A New Mathematical Technique for Geographic Profiling

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Geographic Profiling

- The Question:
  Given a series of linked crimes committed by the same offender, can we make predictions about the anchor point of the offender?

- The anchor point can be a place of residence, a place of work, or some other commonly visited location.
Implementation

- CrimeStat
  - Ned Levine
- Dragnet
  - David Canter
- Rigel
  - Kim Rossmo
- Predator
  - Maurice Godwin
Current Techniques

- Spatial distribution strategies
- Probability distance strategies
Spatial Distribution Strategies

Centroid:
- Use the average value of the crime coordinates
Spatial Distribution Strategies

- Center of minimum distance:
  - Find the point where the sum of the distance to all crime sites is minimized.

![Diagram showing anchor point and crime locations with distance sums]

- Distance sum = 10.63
- Distance sum = 9.94
- Smallest possible sum!
Spatial Distribution Strategies

Circle Method:

- Use the center of the smallest circle that encloses all crime scenes
Probability Distribution Strategies

- The anchor point is located in a region with a high “hit score”.
- The hit score $H(z)$ has the form

$$H(z) = \sum_{i=1}^{n} h(z, x_i)$$

$$= h(z, x_1) + h(z, x_2) + \cdots + h(z, x_n)$$

where $x_i$ are the crime locations and $h(z, x)$ has a defined form.
Probability Distribution Strategies

- Linear:
  \[ h(z, x) = a - b |x - z| \]
Probability Distance Strategies

- Negative exponential
  \[ h(z, x) = A \exp(-B |x - z|) \]
Probability Distance Strategies

- Normal distribution

\[ h(z, x) = A \exp\left(-B |x - z|^2\right) \]
Probability Distance Strategies

- Truncated negative exponential:
Shortcomings

- What is the theoretical justification?
  - What assumptions are being made about criminal behavior?
  - What mathematical assumptions are being made?
  - How do you check the assumptions?
Shortcomings

- How do you add in local information?
- How could you incorporate socio-economic variables into the model?

Snook, *Individual differences in distance travelled by serial burglars*
Malczewski, Poetz & Iannuzzi, *Spatial analysis of residential burglaries in London, Ontario*
Bernasco & Nieuwbeerta, *How do residential burglars select target areas?*
Osborn & Tseloni, *The distribution of household property crimes*
Shortcomings

- The convex hull effect:
  - The anchor point always occurs inside the convex hull of the crime locations.
A New Approach

- In previous methods, the unknown quantity was:
  - The anchor point
    (spatial distribution strategies)
  - The hit score
    (probability distance strategies)
- We use a different unknown quantity.
A New Approach

- Let $P(x; z)$ be the density function for the probability that an offender with anchor point $z$ commits a crime at location $x$.
- This distribution is our new unknown.
- This has criminological significance.
  - In particular, assumptions about the form of $P(x; z)$ are equivalent to assumptions about the offender's behavior.
The Mathematics

- Given crimes located at \( x_1, x_2, \ldots, x_n \), the maximum likelihood estimate for the anchor point \( z \) is the value of \( z \) that maximizes

\[
L(z) = \prod_{i=1}^{n} P(x_i, z)
\]

or equivalently, the value that maximizes

\[
\lambda(z) = \sum_{i=1}^{n} \ln P(x_i, z)
\]

\[
= \ln P(x_1, z) + \ln P(x_2, z) + \cdots + \ln P(x_n, z)
\]
Relation to Spatial Distribution Strategies

- If we make the assumption that offenders choose target locations based only on a distance decay function in normal form, then

\[ P(\mathbf{x}; \mathbf{z}) = A \exp(-B|\mathbf{x} - \mathbf{z}|^2) \]

- The maximum likelihood estimate for the anchor point is the centroid.
Relation to Spatial Distribution Strategies

- If we make the assumption that offenders choose target locations based only on a distance decay function in exponentially decaying form, then

$$P (x; z) = A \exp (-B |x - z|)$$

- The maximum likelihood estimate for the anchor point is the center of minimum distance.
Relation to Probability Distance Strategies

- We can generate a hit score by using either

\[ L(z) = \prod_{i=1}^{n} P(x_i, z) \quad \lambda(z) = \sum_{i=1}^{n} \ln P(x_i, z) \]

- If we multiply rather than add in the usual method of probability distance strategies, we obtain our method.
Advantages

- Our method recaptures existing methods.
- Assumptions about offender behavior can be directly used in the model.
- We can explicitly incorporate information about geography and socio-economic factors into the model.
- We do not suffer from the convex hull problem.
Better Models

• Recall that $P(x; z)$ is the density function for the probability that an offender with anchor point $z$ commits a crime at the point $x$.

• Suppose that $P(x; z)$ has the general form

$$P(x; z) = K(|x - z|) \cdot G(x) \cdot N(x; z)$$

Dispersion kernel
Geographic factors
Normalization
The Simplest Case

- We have information about crimes committed by the offender only for a portion of the region.
The Simplest Case

- **Regions**
  - $\Omega$: Jurisdiction(s). Crimes and anchor points may be located here.
  - $E$: “elsewhere”. Anchor points may lie here, but we have no data on crimes here.
  - $W$: “water”. Neither anchor points nor crimes may be located here.
  - In all other respects, we assume the geography is *homogeneous*.
The Simplest Case

- We know $z \notin W$ and $P(x ; z) = 0$ if $x \notin \Omega$.
- We set
  \[
  G(x) = \begin{cases} 
  1 & x \in \Omega \\
  0 & x \notin \Omega 
  \end{cases}
  \]

  We choose an appropriate dispersion kernel; say

  \[
  K(x ; z) = \exp \left( -\frac{|x - z|^2}{\sigma^2} \right)
  \]

- The required normalization function is
  \[
  N(x ; z) = \left[ \iint_\Omega \exp \left( -\frac{|y - z|^2}{\sigma^2} \right) dy_1 dy_2 \right]^{-1}
  \]
Sample Results

Baltimore County
Vehicle Theft
Predicted Anchor Point
Offender's Home
Sample Results

- Crimes were vehicle thefts in 2003-2004.
  - Data provided by Phil Canter, Baltimore County Police Department.
- Predicted anchor point was not in the convex hull of the crime locations.
Better Models

- Method is just a modification of the centroid method that accounts for possibly missing crimes outside the jurisdiction.
- Clearly, better models are needed.
- This is ongoing work.
- More data!
Questions?

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