

# Comparison of User Trajectories Based on Coordinate Data and State Transitions

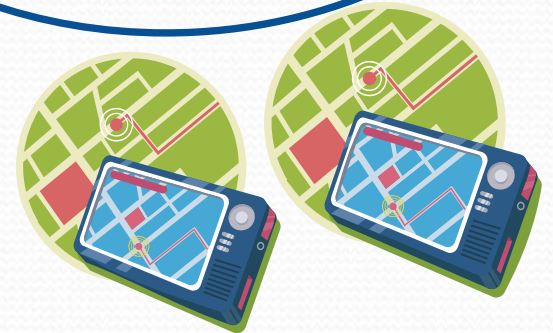
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Academia Sinica, Taiwan*

# Background

- Trajectory analysis
  - Feature extraction
  - Trajectory comparison
  - Behavior prediction



The next step is

Similar to  
shoplifting's  
behavior.



**Analysis**

His behavior  
is  
suspect.

# Problems

- Traditional model
  - The state set is definite
  - Over-approximate
  - Small movements cannot be expressed exactly.

time series      state transition

$t \quad (x, y) \rightarrow \text{State}$

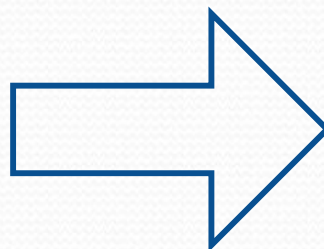
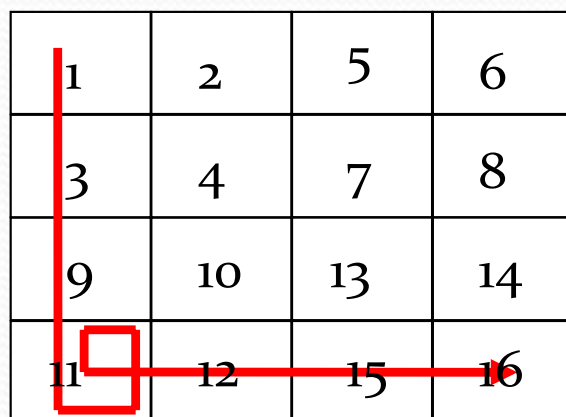
1  $(x_1, y_1) \rightarrow h_1$

2  $(x_2, y_2) \rightarrow h_2$

3  $(x_3, y_3) \rightarrow h_3$

⋮

1	2	5	6
3	4	7	8
9	10	13	14
11	12	15	16



State series

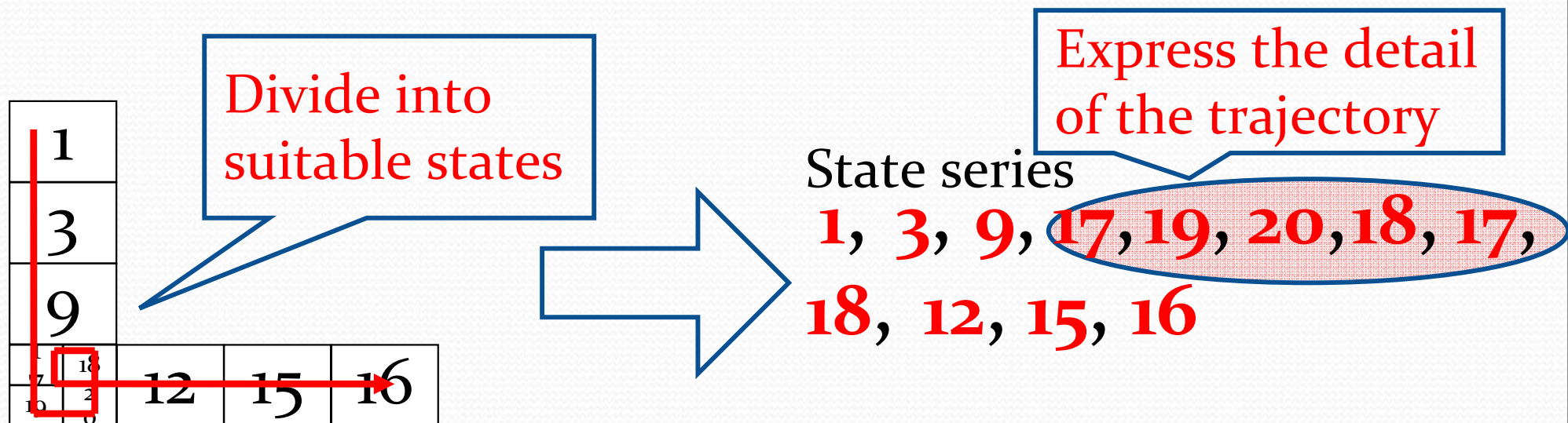
**1, 3, 9, 11, 11, 11, 11, 11, 11,**  
**12, 15, 16**

Lose features

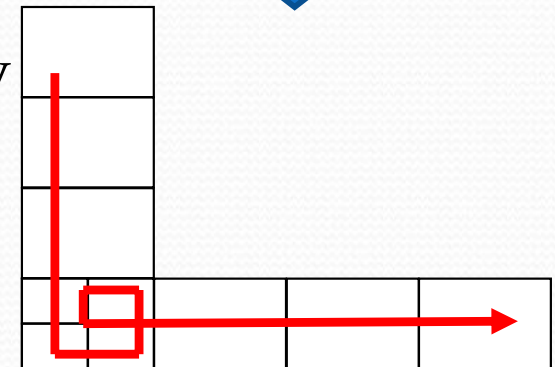
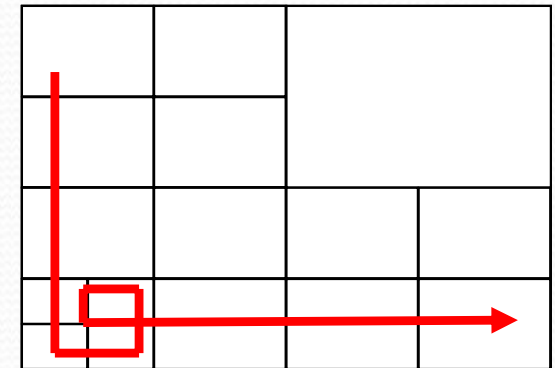
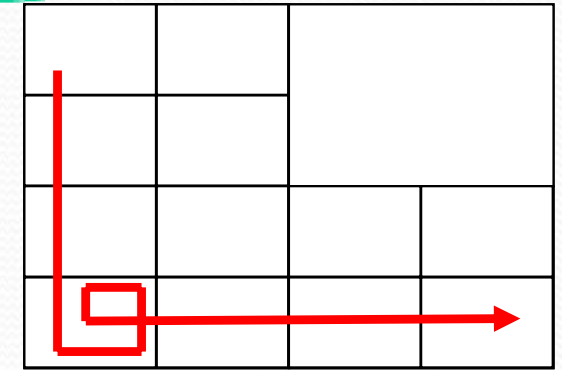
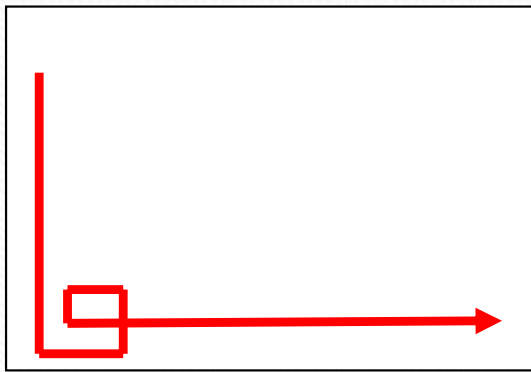


# The way of coping

- Divide into suitable states for each trajectory
- Need the method comparing trajectories expressed by transitions in different state sets.
- The comparing method based on **coordinate data**
- The comparing method based on **state transitions**



# Divide the space

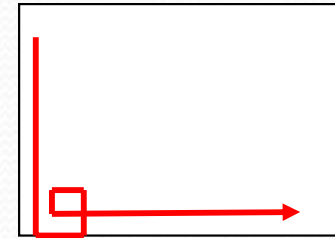


- Dynamic map division
  - Repeat the following
    - ① Evaluate the density in the area
    - ② Divide the area into 4 areas if the density is higher than the threshold.
  - Delete areas which don't have trajectory data

The initial state

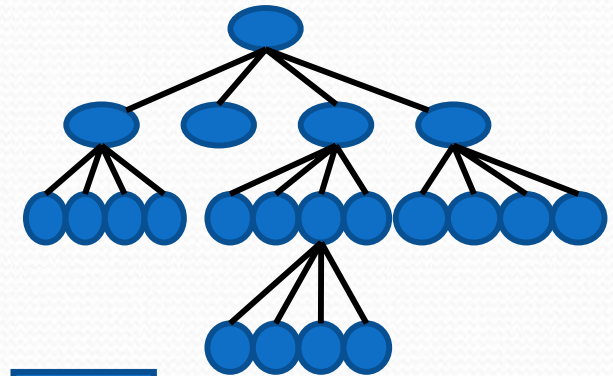
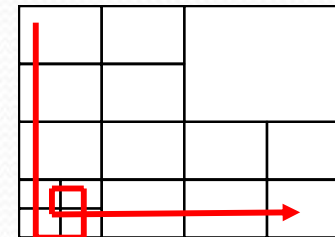


# Divide the space

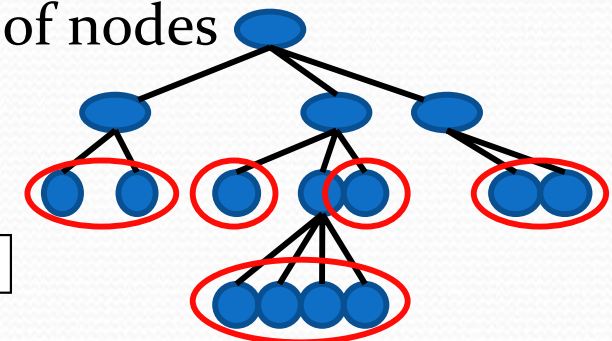
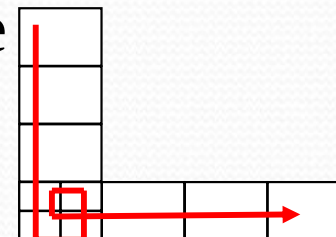


- Implemented by quadtree
  - Extension of the tree corresponds to division of the area.
  - Deletion of nodes corresponds to deletion of areas.
  - Left areas correspond to leaf nodes.
  - The number of area corresponds to the number of node.
- Comparison based on coordinate data is to compare structures of quadtree.

Extension of the tree

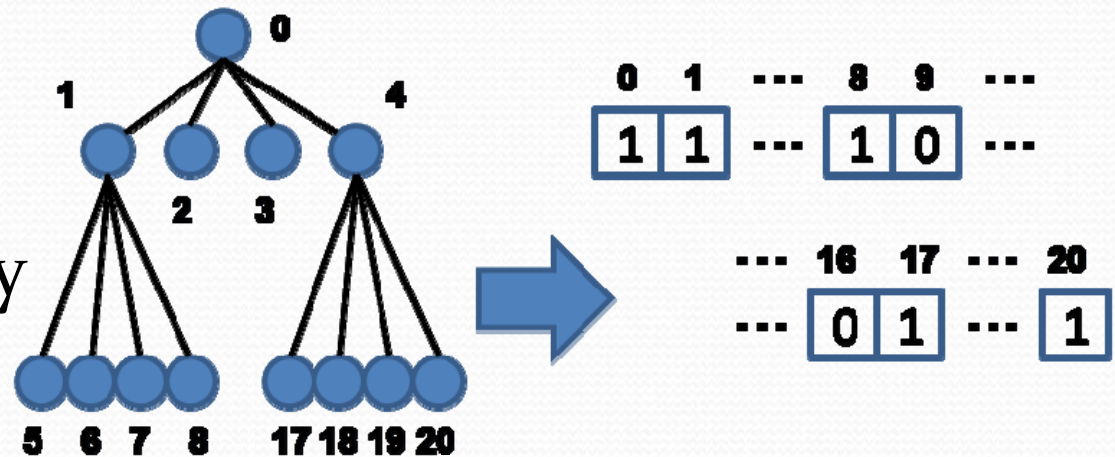


Deletion of nodes



# Comparison based on coordinate data

- Represented by bit sequences
- Evaluate difference by Hamming distance



XO

**A**

1	1	1	1	1
---	---	---	---	---

 → 

0	1	1	1	0
---	---	---	---	---

 → Hamming distance :

**B**

1	0	0	0	1
---	---	---	---	---

 → 

0	1	1	1	0
---	---	---	---	---

 (A, B)

**C**

1	1	0	0	1
---	---	---	---	---

 → 

0	1	1	1	0
---	---	---	---	---

**D**

1	1	1	0	1
---	---	---	---	---

 → 

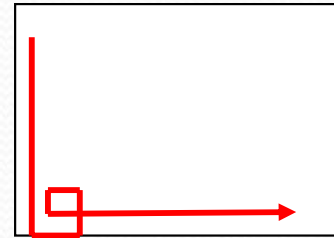
0	1	1	1	0
---	---	---	---	---

→ Hamming distance :

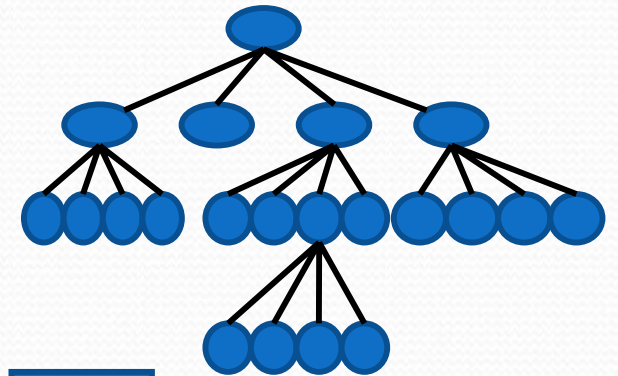
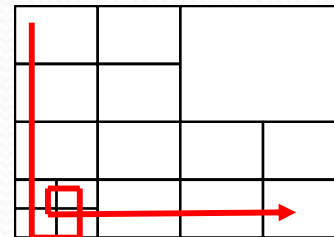
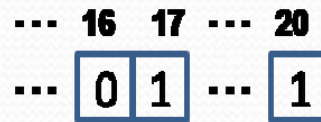
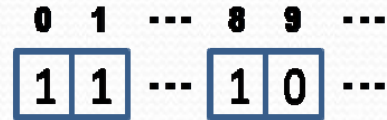
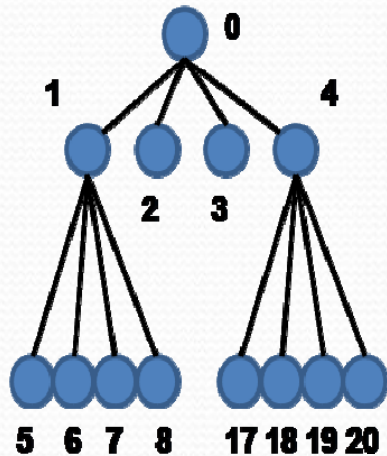
		3		
		A	B	C
B		3		
C		2	1	
D		1	2	1

# Hamming distance of quadtree

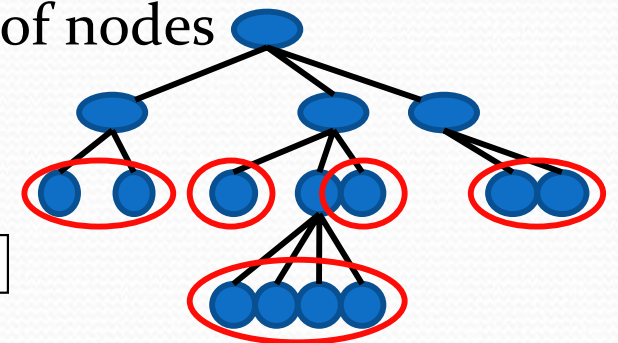
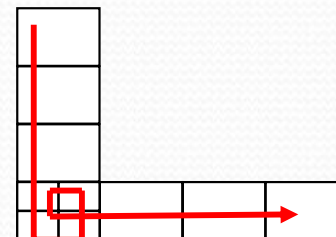
The initial state



Extension of the tree



Deletion of nodes



**A**

1	1	1	1	1
---	---	---	---	---

**B**

1	0	0	0	1
---	---	---	---	---

**C**

1	1	0	0	1
---	---	---	---	---

**D**

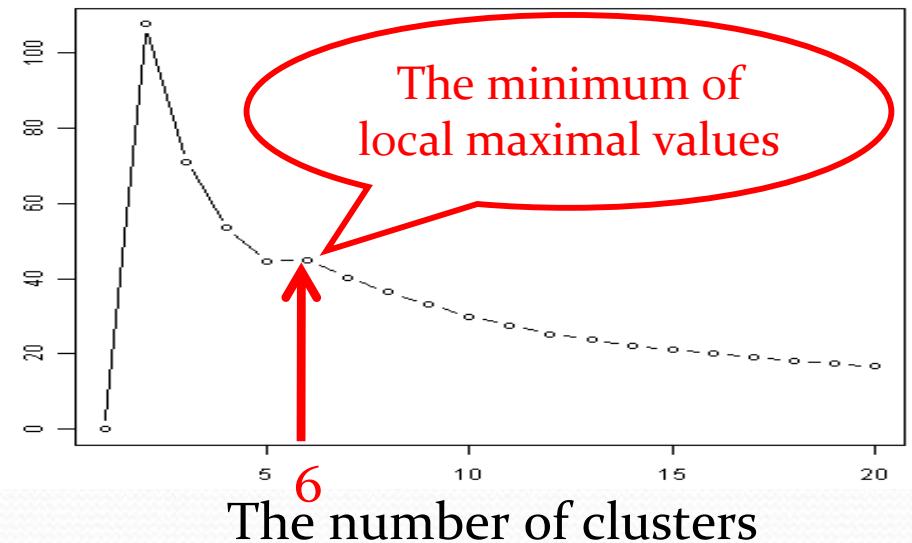
1	1	1	0	1
---	---	---	---	---



	A	B	C
B	3		
C	2	1	
D	1	2	1

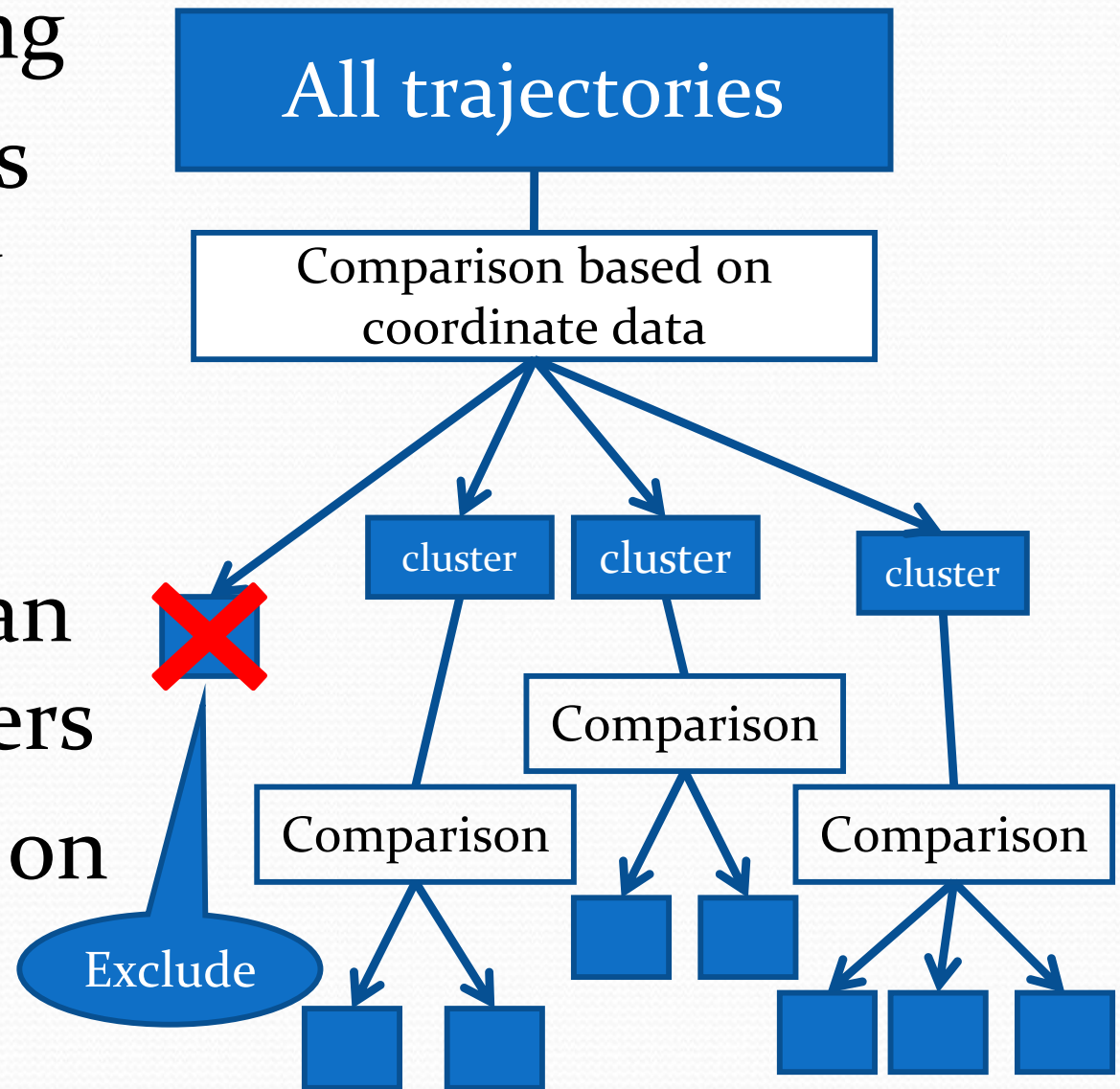
# Clustering

- The Ward clustering
- Decide the number of clusters.
  - Show the graph of the proportion of internal variance of the cluster to external variance of all clusters
  - Adopt the number of clusters with the minimum of local maximal values



# Comparison based on coordinate data

- The Ward clustering
- Exclude trajectories as errant trajectory
  - The cluster with the number of members less than 10% of all members
- Comparison based on state transitions in each cluster



time series transition

state

$t \quad (x, y) \rightarrow \text{state}$   
 1  $(x_1, y_1) \rightarrow h_1$   
 2  $(x_2, y_2) \rightarrow h_2$   
 3  $(x_3, y_3) \rightarrow h_3$   
 ⋮

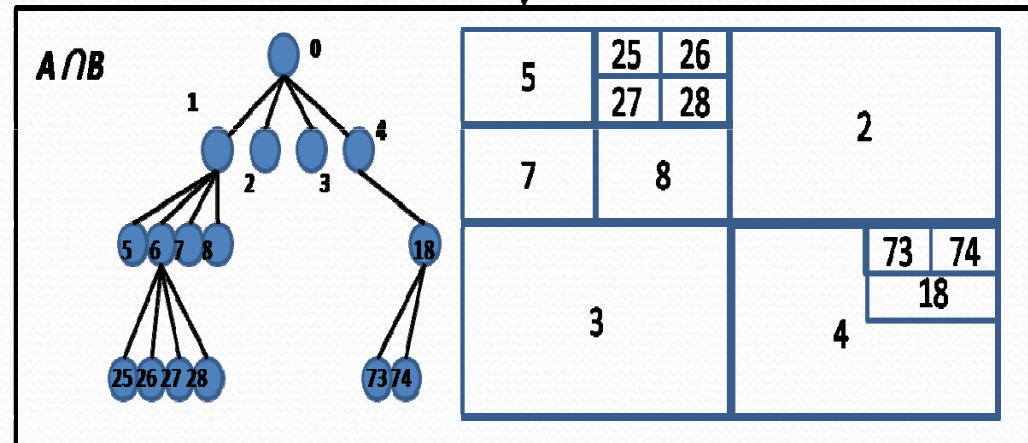
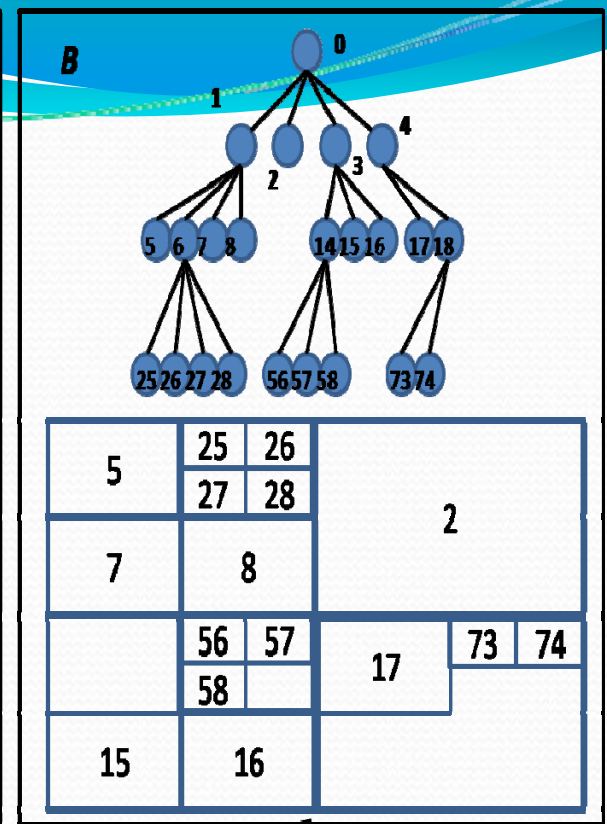
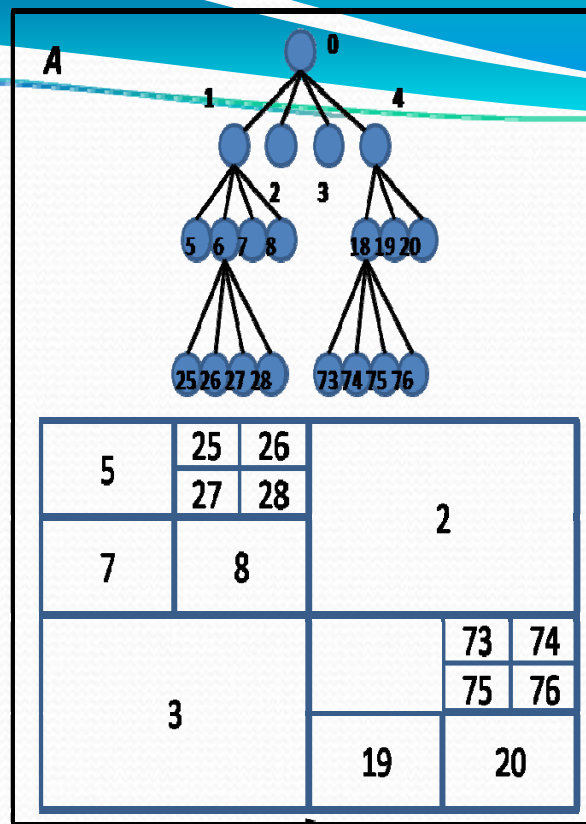


$a_{11}, a_{12}, \dots, a_{1n}$

$a_{21}, a_{22}, \dots, a_{2n}$

⋮ ⋮ ⋮

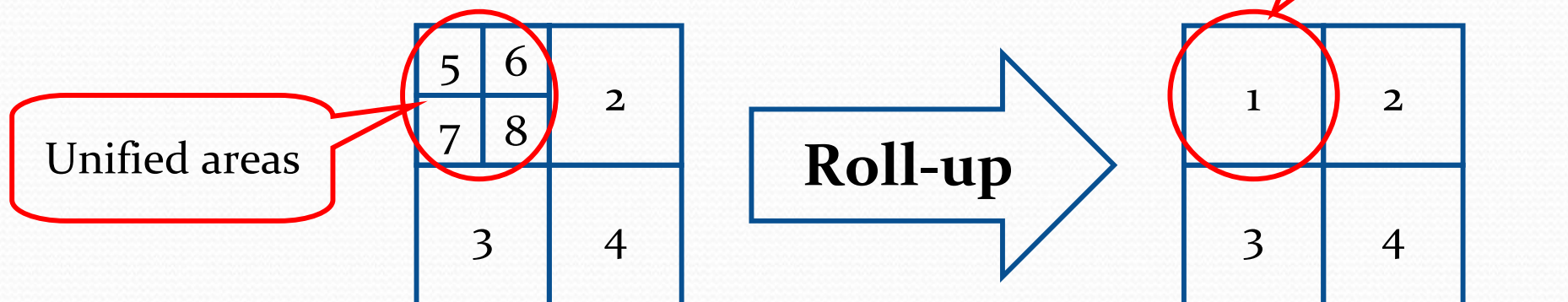
$a_{n1}, a_{n2}, \dots, a_{nn}$



# Comparison based on state transitions

- Roll-up algorithm
  - Evaluate the transition probability of the derived states
    - ① Before and after transition areas are unified area.
    - ② Before transition area is unified area.
    - ③ After transition area is unified area.

## Example



# Comparison based on state transitions

- Roll-up algorithm

① Before and after transition areas are unified area.

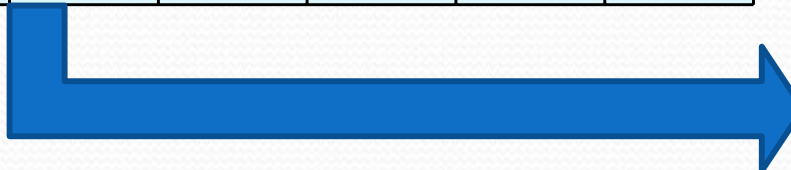
After

Before

	a5	a6	a7	a8	a2	a3	a4
a5	a55	a56	a57	a58	a52	a53	a54
a6	a65	a66	a67	a68	a62	a63	a64
a7	a75	a76	a77	a78	a72	a73	a74
a8	a85	a86	a87	a88	a82	a83	a84
a2	a25	a26	a27	a28	a22	a23	a24
a3	a35	a36	a37	a38	a32	a33	a34
a4	a45	a46	a47	a48	a42	a43	a44

$$a_{11} = (a_{55} + a_{56} + a_{57} + a_{58} + a_{65} + a_{66} + a_{67} + a_{68} + a_{75} + a_{76} + a_{77} + a_{78} + a_{85} + a_{86} + a_{87} + a_{88}) / 4$$

	a1	a2	a3	a4
a1	a11			
a2		a22	a23	a24
a3		a32	a33	a34
a4		a42	a43	a44



# Comparison based on state transitions

- Roll-up algorithm
  - ② Before transition area is unified area.

After

Before

	a5	a6	a7	a8	a2	a3	a4
a5	a55	a56	a57	a58	a52	a53	a54
a6	a65	a66	a67	a68	a62	a63	a64
a7	a75	a76	a77	a78	a72	a73	a74
a8	a85	a86	a87	a88	a82	a83	a84
a2	a25	a26	a27	a28	a22	a23	a24
a3	a35	a36	a37	a38	a32	a33	a34
a4	a45	a46	a47	a48	a42	a43	a44

$$a_{12} = (a_{52} + a_{62} + a_{72} + a_{82}) / 4$$

$$a_{13} = (a_{53} + a_{63} + a_{73} + a_{83}) / 4$$

$$a_{14} = (a_{54} + a_{64} + a_{74} + a_{84}) / 4$$

	a1	a2	a3	a4
a1		a12	a13	a14
a2		a22	a23	a24
a3		a32	a33	a34
a4		a42	a43	a44

# Comparison based on state transitions

- Roll-up algorithm

③ After transition area is unified area.

After

Before

	a5	a6	a7	a8	a2	a3	a4
a5	a55	a56	a57	a58	a52	a53	a54
a6	a65	a66	a67	a68	a62	a63	a64
a7	a75	a76	a77	a78	a72	a73	a74
a8	a85	a86	a87	a88	a82	a83	a84
a2	a25	a26	a27	a28	a22	a23	a24
a3	a35	a36	a37	a38	a32	a33	a34
a4	a45	a46	a47	a48	a42	a43	a44

$$a_{21} = a_{25} + a_{26} + a_{27} + a_{28}$$

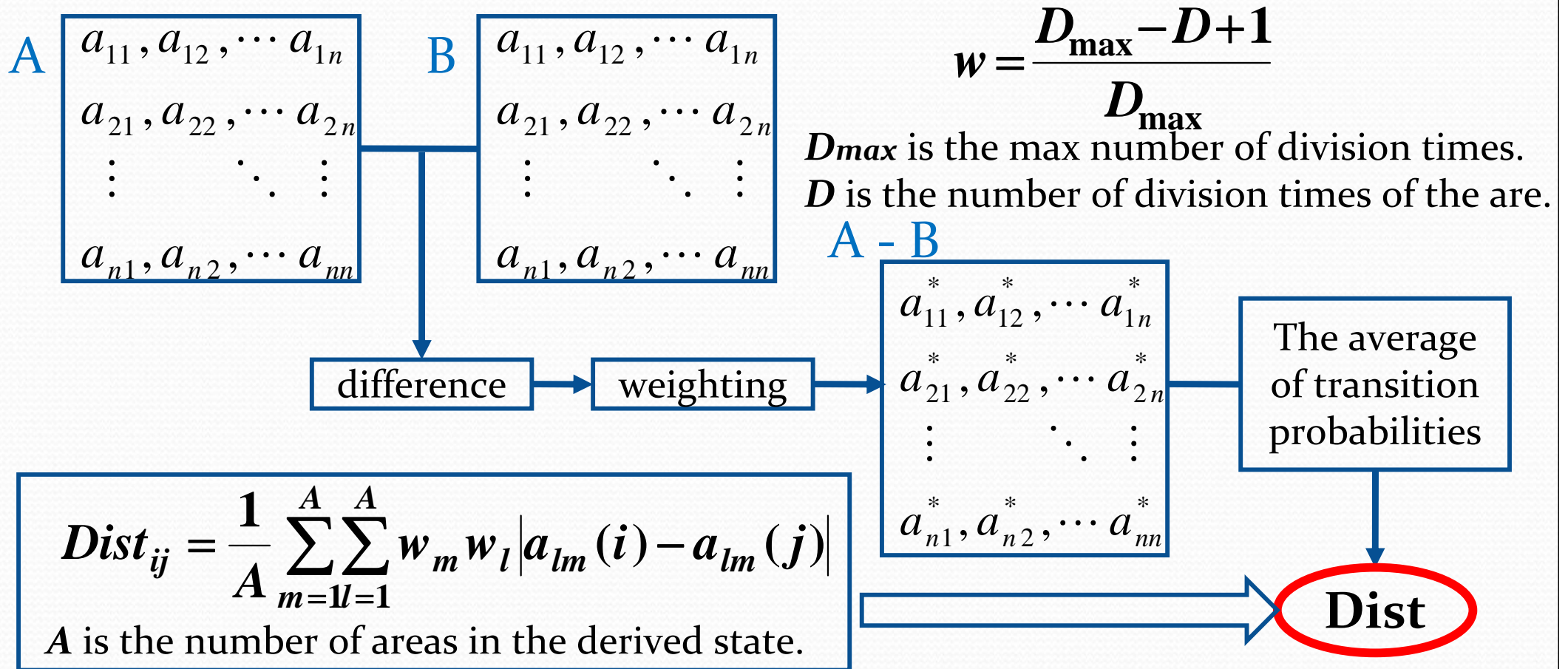
$$a_{31} = a_{35} + a_{36} + a_{37} + a_{38}$$

$$a_{41} = a_{45} + a_{46} + a_{47} + a_{48}$$

	a1	a2	a3	a4
a1				
a2	a21	a22	a23	a24
a3	a31	a32	a33	a34
a4	a41	a42	a43	a44

# Comparison based on state transitions

- Difference of transition probability
  - Weighting in accordance with the size of area
  - The smaller the size of the area is, the heavier the weight is.



# Experiment

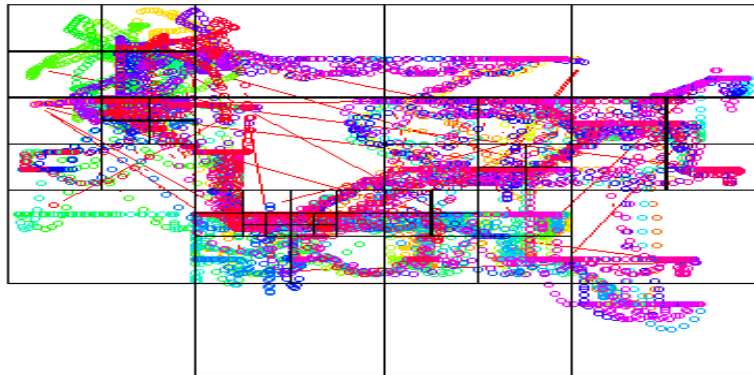
- Quake II
  - Trajectories of human player : 105
  - Trajectories of BOT : 66(Crbot : 25, Eraser : 21, ice : 20)
- Compared method
  - Dynamic map division with all trajectories.
  - Divide a map from all trajectories data distribution

Evaluation	Method	Entropy
	Dynamic map division for all trajectory data	1.58
	Our method	0

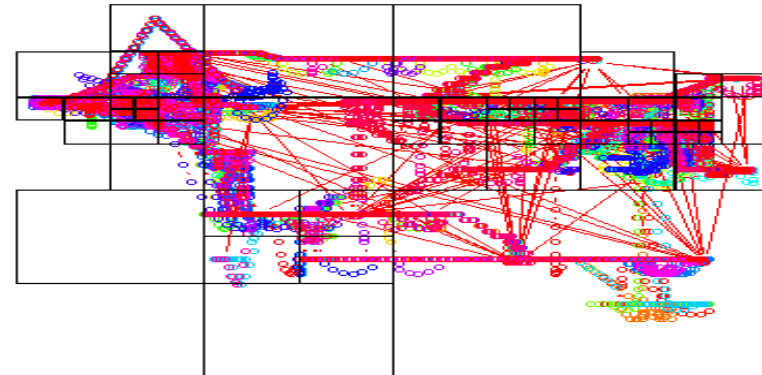
# Experiment

- Quake II
  - Trajectories of human player : 105
  - Trajectories of BOT : 66(Crbot : 25, Eraser : 21, ice : 20)

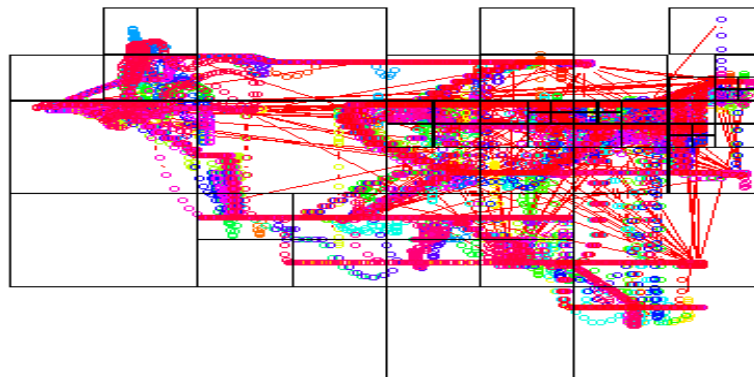
human



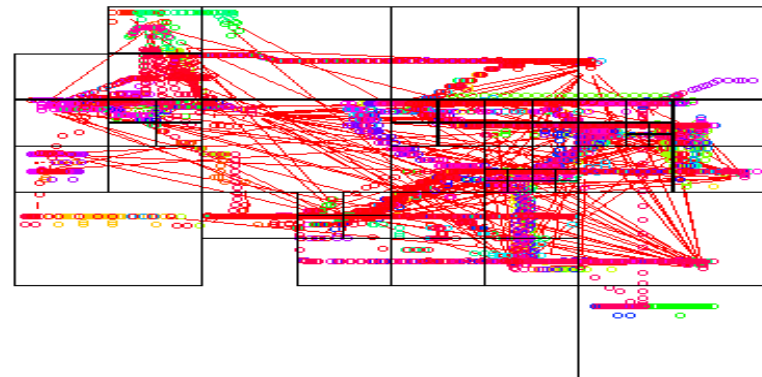
Crbot



ice

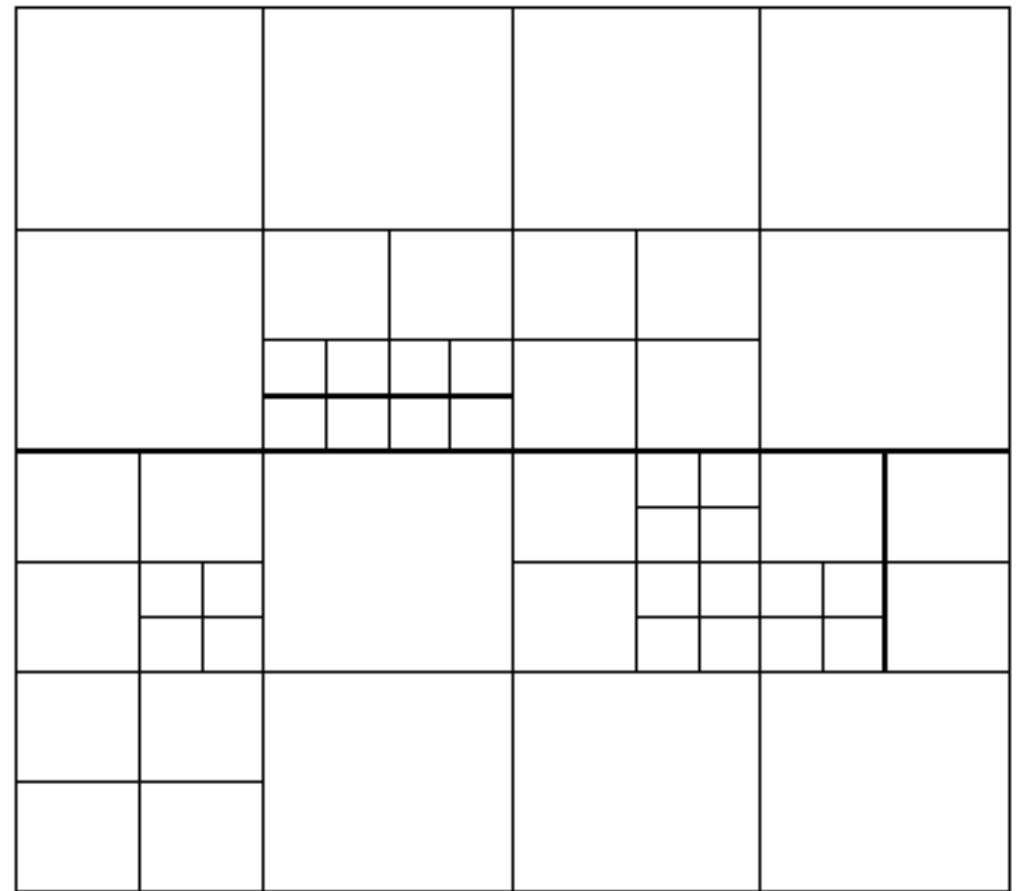


Eraser



# Experiment

- The other method
  - Dynamic map division with all trajectories.
  - Divide a map from all trajectories data distribution.
- Evolution
  - Evaluate the entropy

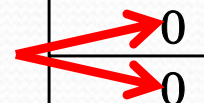


# Result

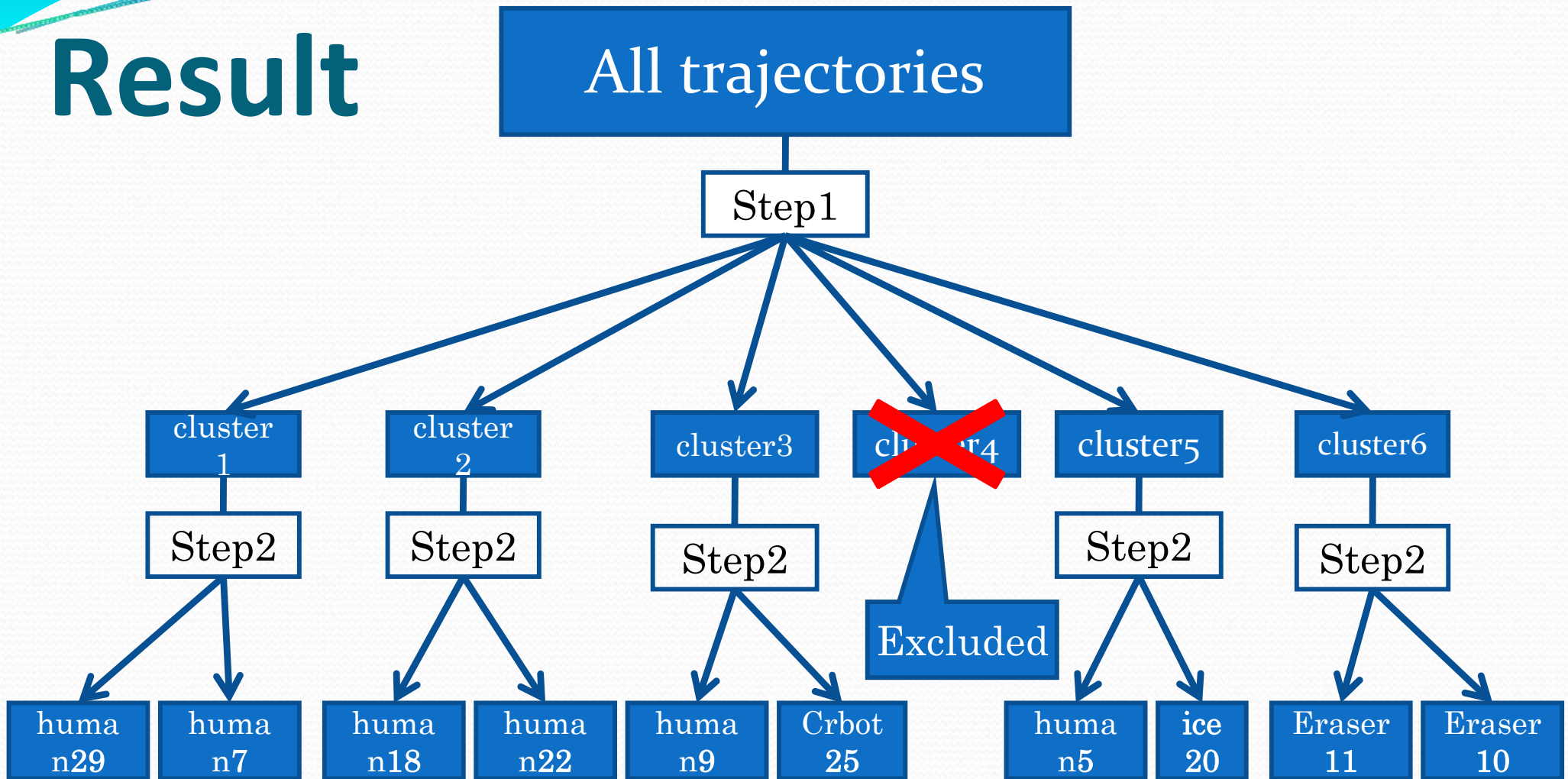
method	Entropy
Dynamic map division for all trajectory data	1.58
Our method	0

Result of our method			Number of members				Entropy	
cluster	structure	transition	human player	Crbot	Eraser	ice	structure	transition
	1	1	29	0	0	0	0	0
		2	7	0	0	0		0
	2	1	22	0	0	0	0	0
		2	18	0	0	0		0
	3	1	9	0	0	0	<u>0.83</u>	0
		2	0	25	0	0		0
	4	1	15	0	0	0	0	0
	5	1	5	0	0	0	<u>0.72</u>	0
		2	0	0	0	20		0
6	1	0	0	0	11	0	0	
	2	0	0	0	10		0	

outliers



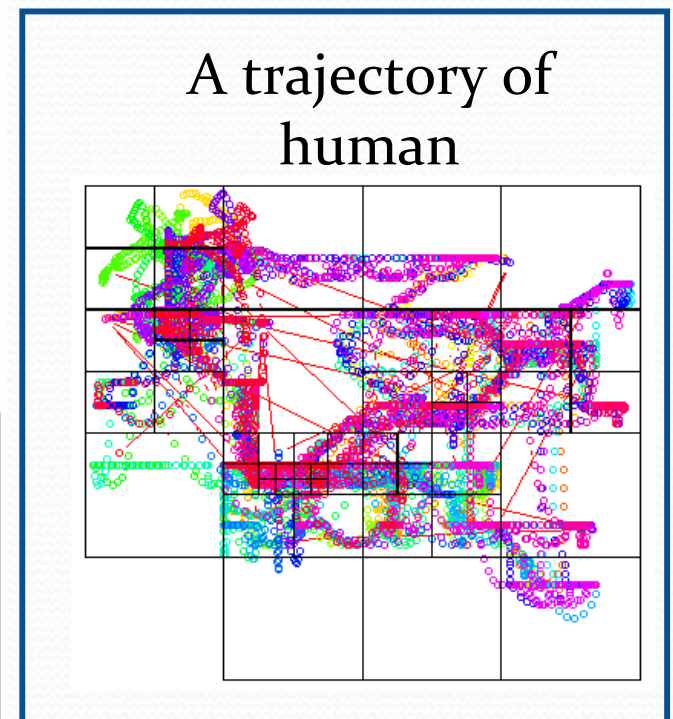
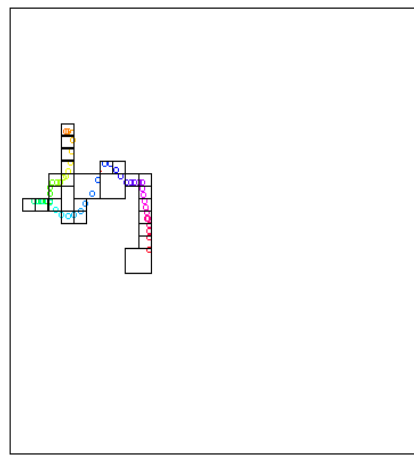
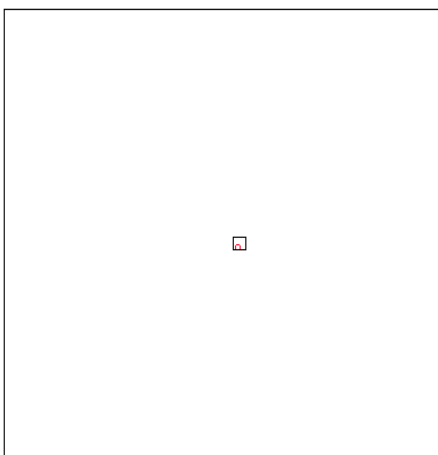
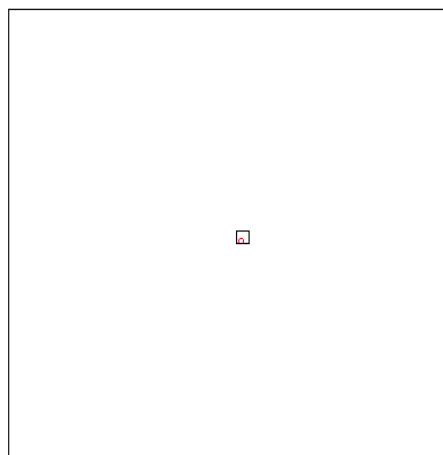
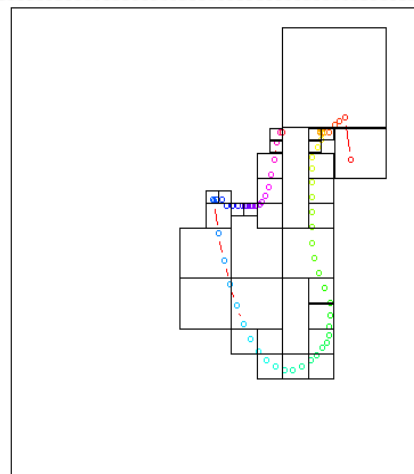
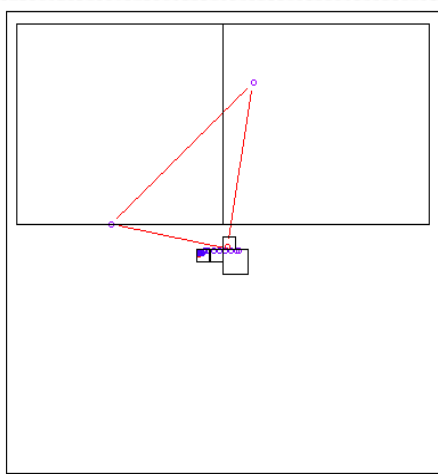
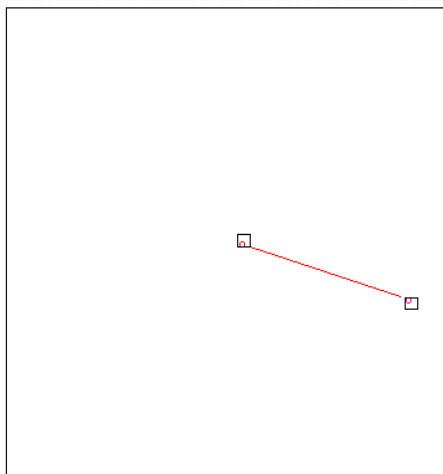
# Result



- Step1: Comparison based on coordinate data
- Step2: Comparison based on state transitions

# Result

- Errant trajectories



# Conclusions

- We proposed dynamic map division for each trajectory and two comparison methods.
  - Based on coordinate data
  - Based on state transitions
- Evaluation
  - Our method could separate players exactly.