ANALYSIS OF USER TRAJECTORIES
BASED ON DATA DISTRIBUTION
AND STATE TRANSITION:
A Case Study with a Massively Multiplayer Online Game
Angel Love Online

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Background

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

The next step is

Similar to shoplifting’s behavior.

His behavior is suspect.
Research Problems

- Traditional model
- The state set is definite
- Over-approximate trajectories
- Cannot expressed exactly small movements

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Lost features

State series
1, 3, 9, 11, 11, 11, 11, 11, 11, 12, 15, 16

time series state transition

\[ t (x, y) \rightarrow \text{State} \]

1 \((x_1, y_1)\) → \(h_1\)

2 \((x_2, y_2)\) → \(h_2\)

3 \((x_3, y_3)\) → \(h_3\)

\[ \vdots \]
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 data distribution
  - The comparing method based on state transition

State series: 1, 3, 9, 17, 19, 20, 18, 17, 18, 12, 15, 16

Divide into suitable states

Express the detail of the trajectory
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
Outline of Our Approach

Dynamic Map Division

- Comparison method based on data distribution
  - Clustering with Ward method

- Comparison method based on state transition
  - Clustering with Ward method

Dynamic Map Division

Comparison method based on data distribution
- Clustering with Ward method
  - cluster 1
  - cluster 2

Comparison method based on state transition
- Clustering with Ward method
  - cluster 1
  - cluster 2
  - cluster 3
  - cluster 4
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.
Comparison Method based on Data Distribution

- Represented by bit sequences
- Evaluate difference by Hamming distance

Hamming distance: 3

(A, B)

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(R, 0 1 1 0)

XO

0 1 1 0

1 1 1 0

1 0 1

2

3

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1

1
Hamming distance of quadtree

The initial state

Extension of the tree

Deletion of nodes
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
time state series transition

$t \ (x, y) \rightarrow h_1$

$2 \ (x_2, y_2) \rightarrow h_2$

$3 \ (x_3, y_3) \rightarrow h_3$

$\vdots$

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

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

$\vdots$

$a_{n1}, a_{n2}, \ldots, a_{nn}$
time state series transition

\[ \begin{align*}
1 \quad & \left( x_1, y_1 \right) \rightarrow \text{state } h_1 \\
2 \quad & \left( x_2, y_2 \right) \rightarrow \text{state } h_2 \\
3 \quad & \left( x_3, y_3 \right) \rightarrow \text{state } h_3 \\
& \quad \vdots \\
\end{align*} \]

\[ \begin{align*}
a_{11}, a_{12}, \ldots, a_{1n} \\
a_{21}, a_{22}, \ldots, a_{2n} \\
& \quad \vdots \\
a_{n1}, a_{n2}, \ldots, a_{nn} \\
\end{align*} \]

adjustment roll-up
Comparison based on state transition

- 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 transition

- Roll-up algorithm
  ① Before and after transition areas are unified area.

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\[ a_{11} = \frac{a_{55} + a_{56} + a_{57} + a_{58} + a_{65} + a_{66} + a_{67} + a_{68} + a_{75} + a_{76} + a_{77} + a_{78} + a_{85} + a_{86} + a_{87} + a_{88}}{4} \]
Comparison based on state transition

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

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\[ a_{12} = \frac{(a_{52} + a_{62} + a_{72} + a_{82})}{4} \]
\[ a_{13} = \frac{(a_{53} + a_{63} + a_{73} + a_{83})}{4} \]
\[ a_{14} = \frac{(a_{54} + a_{64} + a_{74} + a_{84})}{4} \]
Comparison based on state transition

- Roll-up algorithm
  ③ After transition area is unified area.

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a21 = a25 + a26 + a27 + a28
a31 = a35 + a36 + a37 + a38
a41 = a45 + a46 + a47 + a48
Comparison Method based on State Transition

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

\[ \text{Weighting} = \frac{D_{\text{max}} - D + 1}{D_{\text{max}}} \]

\[ D_{\text{max}} \] is the max number of division times. \( D \) is the number of division times of the area.

\[ \text{Dist}_{ij} = \frac{1}{A} \sum_{m=1}^{A} \sum_{l=1}^{A} w_m w_l |a_{lm}(i) - a_{lm}(j)| \]

\( A \) is the number of areas in the derived state.
Experiment I

- **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**

<table>
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<th>Method</th>
<th>Entropy</th>
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<td>Dynamic map division for all trajectory data</td>
<td>1.58</td>
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<td>Our method</td>
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- **Step 1:** Comparison based on data distribution
- **Step 2:** Comparison based on state transition
Result

- Errant trajectories

A trajectory of human
Experiment II

- Angel Love Online
  - About 70 hours
  - 394 trajectories

- Map
  - A facility to help
  - Distributed enemies

- Purpose
  - To give a case study in understanding players
Typical Result

- Cluster #2 (out of 21 clusters)
  - Map division and transitions
  - No movement in the left of map
  - A lot of transitions below the map
  - Small rectangles and no arrow
Conclusions

- We proposed
  - Dynamic Map Division
  - Comparison Methods
    - Based on data distribution
    - Based on state transition
- We experimented with
  - Quake II
  - ALO