QUANTIFYING SPATIO-TEMPORAL ANIMAL INTERACTIONS USING PROBABILISTIC SPACE-TIME PRISMS

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Quantifying animal interactions

From an ecological perspective: animal interactions are important for understanding population and community dynamics
Quantifying animal interactions

Include intra- and inter-species interactions

Intra-species

(individuals of same species)

- Courtship and mating
- Social activity
- Flocking or herding
- Territorial defense
- etc.
Quantifying animal interactions

Include intra- and inter-species interactions

Inter-species

(Individuals of diff. species)

- Predator-prey
- Competition
- Parasitism
- Mutualism
- etc.
Quantifying animal interactions

From a GIS perspective—interactions are an interesting problem since individuals must be at the same place at the same time in order to physically interact.
Quantifying animal interactions

From a GIS perspective—interactions are an interesting problem since individuals must be at the same place at the same time in order to physically interact.

**Questions**

- Could two or more individuals have interacted?
- What is the probability that they interacted?
- Where/when did they possibly or probably interact?
- How often do they interact?
Quantifying animal interactions

My approach quantifies **probabilities** of **when** and **where** animals could have interacted → using methods of time geography
Quantifying animal interactions

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→ using methods of time geography

**Method**

- Requires tracking data
- Points do not need to be taken at exactly the same time
- Uses probabilistic space-time prisms
Basics of probabilistic space-time prisms
Computing the space-time prism

The STP maps—in space and time—all of the potential locations for an object from tracking data.
Computing the space-time prism

We can also map the STP using voxels -- a raster based approach

Voxel = volume element, or cube in 3D space-time; Represents an area at a particular time
Computing the space-time prism

Geovisualized using voxel centroids
Computing the space-time prism

Geovisualized using voxel centroids

Space-time disk—collection of all accessible cells at a given time step
Probabilistic Space-time prisms

Probabilistic STPs are a recent development; assign probabilities to each voxel in each space-time disk
Probabilistic Space-time prisms

Probabilistic STPs are a new development; assign probabilities to each space-time disk

Accomplished by applying distance-weighting function to each disk; use it to weight probabilities in the disk
(here shown as raster cells though all calculations done at voxel centroids)

\[
P(STP_l) = \frac{1}{\sum_{l \in L_k} \frac{1}{\|x_s - x_l\|}}
\]

Intersection with space-time path
Probabilistic Space-time prisms

The result quantifies the probability of where an object was at any time (each voxel has a probability—calculated and recorded from its centroid).

One voxel in disk, \( P = 1 \)

Probability outside disk = 0

Probs. of voxels in same disk must sum to 1.
quantify animal interactions

→ By intersecting prisms and using probability equations
Example of 3 zebras tracked simultaneously
(tracking data from Wang et al.)
Resulting probabilistic space-time prisms
Resulting probabilistic space-time prisms

A number of interaction probabilities of interest
1. **Probability** that zebras (A and B) were at a specific location at a specific time

In other words: probability of interacting at the same voxel at the same time (as measured from the centroid—so has to be possible for them physically interact)
1. **Probability** that zebras (A and B) were together at a specific location at a specific time

\[
P(A \cap B)_{l_{b,a}} = P(A)_{l_{b,a}} \times P(B)_{l_{b,a}}
\]
Probabilistic Space-time prisms

1. **Probability** that zebras (A and B) were together at a specific location at a specific time

   equivalent to multiplying intersecting voxels

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(space-disks for time 1)
1. **Probability** that zebras (A and B) were together at a **specific location** at a **specific time**

*calculated for every voxel in a map; (stored as rasters for each time step)*
Probabilistic Space-time prisms

1. **Probability** that zebras (A and B) were together at a specific location at a specific time.

   *calculated for every voxel in a map; (stored as rasters for each space – time disk)*

   But more useful to summarize these results in different ways ⇒ use them to calculate others.
Probabilistic Space-time prisms

2. **Probability** that zebras (A and B) were together at a specific time (any location)
Probabilistic Space-time prisms

2. **Probability** that zebras (A and B) were together at a specific time (any location)

\[ P(A \cap B)_{t_b} = \bigcup \left[ P(A \cap B)_{l_b,1} \right] \bigcup \left[ P(A \cap B)_{l_b,2} \right] \bigcup \ldots \bigcup \left[ P(A \cap B)_{l_b,m} \right] \]

calculated as the union of all voxels in corresponding space – time disks
Probabilistic Space-time prisms

2. **Probability** that zebras (A and B) were together at a specific time (any location)

\[ P(A \cap B)_{t_b} = \]
\[ [P(A \cap B)_{l_b,1}] \text{ OR } [P(A \cap B)_{l_b,2}] \text{ OR } \ldots \text{ OR } [P(A \cap B)_{l_b,m}] \]

which can be written as an OR statement
Probabilistic Space-time prisms

2. **Probability** that zebras (A and B) were together at a
   at a specific time (any location)

\[
P(A \cap B)_{t_b} = \\
[P(A \cap B)_{l_b,1}] + \\
[P(A \cap B)_{l_b,2}] + \\
... +... \\
[P(A \cap B)_{l_b,m}]
\]

*In other words, we sum the interaction probabilities for all voxels in the overlapping space – time disks to get total probability*
2. **Probability** that zebras (A and B) were together at a specific time (any location)

Add all of these up for time step b

\[ P(A \text{ AND } B)_{t_2} = 0.111 \]
2. **Probability** that zebras (A and B) were together at a specific time (any location)

=summing across all space–time disks: probability clock (12 hour period) for two zebras
2. Probability that zebras (A and B) were together at a specific time (any location)
3. **Probability** that zebras (A and B) were together at a specific location (at any time)
3. **Probability** that zebras (A and B) were together at a
at a specific location (at any time)

**Results:** *probability map of interactions*

(derived from probabilities at each cell over all time steps—iterative OR calculation)
Results: probability map of interactions
4. **Probability** that zebras (A and B) were together at all locations at any time (i.e. interacted at least once)

<table>
<thead>
<tr>
<th>Zebras</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>A AND B</td>
<td>0.9999</td>
</tr>
<tr>
<td>A AND C</td>
<td>1.0000</td>
</tr>
<tr>
<td>B AND C</td>
<td>0.4778</td>
</tr>
<tr>
<td>A AND B AND C</td>
<td>0.0093</td>
</tr>
</tbody>
</table>
Conclusions

- Probabilistic space-time prisms offer a new way to quantify animal interactions in space and time
- Many options for visualizing and summarizing interactions
• But, computationally expensive:
  • Prism (points layer)—millions of voxels
  • → 1 raster file for each space-time disk (lots of cells)
  • → calculations done by multiplying and adding successive rasters iteratively
  • → RAM, data intensive

• Assumes animals are independent
• Important to understand how resolution impacts the results