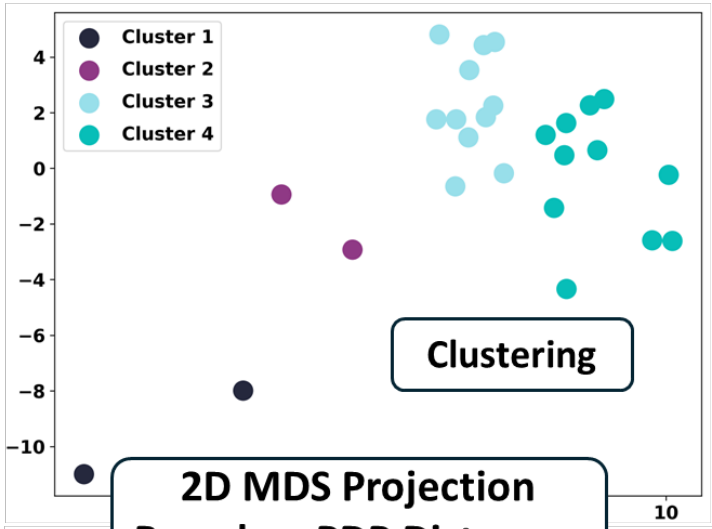
PDP representation of A_0

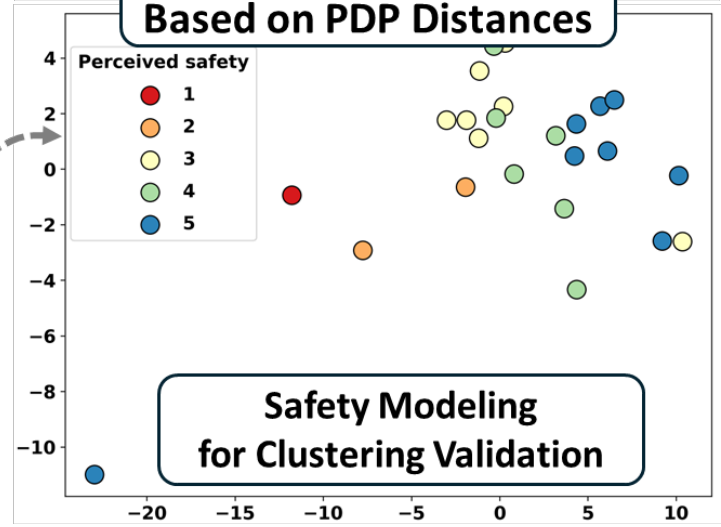
PDP representation of A_n



Calculate PDP conceptual distance

Clustering and Validation

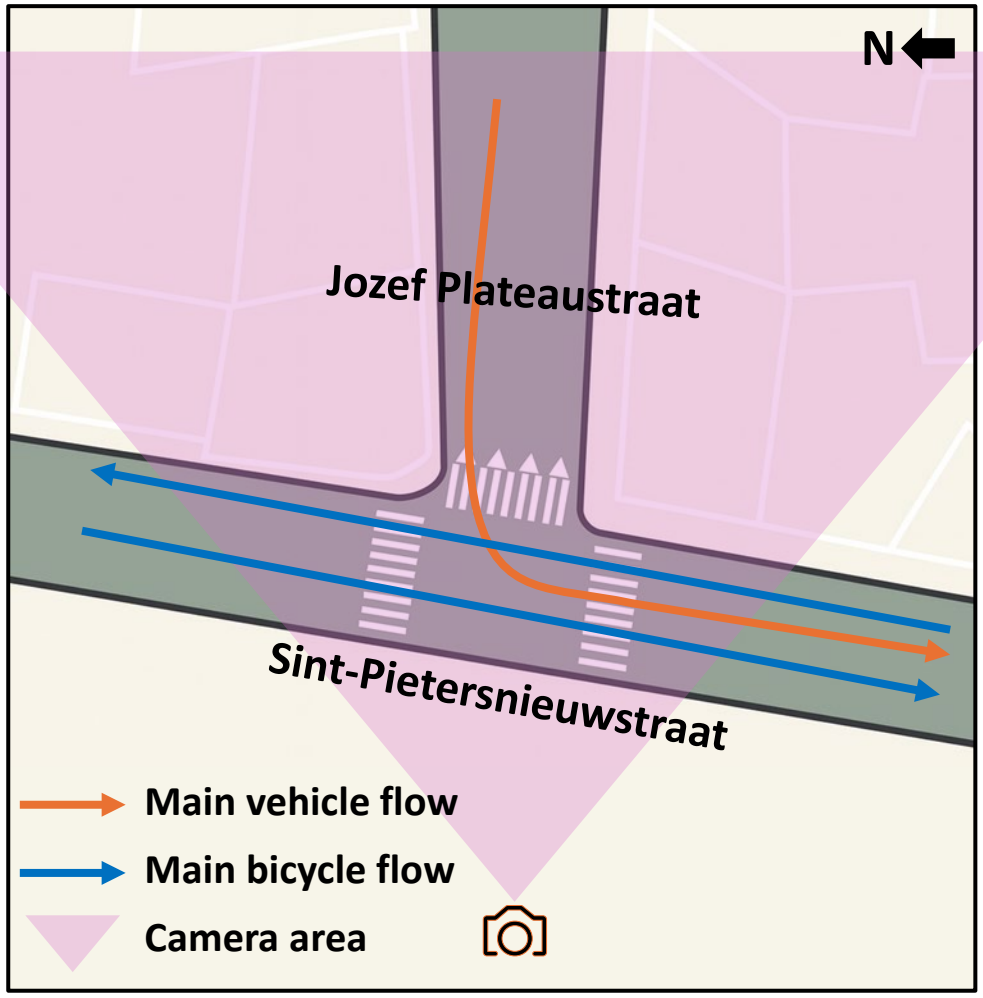




3 Experiment

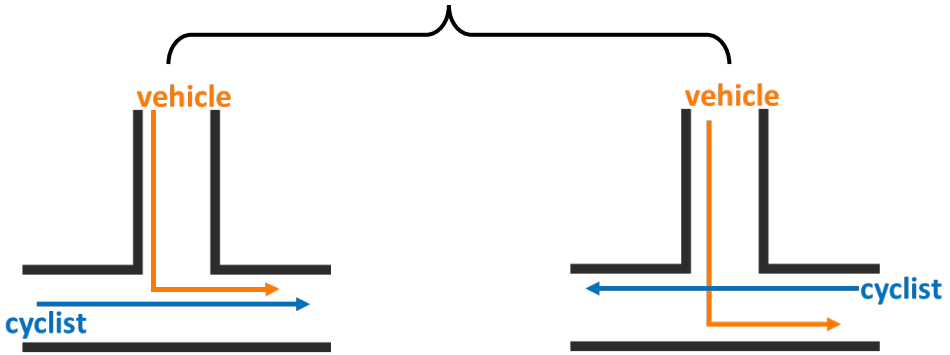
Data Collection

Overview scene



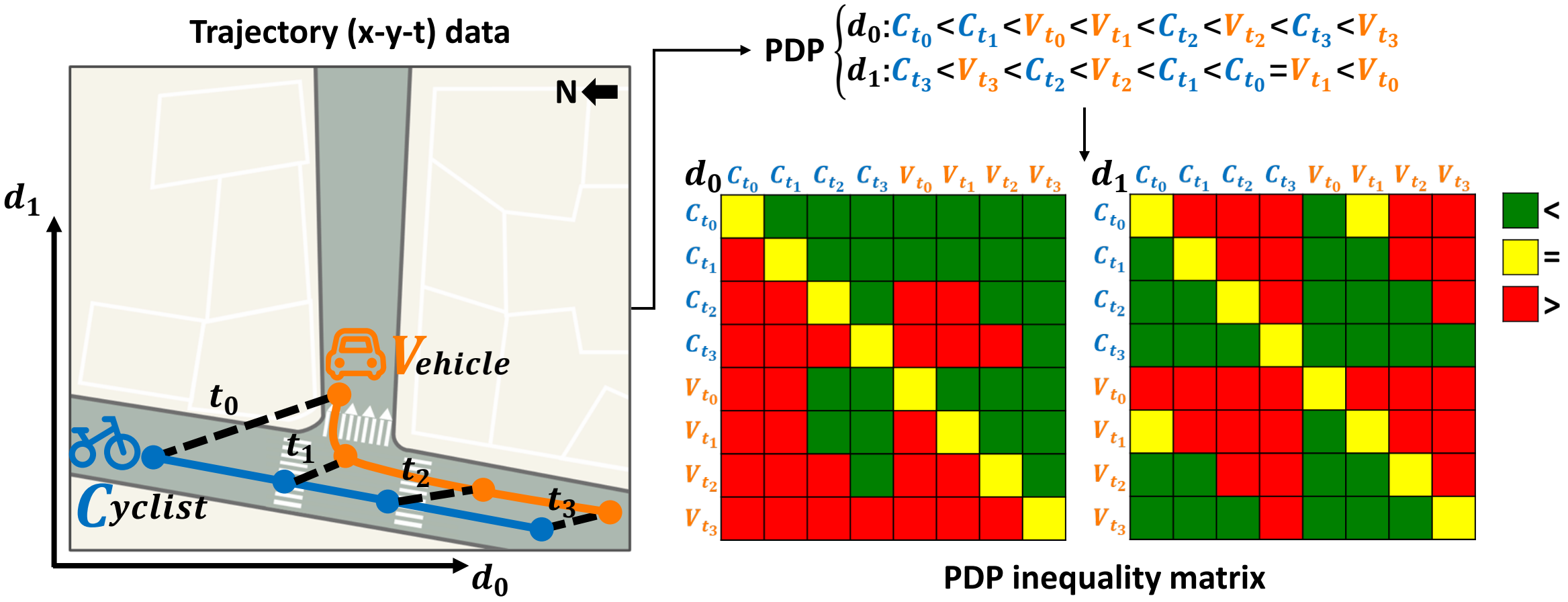
Camera scene

Detected interaction scenarios

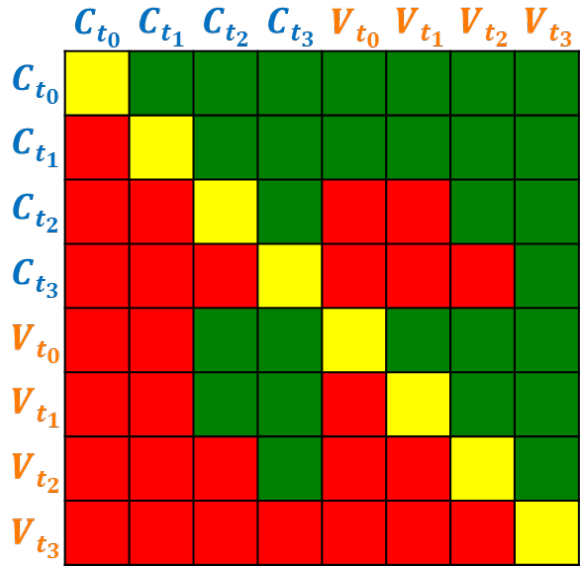


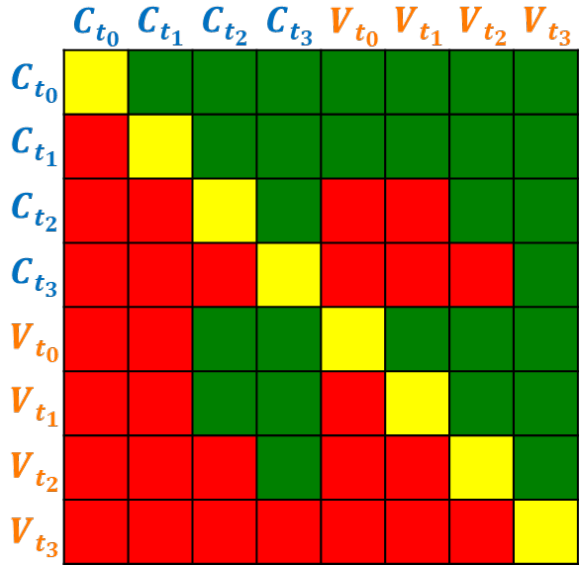
3 Experiment

PDP Representation and PDP inequality matrix



PDP inequality matrix

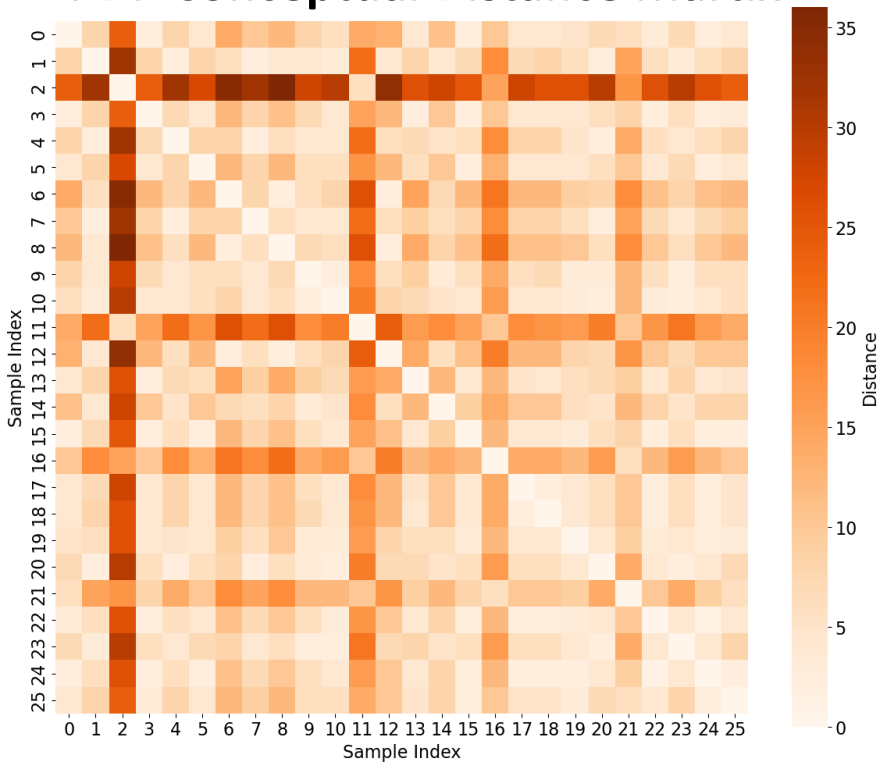

C_{t_0} C_{t_1} C_{t_2} C_{t_3} V_{t_0} V_{t_1} V_{t_2} V_{t_3}
C_{t_0}
C_{t_1}
C_{t_2}
C_{t_3}
V_{t_0}
V_{t_1}
V_{t_2}
V_{t_3}

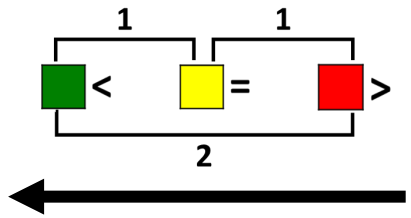

C_{t_0} C_{t_1} C_{t_2} C_{t_3} V_{t_0} V_{t_1} V_{t_2} V_{t_3}
C_{t_0}
C_{t_1}
C_{t_2}
C_{t_3}
V_{t_0}
V_{t_1}
V_{t_2}
V_{t_3}

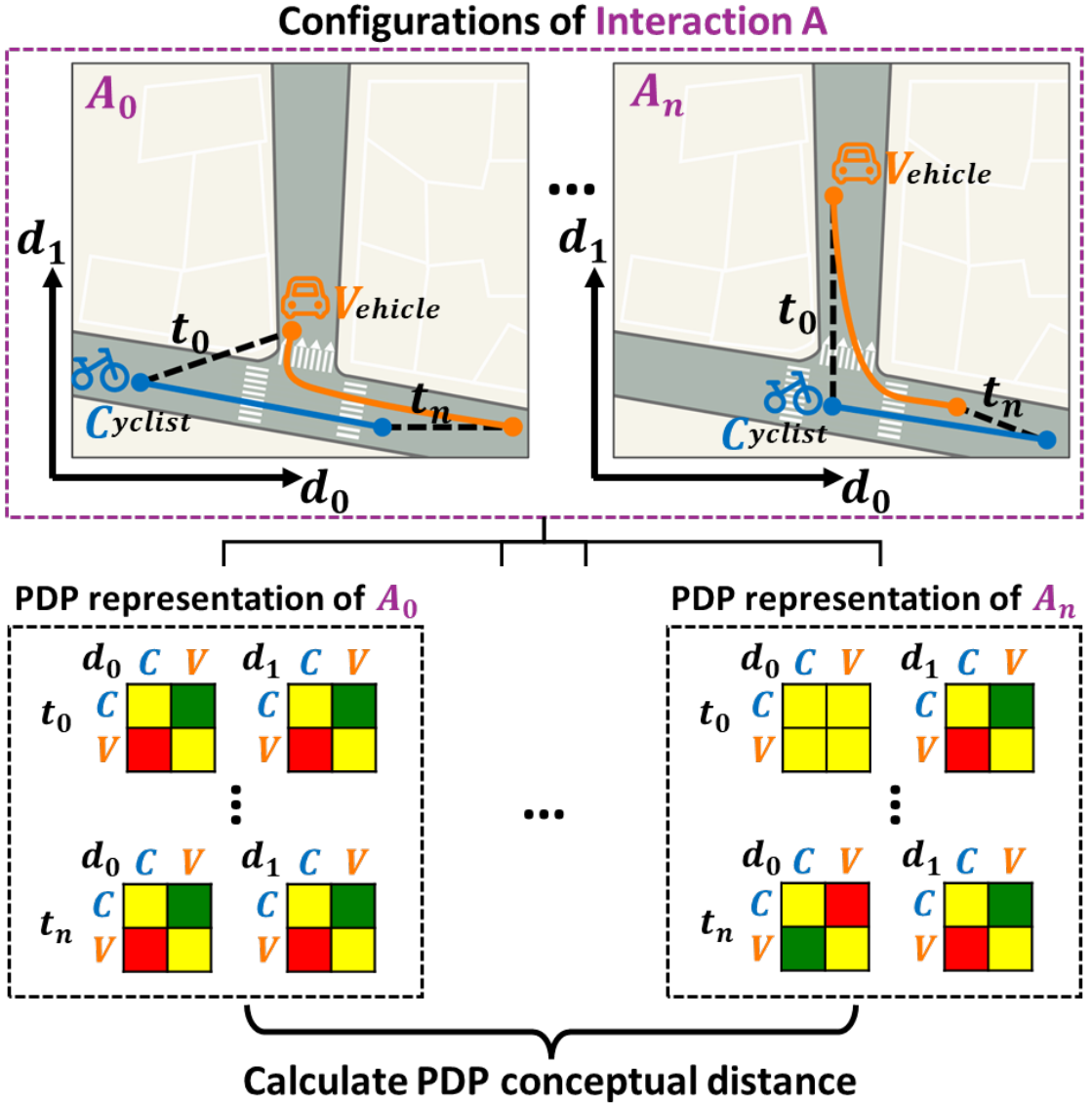
3 Experiment

PDP Conceptual Distance

PDP Conceptual Distance Martix

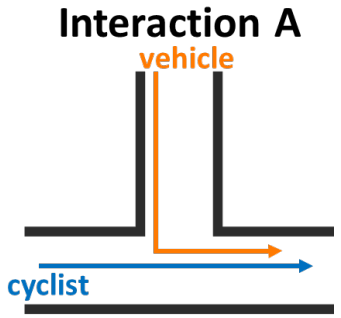


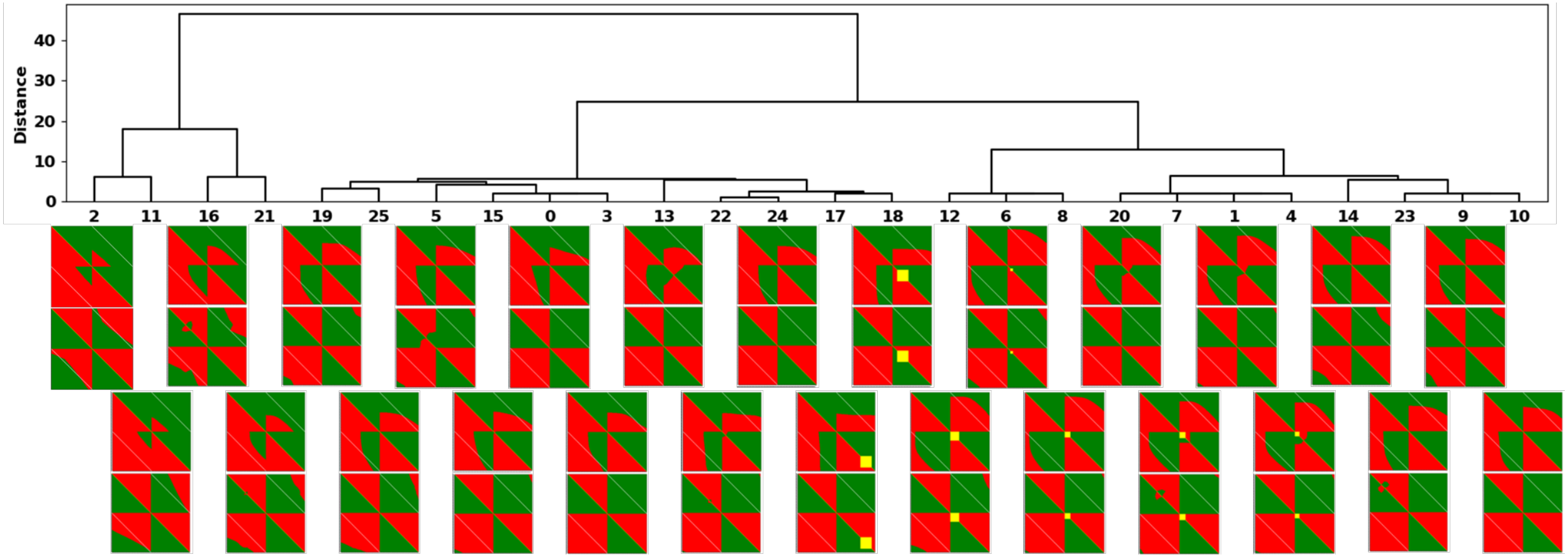




3 Experiment

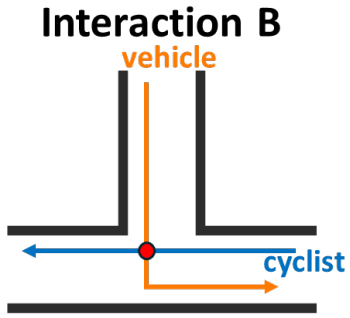
Hierarchical Clustering Dendrogram



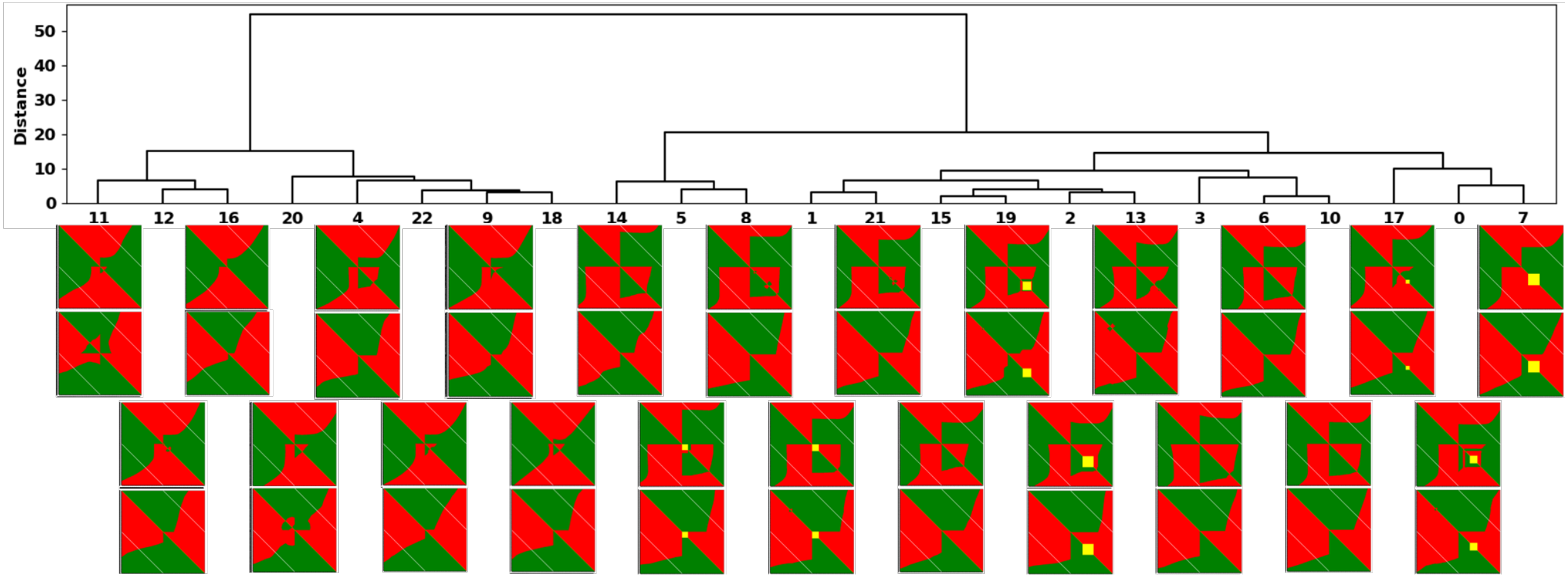


3 Experiment

Hierarchical Clustering Dendrogram

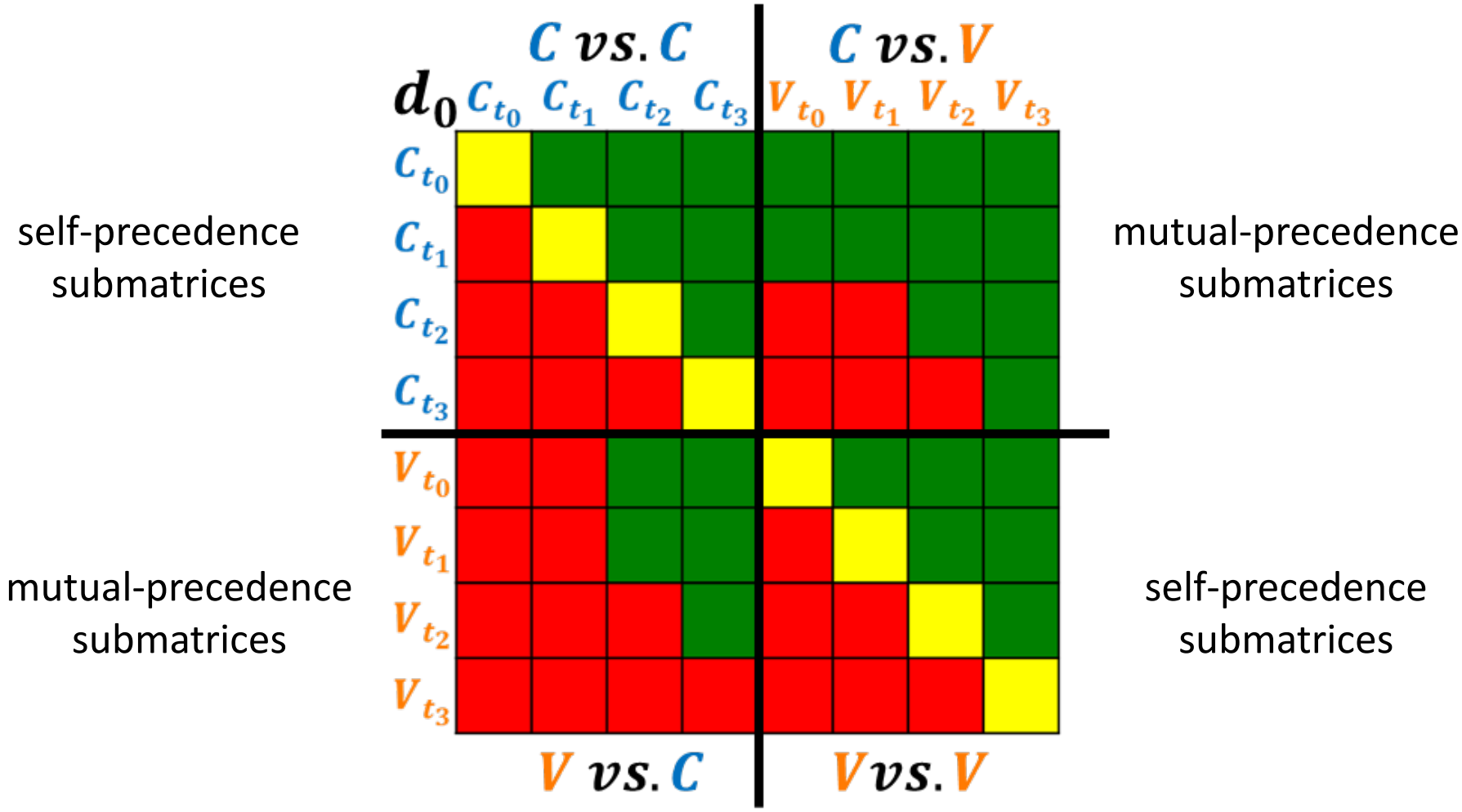


How we can understand and interpret our clustering results



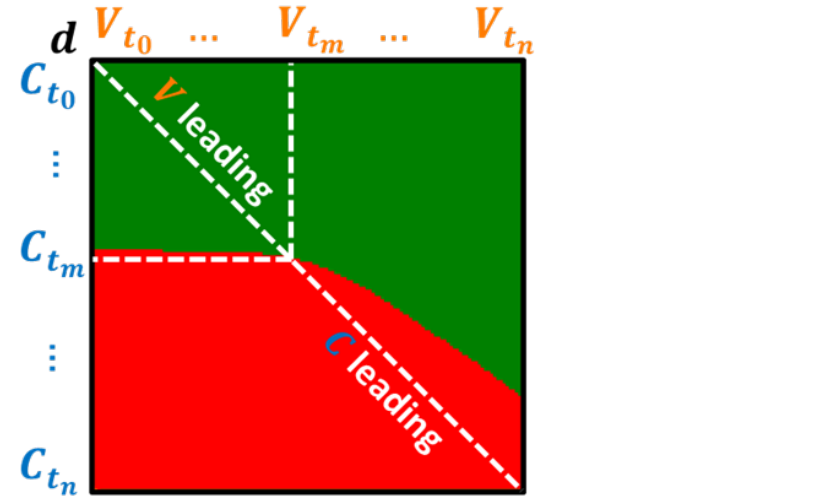
3 Experiment

Interpretation of PDP inequality matrix

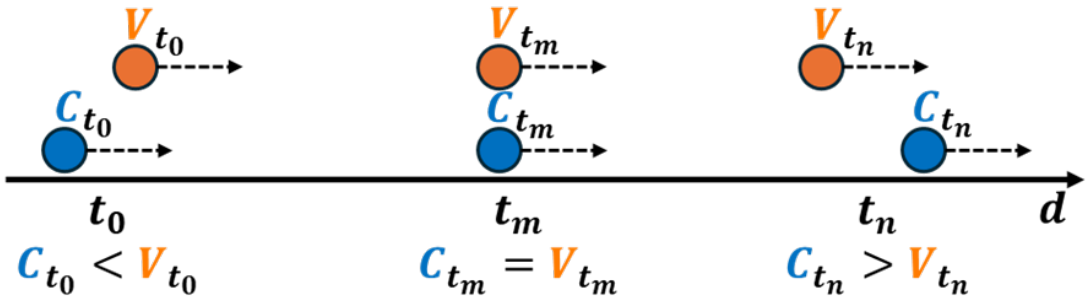


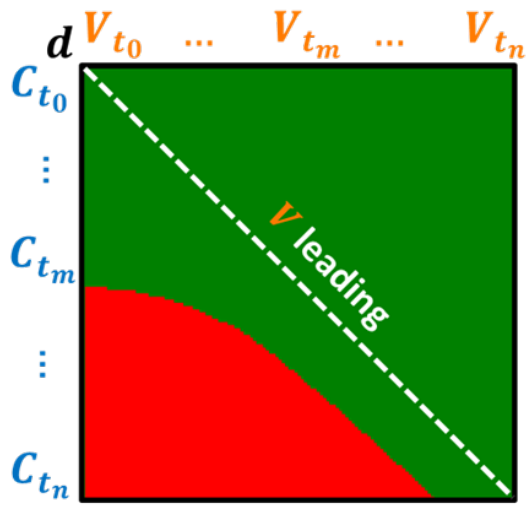
3 Experiment

Generic Interpretation of PDP Inequality Matrix (Relative Position from mutual-precedence submatrices)

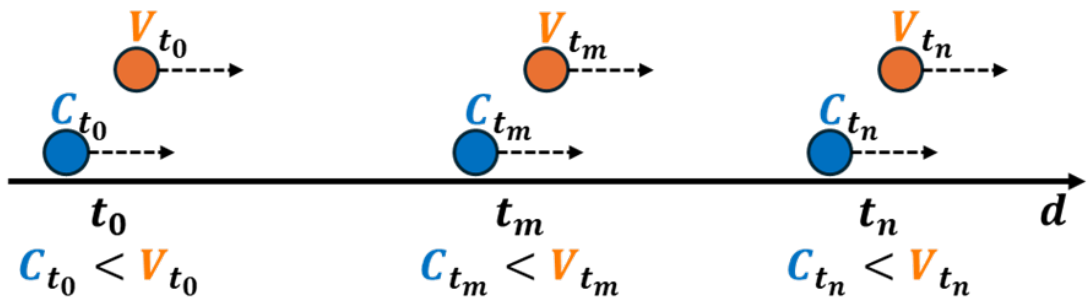


Relative position changes at t_m



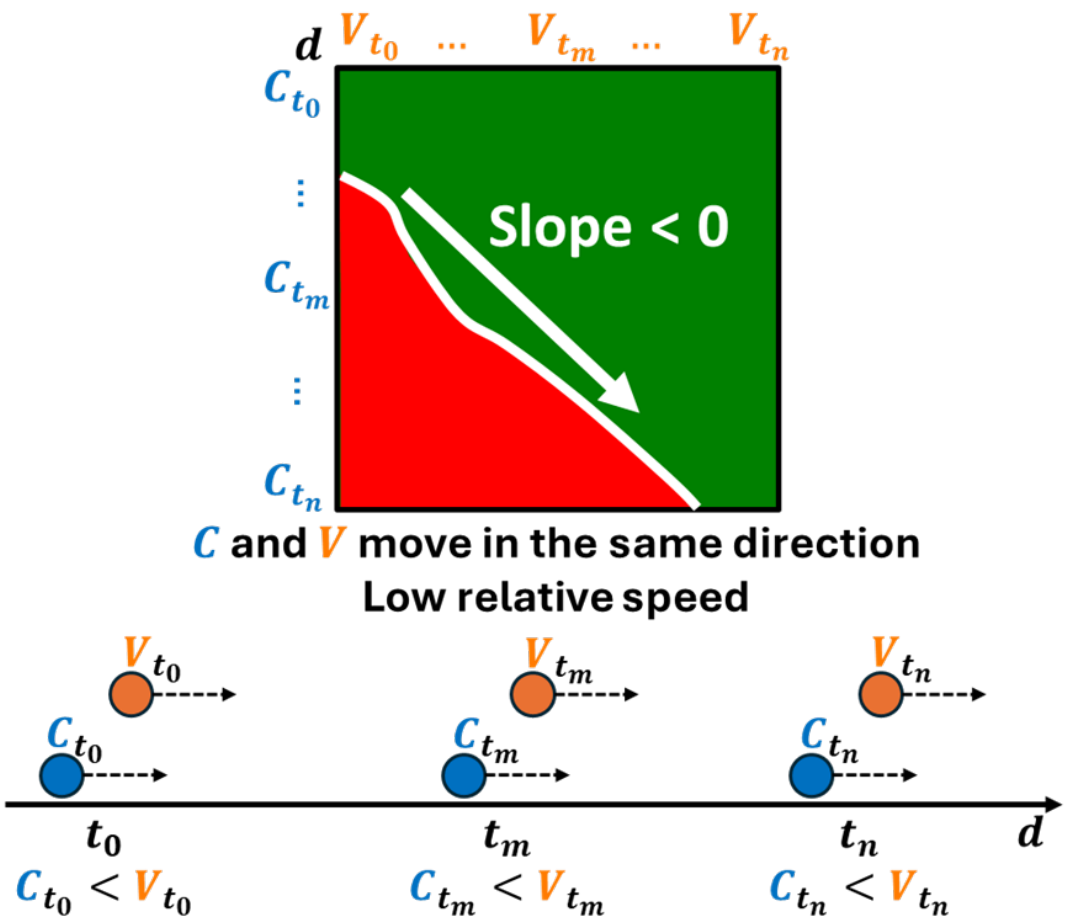


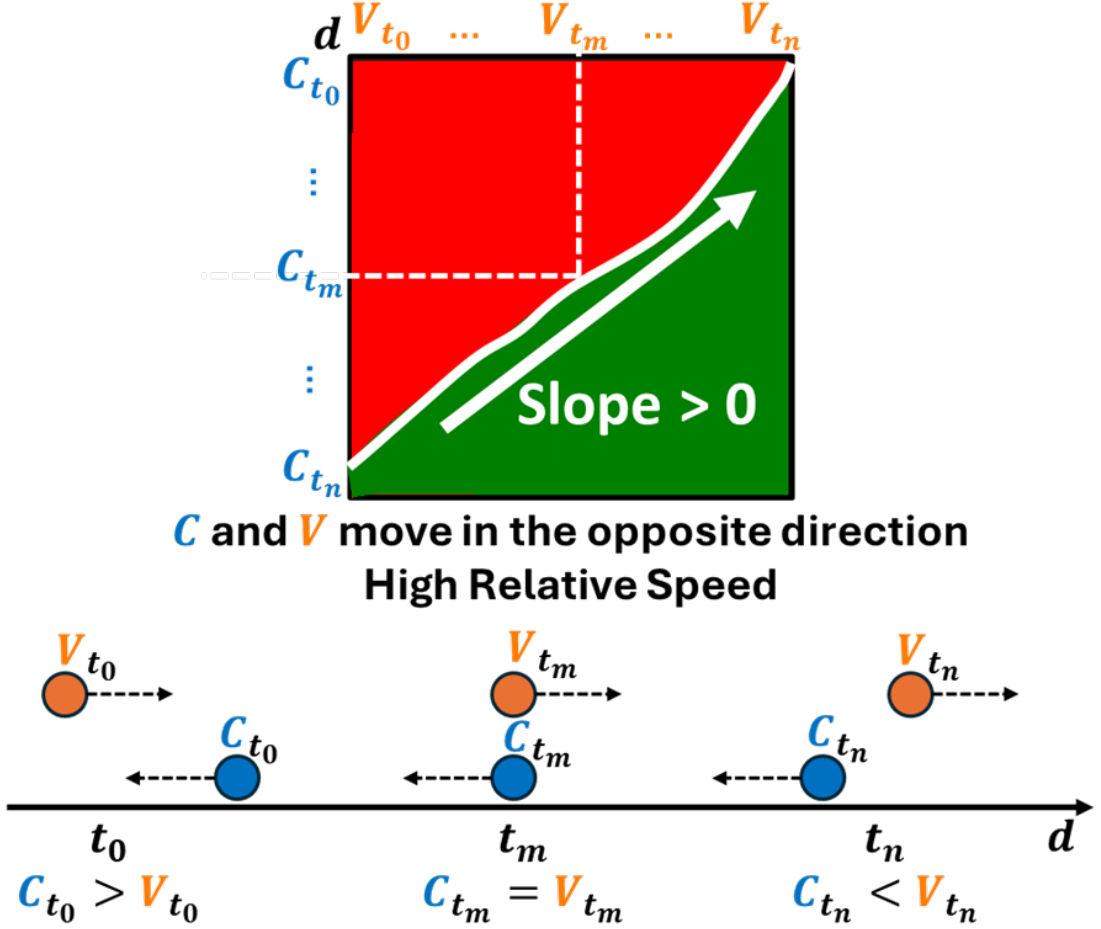
Relative position keeps unchanged



3 Experiment

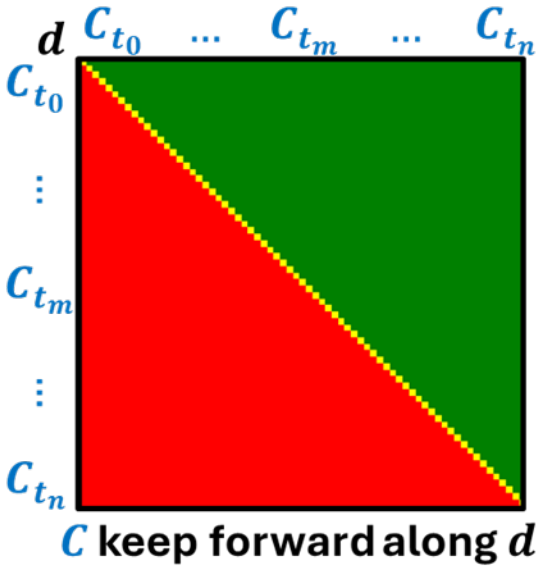
Generic Interpretation of PDP Inequality Matrix (Relative Speed from mutual-precedence submatrices)



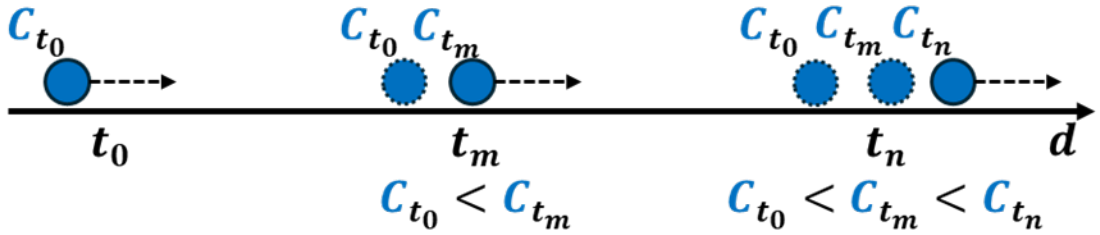


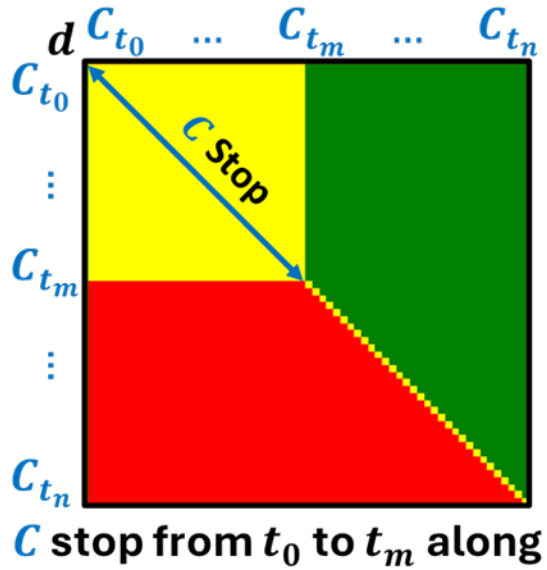
3 Experiment

Generic Interpretation of PDP Inequality Matrix (Ego Motion State from self-precedence submatrices)

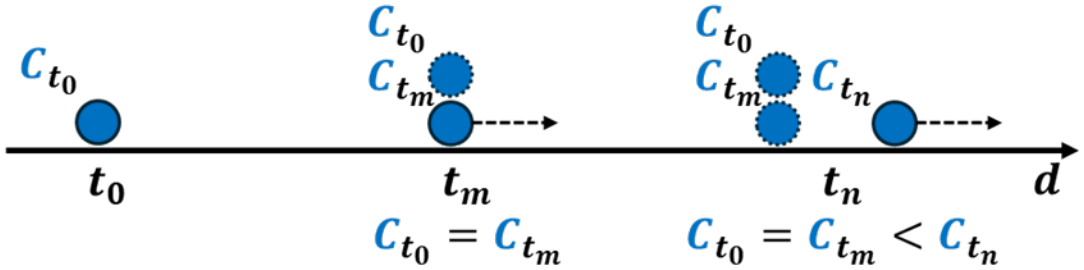


C keep forward along d



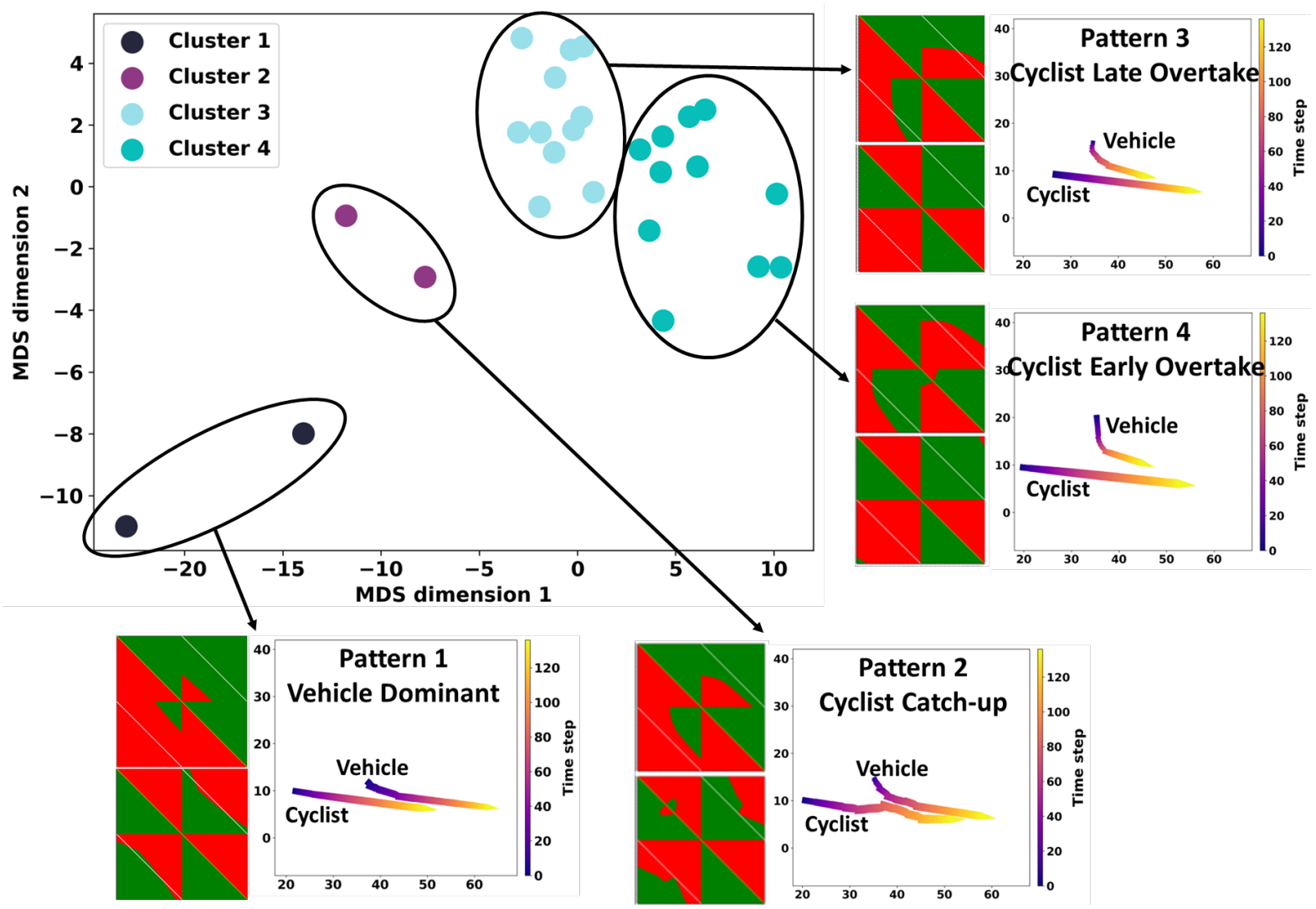


C stop from t_0 to t_m along d



4 Results

Clustering Results & Pattern Interpretation (Interaction A)



4 Results

Pattern 1 (Vehicle Dominant)

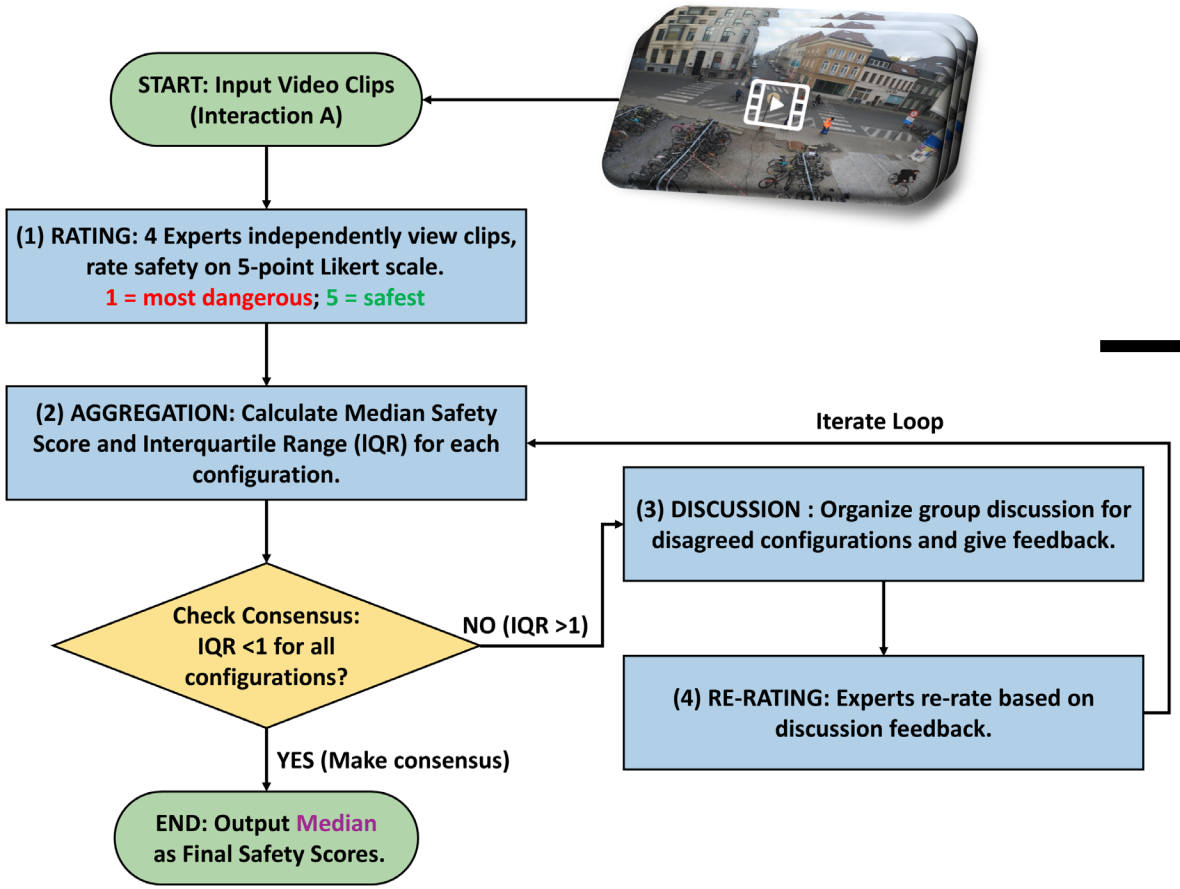
Pattern 2 (Cyclist Catch-up)

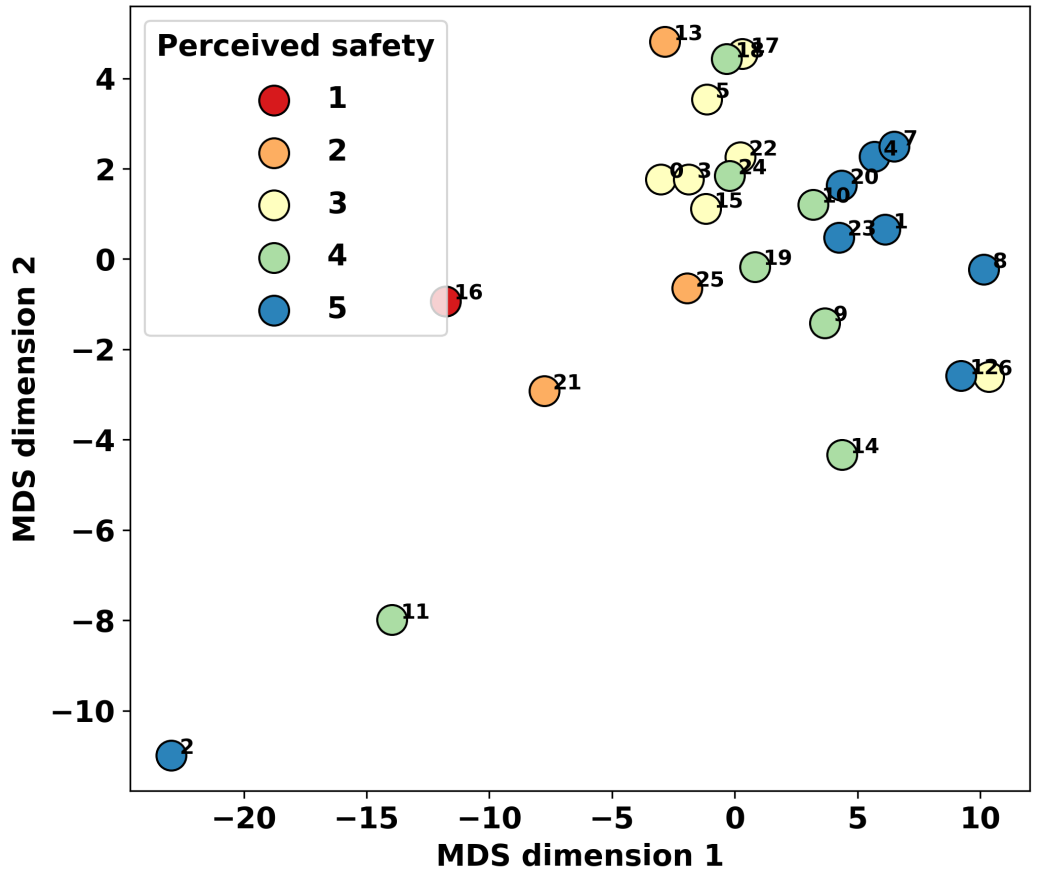
Pattern 3 (Cyclist Late Overtake)

Pattern 4 (Cyclist early Overtake)

5 Validation

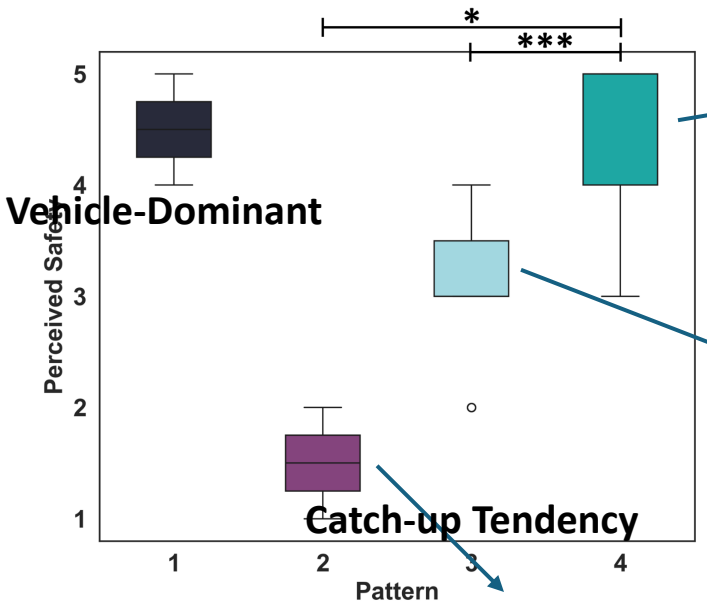
PDP Results For Safety Assessment





5 Validation

PDP Results For Safety Assessment



Vehicle-Dominant

Early Overtake

Late Overtake

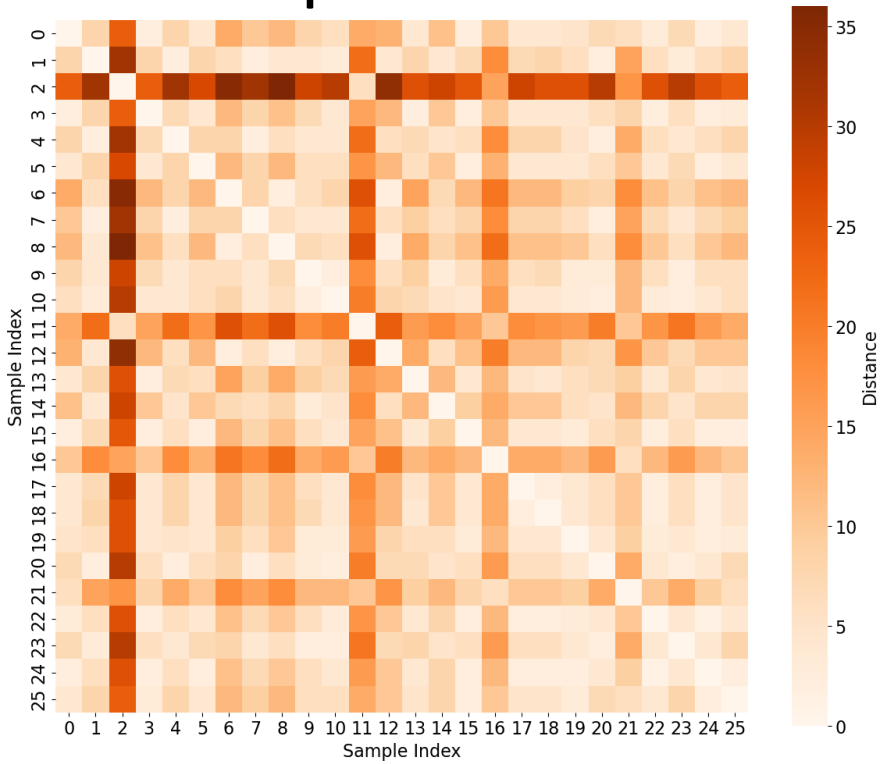
Catch-up Tendency

Different patterns show significant perceived safety

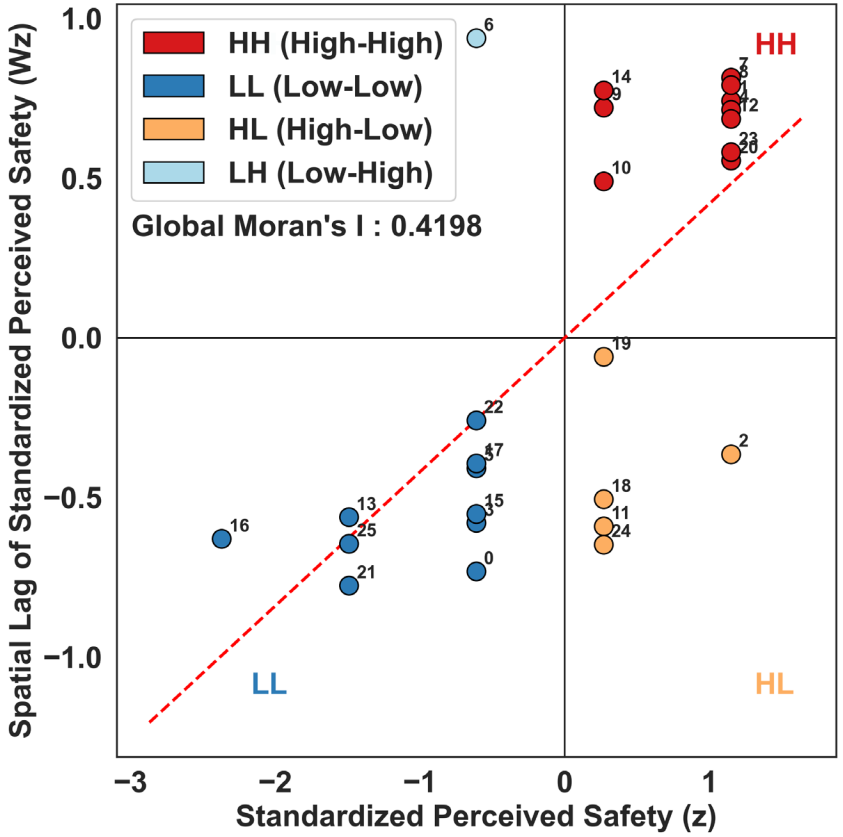
5 Validation

PDP Results For Safety Assessment

PDP Conceptual Distance Martix



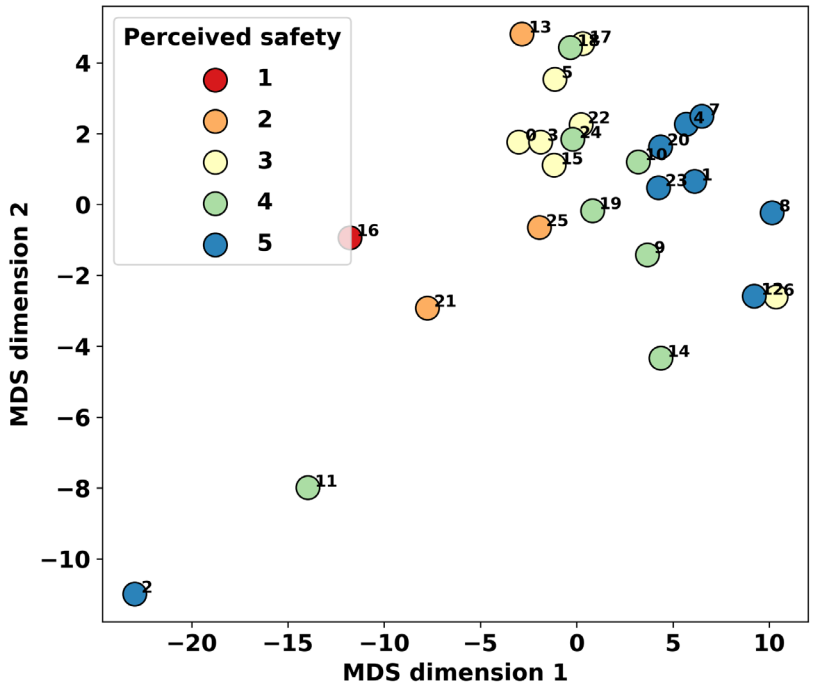
Moran's *I* analysis of Perceived Safety Based on PDP Distance



More similar in PDP, more similar in perceived safety

5 Validation

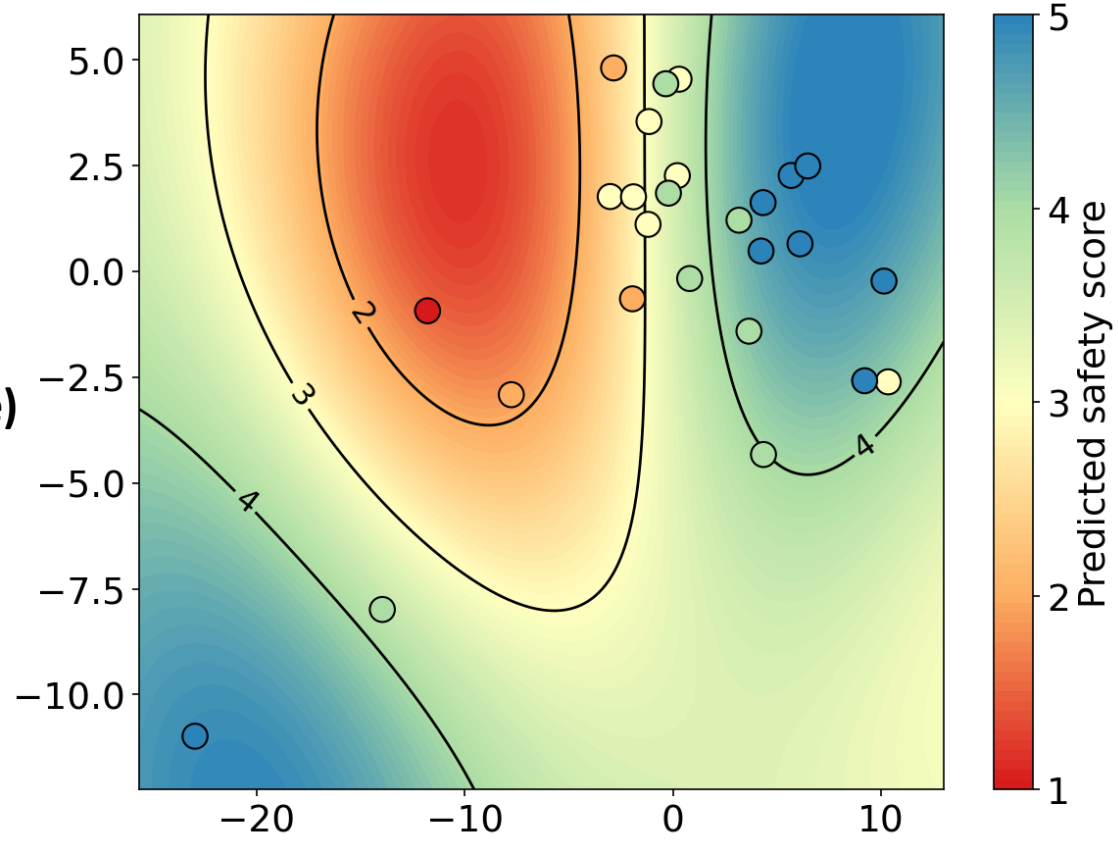
PDP Results For Safety Assessment



Distance Regression

(PDP concept distance)

r = 0.760



PDP conceptual distance may be used in perceived safety modeling

6 Summary

- **We used PDP to identify vehicle-cyclist interaction at a T-junction**
  - **Interpretable**
  - **Only require xyt data**
- **PDP-based patterns are behaviorally meaningful since they reflect different perceived safety**
- **PDP holds the potential for perceived safety modeling**

Thanks

Q&A

Reporter: Changbo Zhang (CB) Changbo.Zhang@Ugent.be

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