Modeling Herds and Their Evolvements from Trajectory Data

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Outline

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Trajectories of Moving Objects

- Many moving objects exist in the air, on the ground, or in the ocean.
- A single trajectory is the time-stamped path of a moving object through space over time.

Illustrations of Herds

- Given a set of trajectories, we propose a new spatio-temporal pattern named **Herd**.

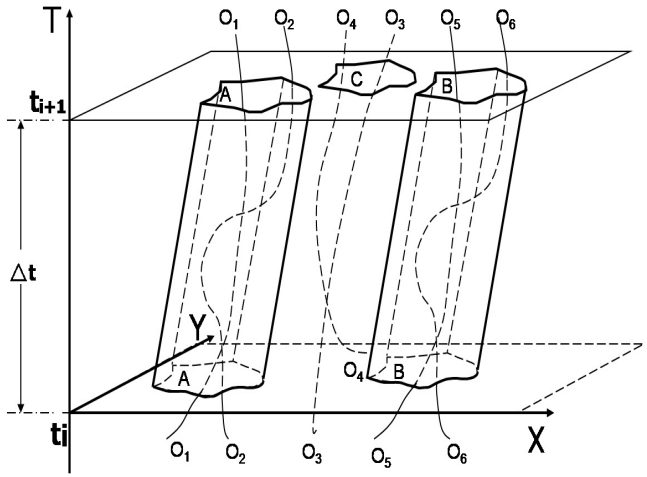
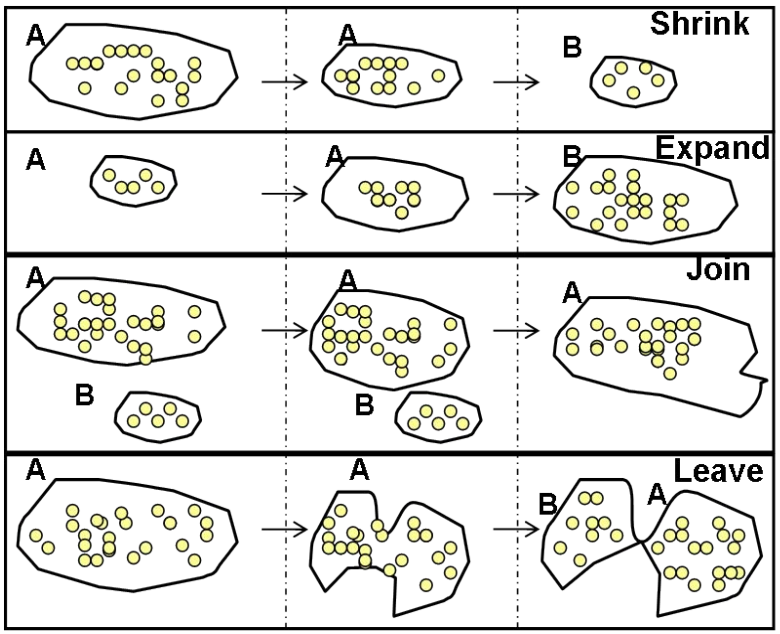


Figure: Trajectories and Herds

We have six trajectories ($O_1, O_2, .., O_6$) over two time snapshots. Suppose we have A, B clusters in snapshot t_i and they will evolve into A, B, C clusters in snapshot t_{i+1}, where C is a new cluster formed in t_{i+1}.

The Dynamics and Mobilities of Herds

- Herds form different groups in the course of the migrations and other behaviors of their members.
- In our work, we further categorize herd's evolvements as **expand, join, shrink, and leave**.



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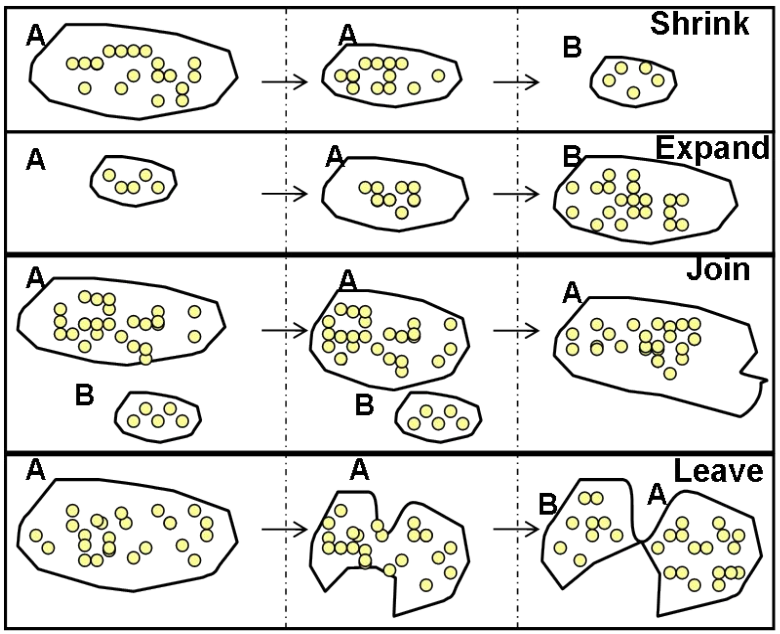

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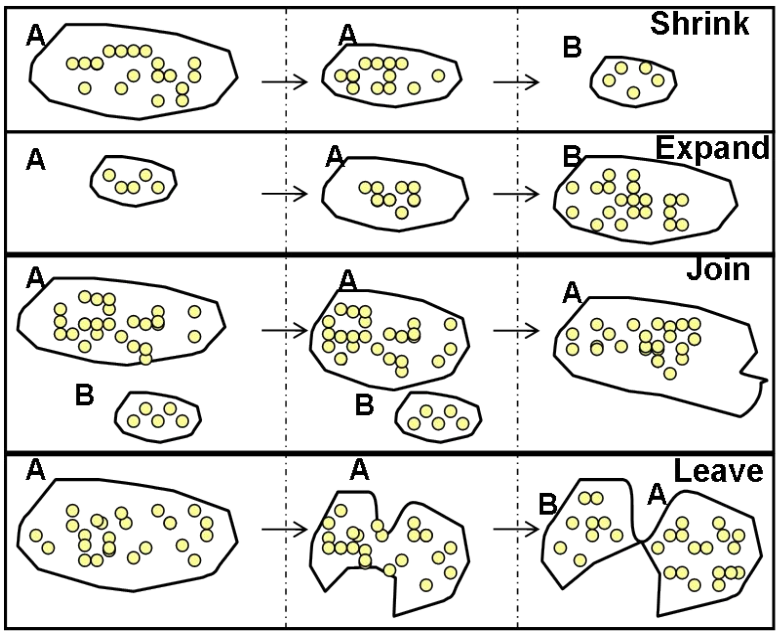

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Trajectory Data Analysis

- **Transformations of Spatial Entity [5, 7, 8]**
  Measuring changes such as shape, size, orientation, and location
- **Single Trajectory Analysis [2, 13, 4, 12]**
  Depicting one specific moving entity, it mainly focuses on looking for individual spatial patterns, and creating predictive models for the moving entity.
- **Multiple Trajectory Analysis [1, 10, 3, 11, 6, 9]**
  Detecting generic *spatial-temporal patterns* such as flock, leadership, convergence etc.
- We proposed another *spatial-temporal pattern*: Herd by exploring their quantitative changes and qualitative changes during their interactions over time.

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Measurements in IR

Traditionally, the *Precision(P), Recall(R) and F-Score(F)* measurements have been used for evaluating the performance of information retrieval systems.

- $$Recall = \frac{|relevant\ documents| \bigcap |retrieved\ documents|}{|relevant\ documents|}$$
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Adoption of Measurements in *Herd*

If we treat moving entities in trajectory data as documents in retrieval system. We have

$$R(H(t), H'(t+i)) = \frac{|H(t) \bigcap H'(t+i)|}{|H(t)|}$$

where $H(t)$ is a herd snapshot at time t and $H'(t+i)$ is another herd snapshot at time $t+i$.

$$P(H(t), H'(t+i)) = \frac{|H(t) \bigcap H'(t+i)|}{|H'(t+i)|}$$

$$F(H(t), H'(t+i)) = \frac{2 \times P(H(t), H'(t+i)) \times R(H(t), H'(t+i))}{P(H(t), H'(t+i)) + R(H(t), H'(t+i))}$$

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Derivations of *F, P, R in* Herd

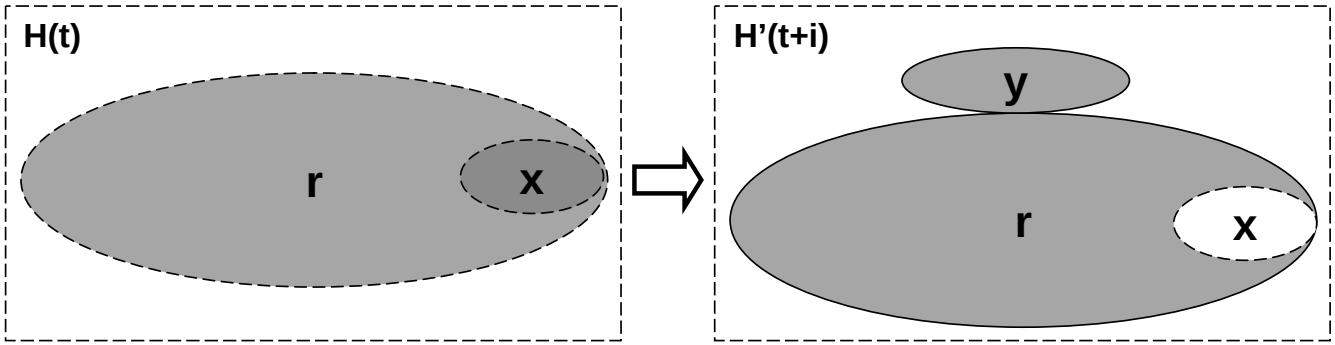

Figure: Generic Herd's Evolvements from t to $t + i$

The *recall* is:

$$R(H(t), H'(t+i)) = \frac{|r|}{|r| + |x|}$$

where $|r \cup x|$ denoting the members of a herd snapshot $H(t)$ at time t.

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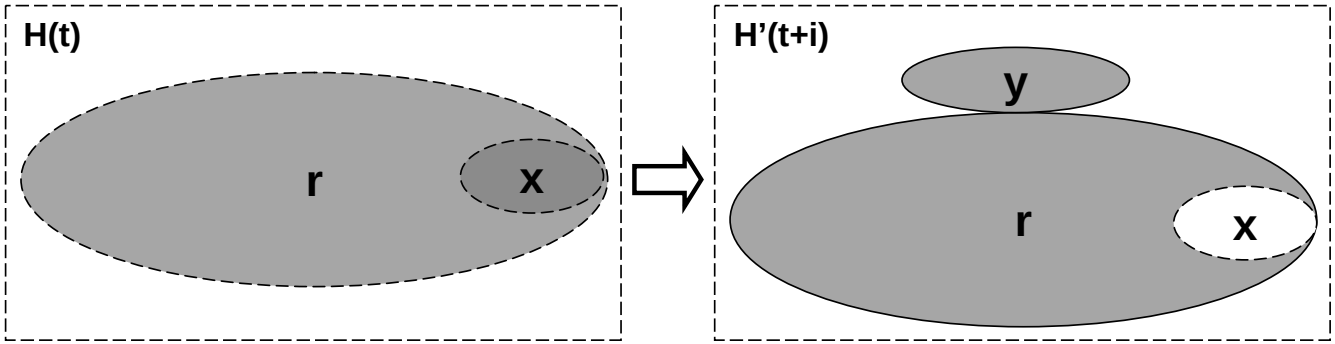

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The *precision* is:

$$P(H(t), H'(t+i)) = \frac{|r|}{|r| + |y|}$$

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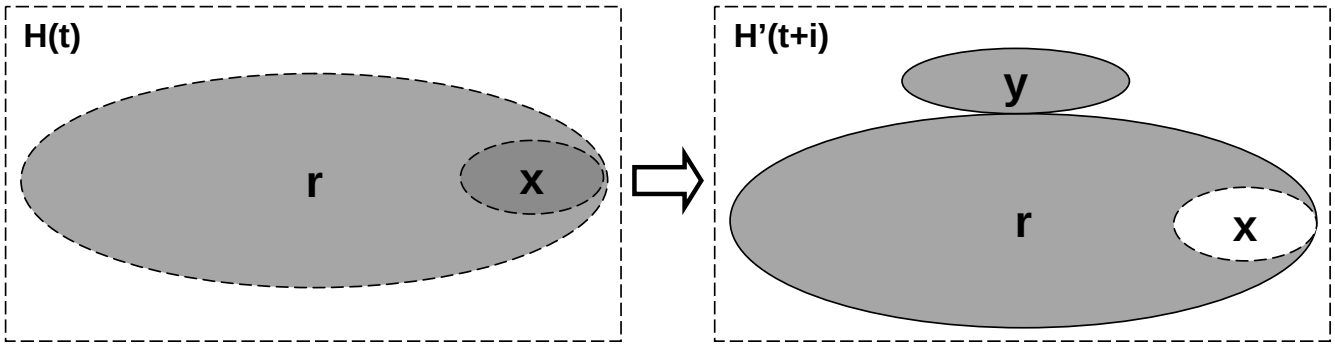

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F-score will be(please note that r,x,y are disjoint):

$$F(H(t), H'(t+i)) = \frac{2 \times P \times R}{P+R} = \frac{2 \times \frac{|r|}{|r \cup y|} \frac{|r|}{|r \cup x|}}{\frac{|r|}{|r \cup y|} + \frac{|r|}{|r \cup x|}} = \frac{2 \times |r|}{2 \times |r| + |x| + |y|}$$

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Measuring Quantitative and Qualitative Changes

We consider that herd undergoes:

- **quantitative** change if $|x| + |y| < |r|$, that is:

$$F(H(t), H'(t+i)) > \frac{2}{3}$$

- **qualitative** change if $|x| + |y| \geq |r|$, that is:

$$F(H(t), H'(t+i)) \leq \frac{2}{3}$$

Measuring Quantitative and Qualitative Changes

For **qualitative** change, it can be further divided into the following scenarios:

- $H(t)$ is shrank or left by others into $H'(t+i)$. When $|x| \geq |r|$ and $|y| < |r|$, that is,

$$R(H(t), H'(t+i)) = \frac{|r|}{|r \cup x|} \leq \frac{1}{2}, P(H(t), H'(t+i)) = \frac{|r|}{|r \cup y|} > \frac{1}{2}$$

- $H(t)$ is expanded or be joined into $H'(t+i)$. When $|y| \geq |r|$ and $|x| < |r|$, that is,

$$R(H(t), H'(t+i)) = \frac{|r|}{|r \cup x|} > \frac{1}{2}, P(H(t), H'(t+i)) = \frac{|r|}{|r \cup y|} \leq \frac{1}{2}$$

- Otherwise, $H(t)$ and $H'(t+i)$ do not have a relationship.

Measuring Quantitative and Qualitative Changes

We summarize the breakdown of various *qualitative changes* in following table.

Table: Qualitative Changes Based on P, R When $F \leq \frac{2}{3}$

$F < \frac{2}{3}$	$P > \frac{1}{2}$	$P \leq \frac{1}{2}$
$R \leq \frac{1}{2}$	Shrink or Split	No Relationship
$R > \frac{1}{2}$	No Relationship	Expand or Merge

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Herd Interaction Graph

- We used *Herd Interaction Graph, or Herding, to represent* Herd's *qualitative* and *quantitative* changes in their membership, such as expand, join, shrink, and leave.

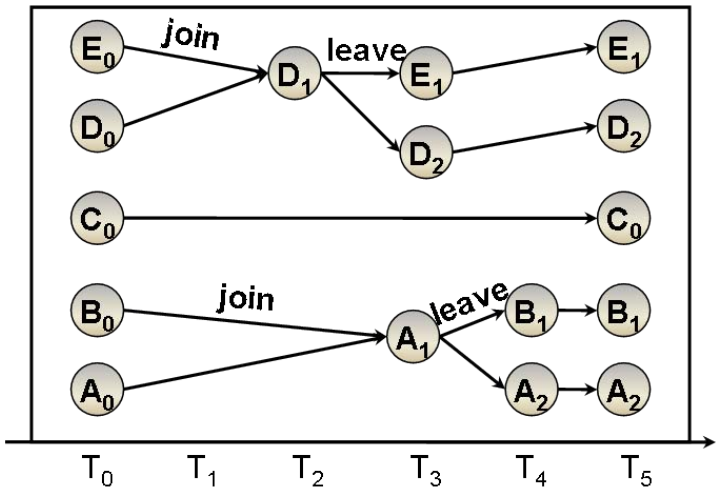

Figure: Graph representing Herds' Evolvements

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Evaluation of Our Herding Model

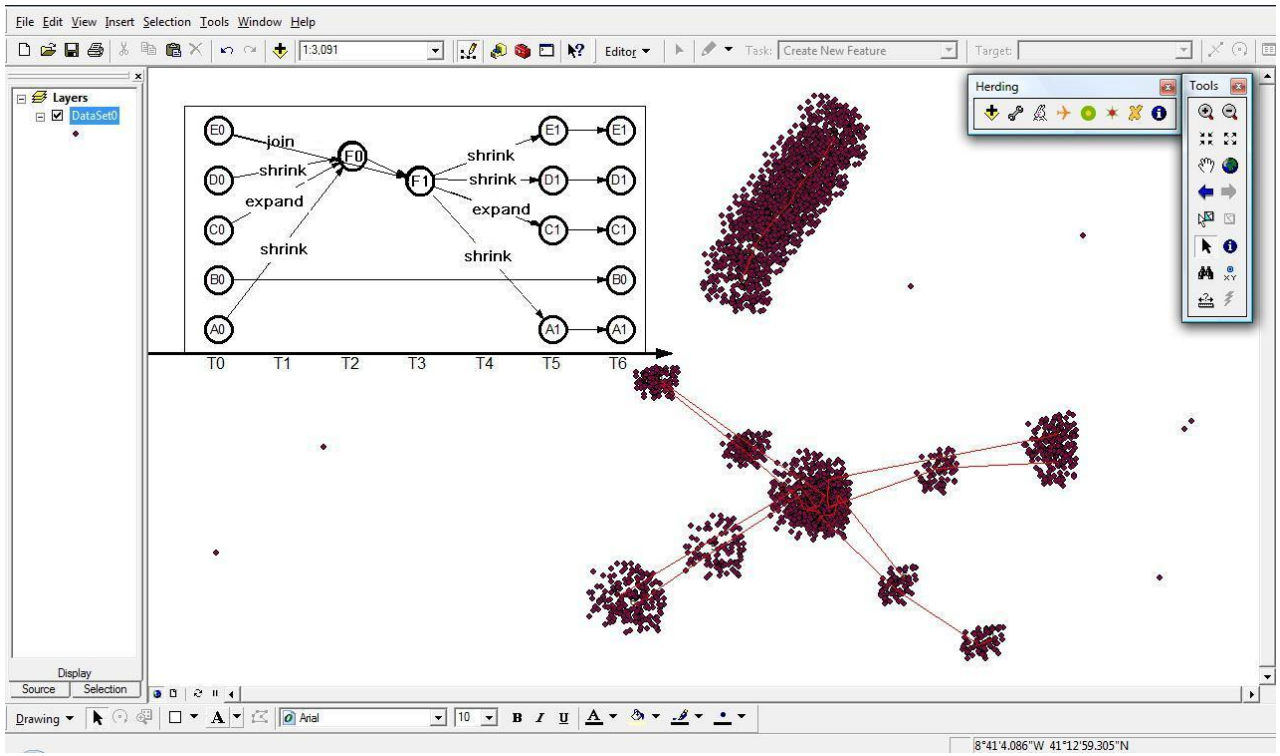

Figure: Herd Interaction Graph in ArcGIS using Synthetic Data

Summary

- Modeling the dynamics in membership for moving objects is a challenging task in general.
- We modeled Herds along with their quantitative and qualitative changes during their temporal interactions.
- We used a general graph to visualize *Herd's dynamical changes in membership*.

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