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

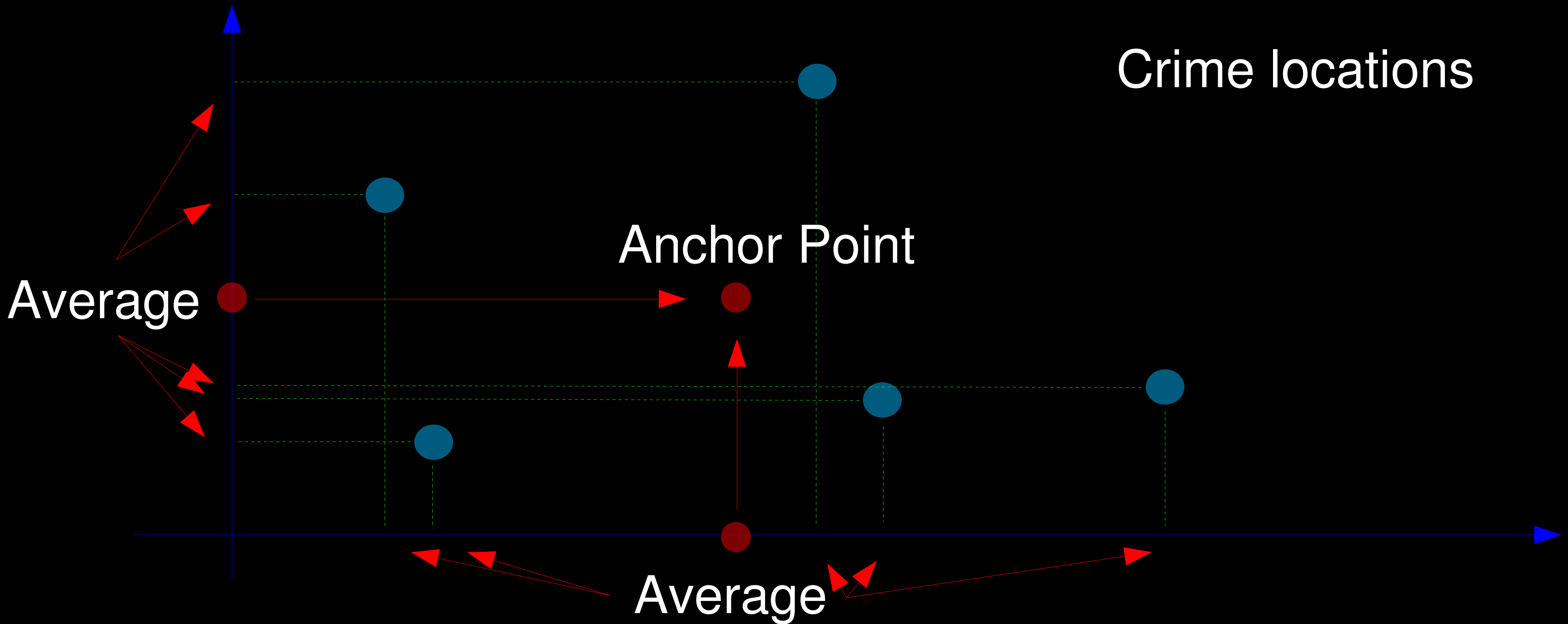
- CrimeStat
  - Ned Levine
- Dragnet
  - David Canter
- Rigel
  - Kim Rossmo
- Predator
  - Maurice Godwin

Current Techniques

- Spatial distribution strategies
- Probability distance strategies

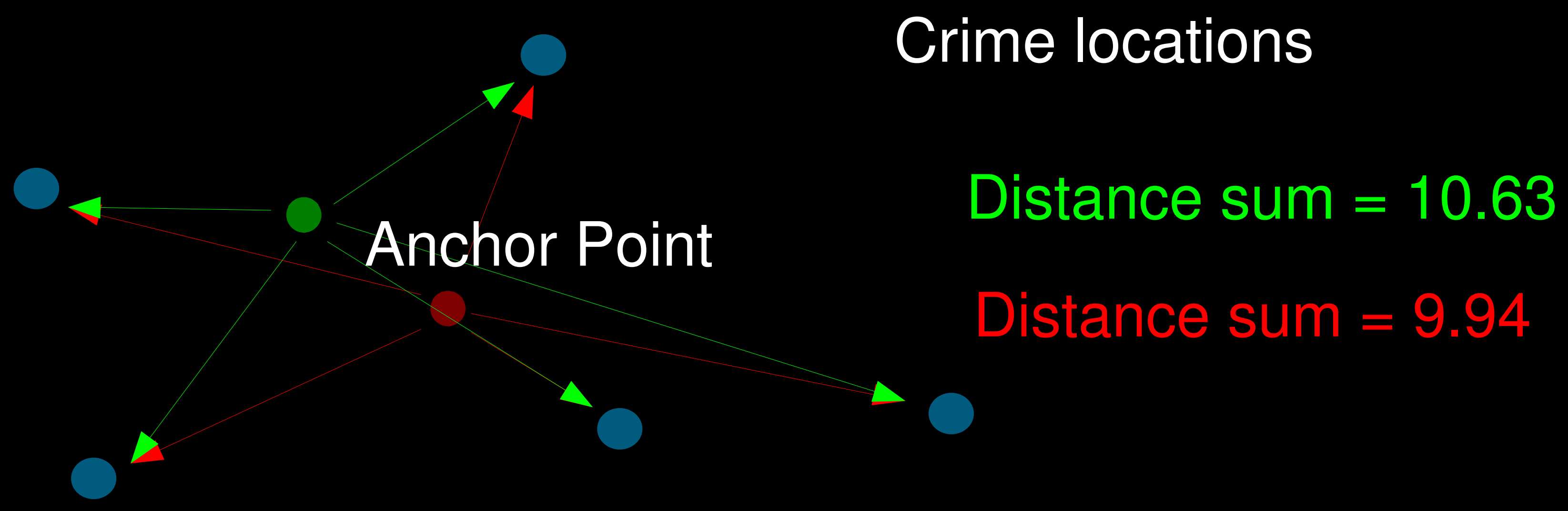
Spatial Distribution Strategies

- Centroid:
  - Use the average value of the crime coordinates



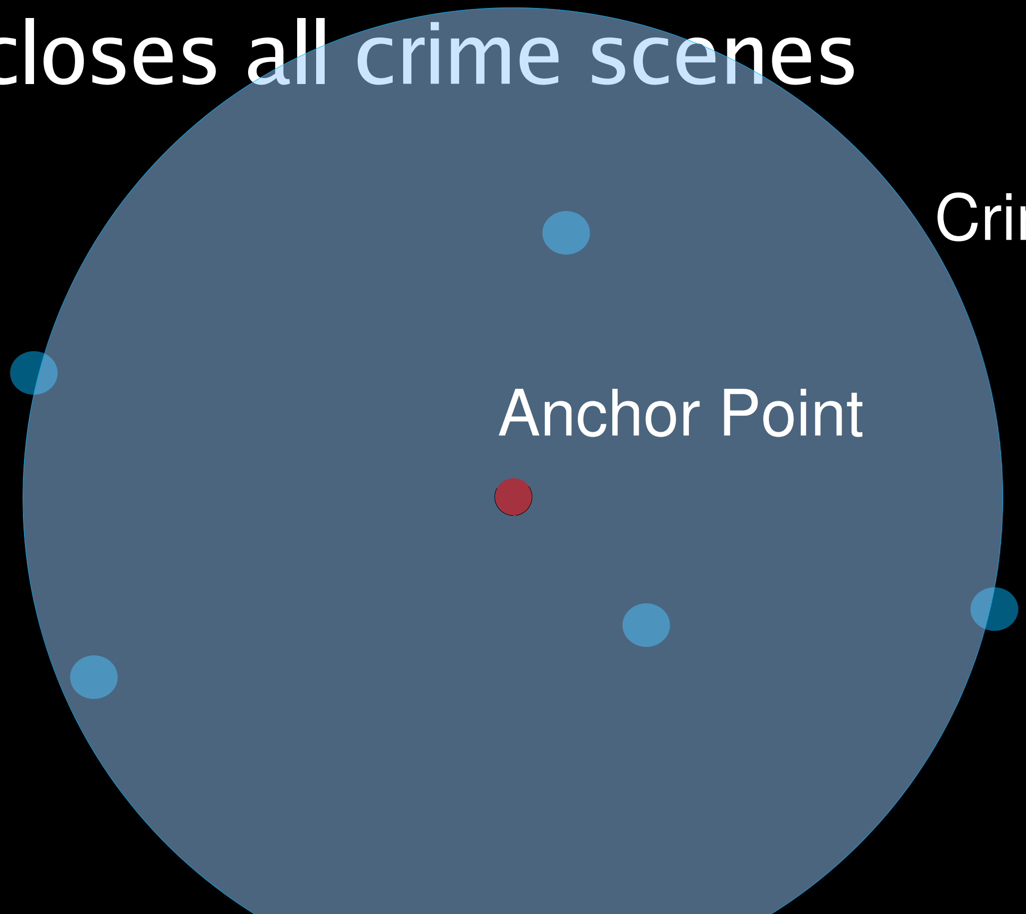
Spatial Distribution Strategies

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



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 $H(\boldsymbol{z})$ has the form

$$H(\boldsymbol{z}) = \sum_{i=1}^{n} h(\boldsymbol{z}, \boldsymbol{x}_i)$$
$$= h(\boldsymbol{z}, \boldsymbol{x}_1) + h(\boldsymbol{z}, \boldsymbol{x}_2) + \cdots + h(\boldsymbol{z}, \boldsymbol{x}_n)$$

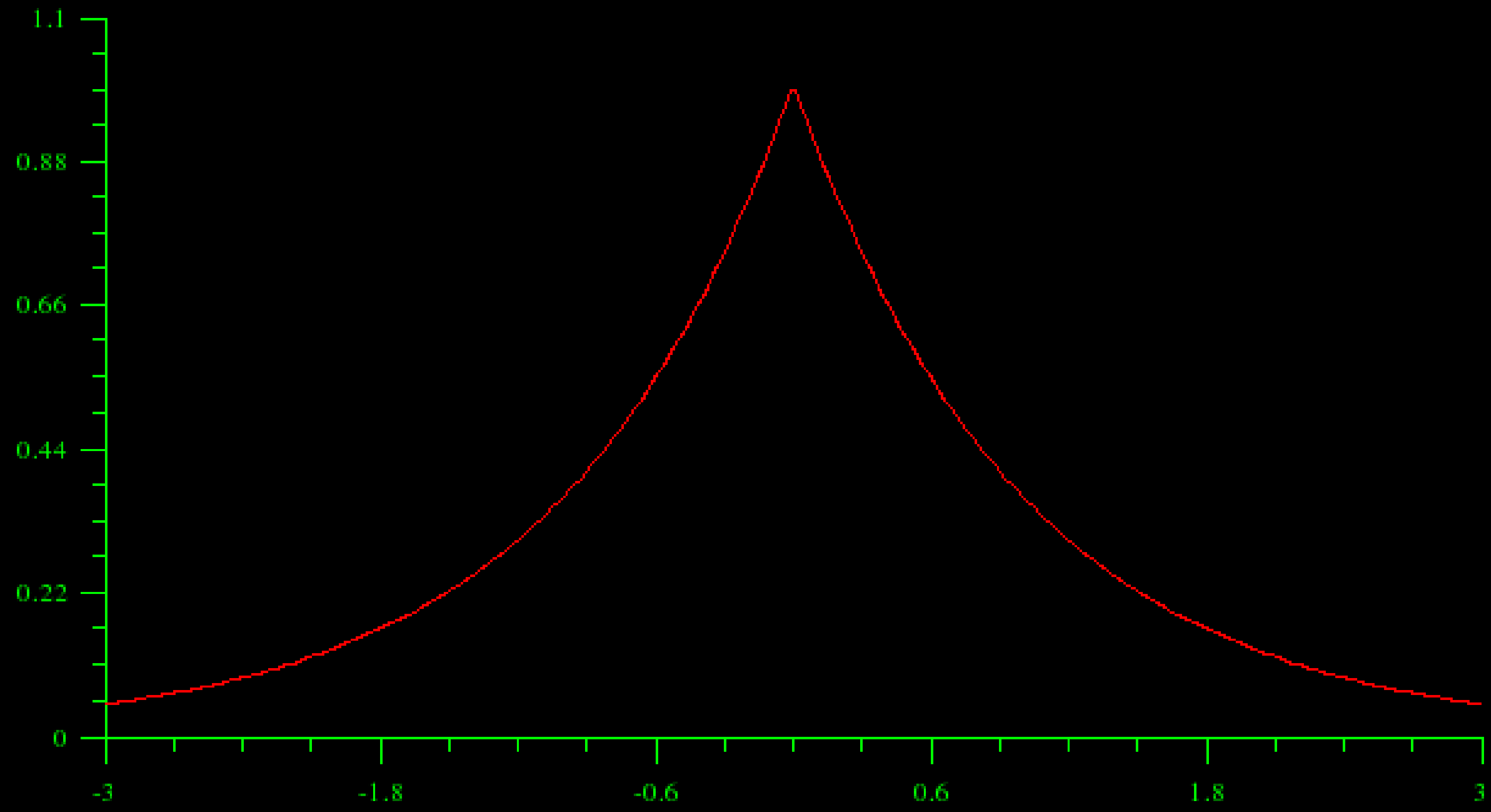
where $\boldsymbol{x}_i$ are the crime locations and $h(\boldsymbol{z}, \boldsymbol{x})$ has a defined form.

Probability Distribution Strategies

- Linear:
  - $h(\boldsymbol{z}, \boldsymbol{x}) = a - b|\boldsymbol{x} - \boldsymbol{z}|$

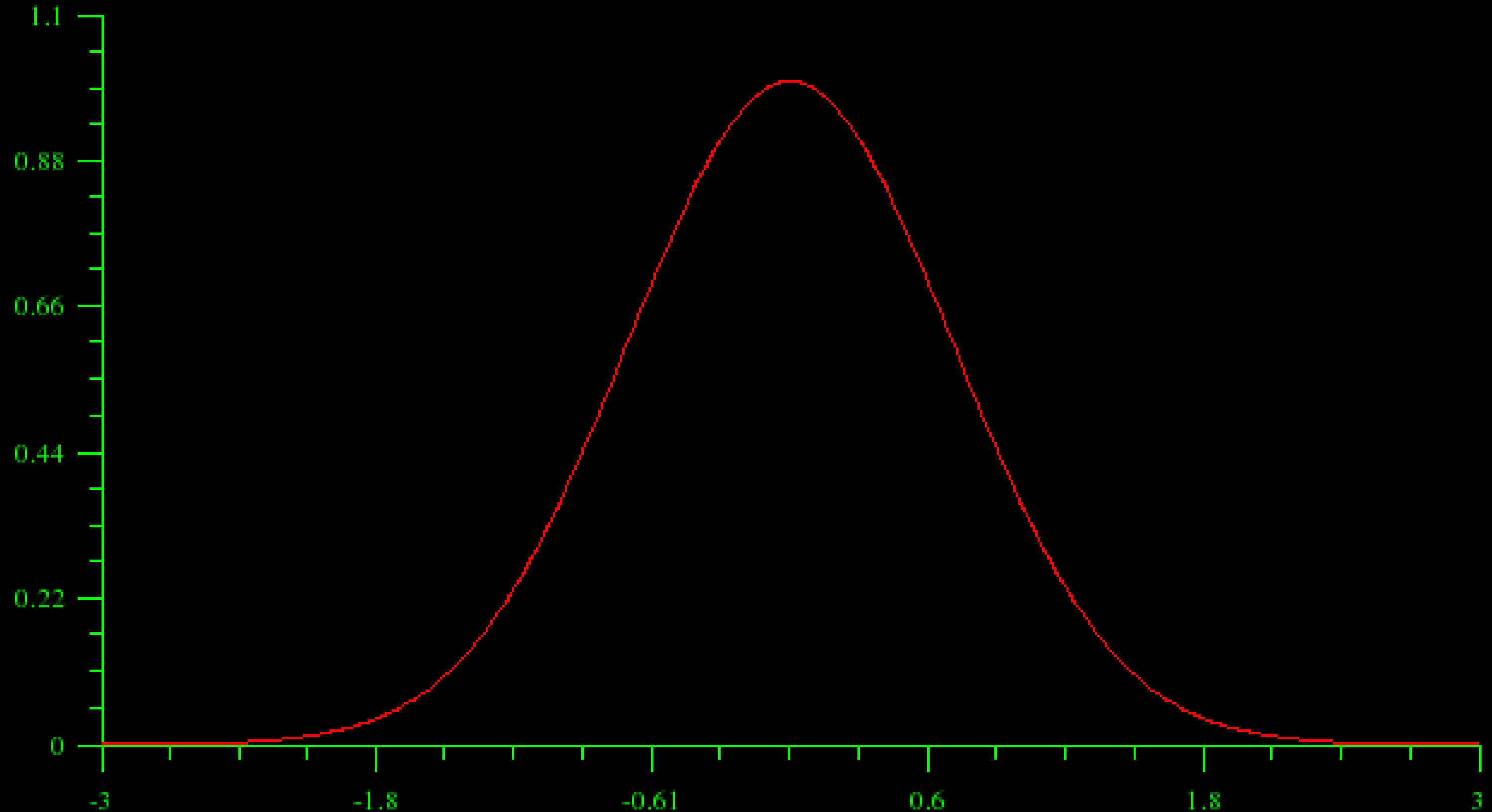
Probability Distance Strategies

- Negative exponential
  - $h(\boldsymbol{z}, \boldsymbol{x}) = A \exp(-B|\boldsymbol{x} - \boldsymbol{z}|)$



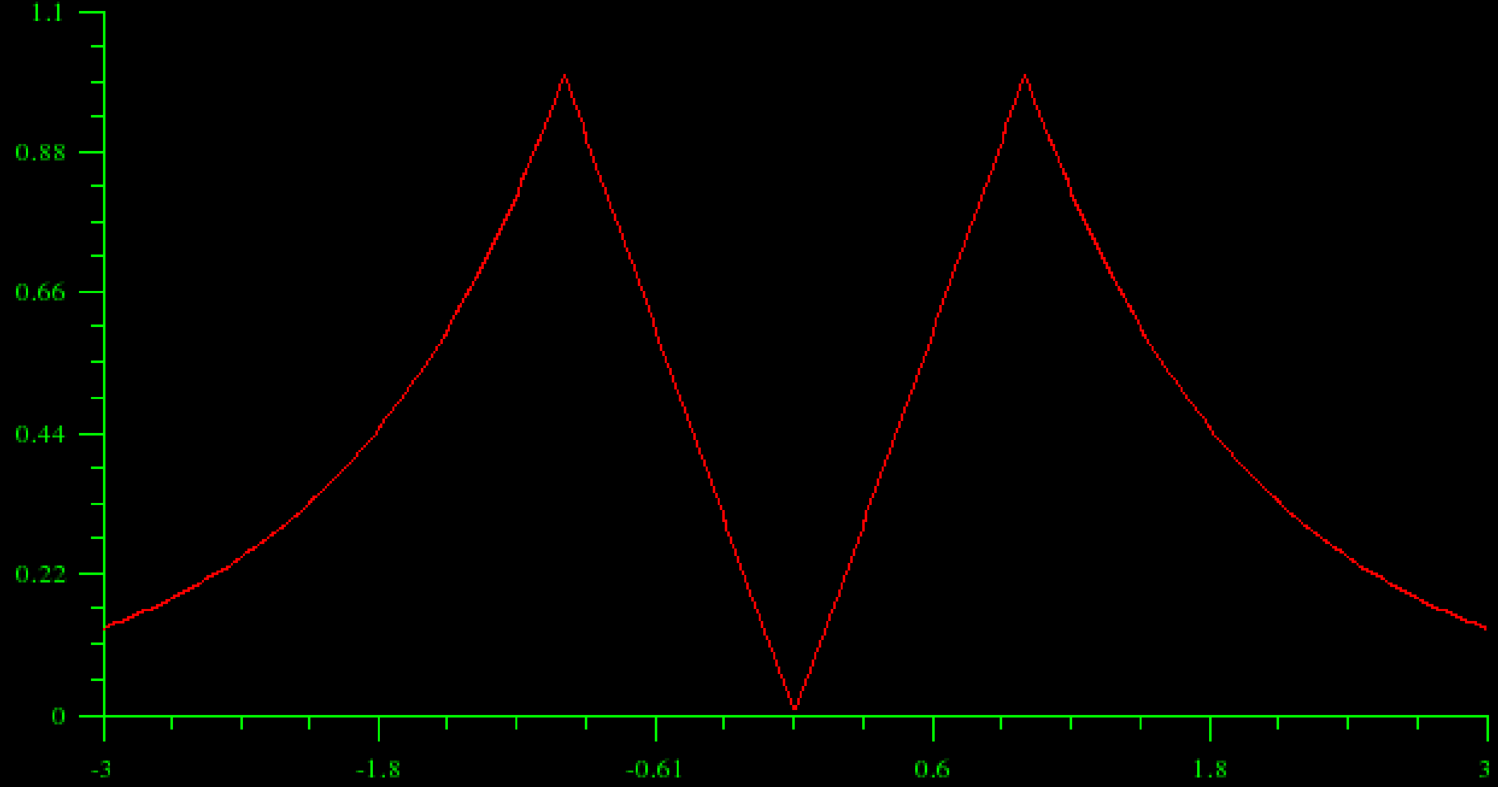
Probability Distance Strategies

- Normal distribution
  - $h(\boldsymbol{z},\boldsymbol{x}) = A\exp\left(-B\left|\boldsymbol{x}-\boldsymbol{z}\right|^2\right)$



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?

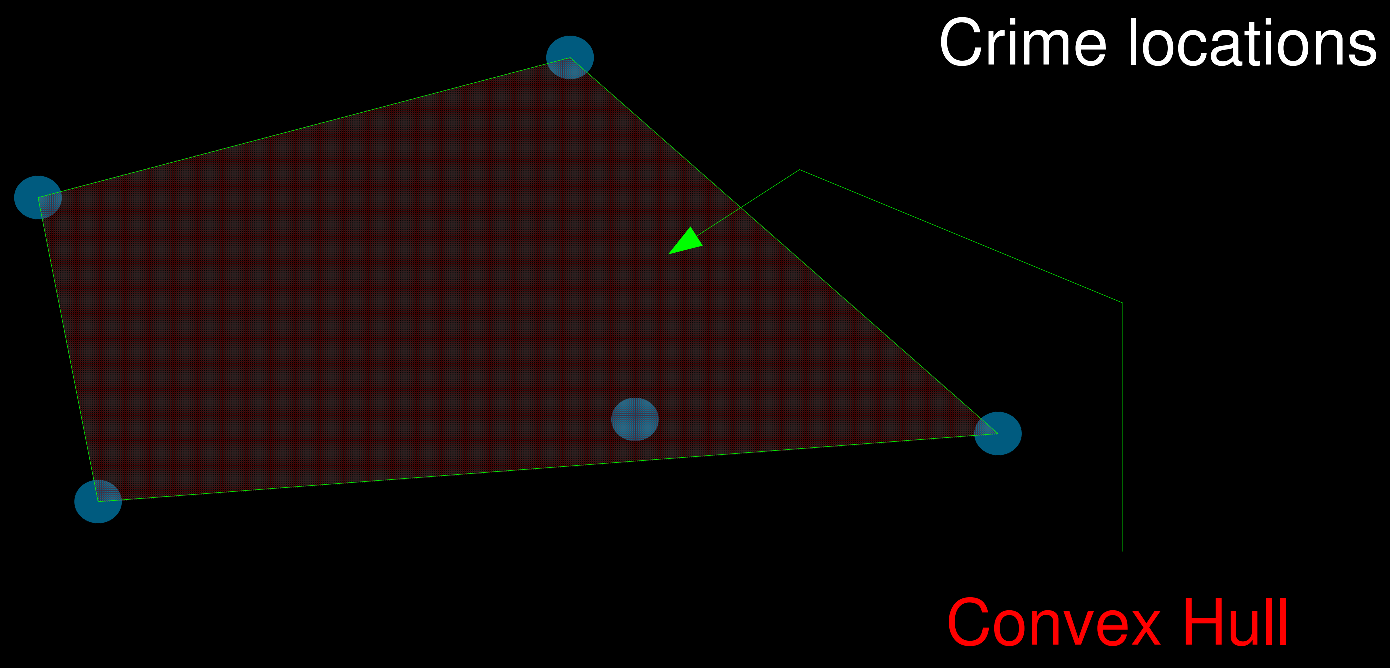
Shortcomings

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

The Mathematics

- Given crimes located at $\mathbf{x}_1, \mathbf{x}_2, \cdots, \mathbf{x}_n$ the *maximum likelihood estimate* for the anchor point $\mathbf{z}$ is the value of $\mathbf{z}$ that maximizes

$$L(\mathbf{z}) = \prod_{i=1}^{n} P(\mathbf{x}_i, \mathbf{z})$$

$$= P(\mathbf{x}_1, \mathbf{z}) P(\mathbf{x}_2, \mathbf{z}) \cdots P(\mathbf{x}_n, \mathbf{z})$$

or equivalently, the value that maximizes

$$\lambda(\mathbf{z}) = \sum_{i=1}^{n} \ln P(\mathbf{x}_i, \mathbf{z})$$

$$= \ln P(\mathbf{x}_1, \mathbf{z}) + \ln P(\mathbf{x}_2, \mathbf{z}) + \cdots + \ln P(\mathbf{x}_n, \mathbf{z})$$

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

$$P(\boldsymbol{x};\boldsymbol{z}) = A\exp\left(-B|\boldsymbol{x}-\boldsymbol{z}|^2\right)$$

- 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

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

- 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

$$L(\boldsymbol{z}) = \prod_{i=1}^{n} P(\boldsymbol{x_i}, \boldsymbol{z}) \qquad \lambda(\boldsymbol{z}) = \sum_{i=1}^{n} \ln P(\boldsymbol{x_i}, \boldsymbol{z})$$

  - 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 $P(\boldsymbol{x};\boldsymbol{z})$ is the density function for the probability that an offender with anchor point $\boldsymbol{z}$ commits a crime at the point x.
- Suppose that $P(\boldsymbol{x};\boldsymbol{z})$ has the general form

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

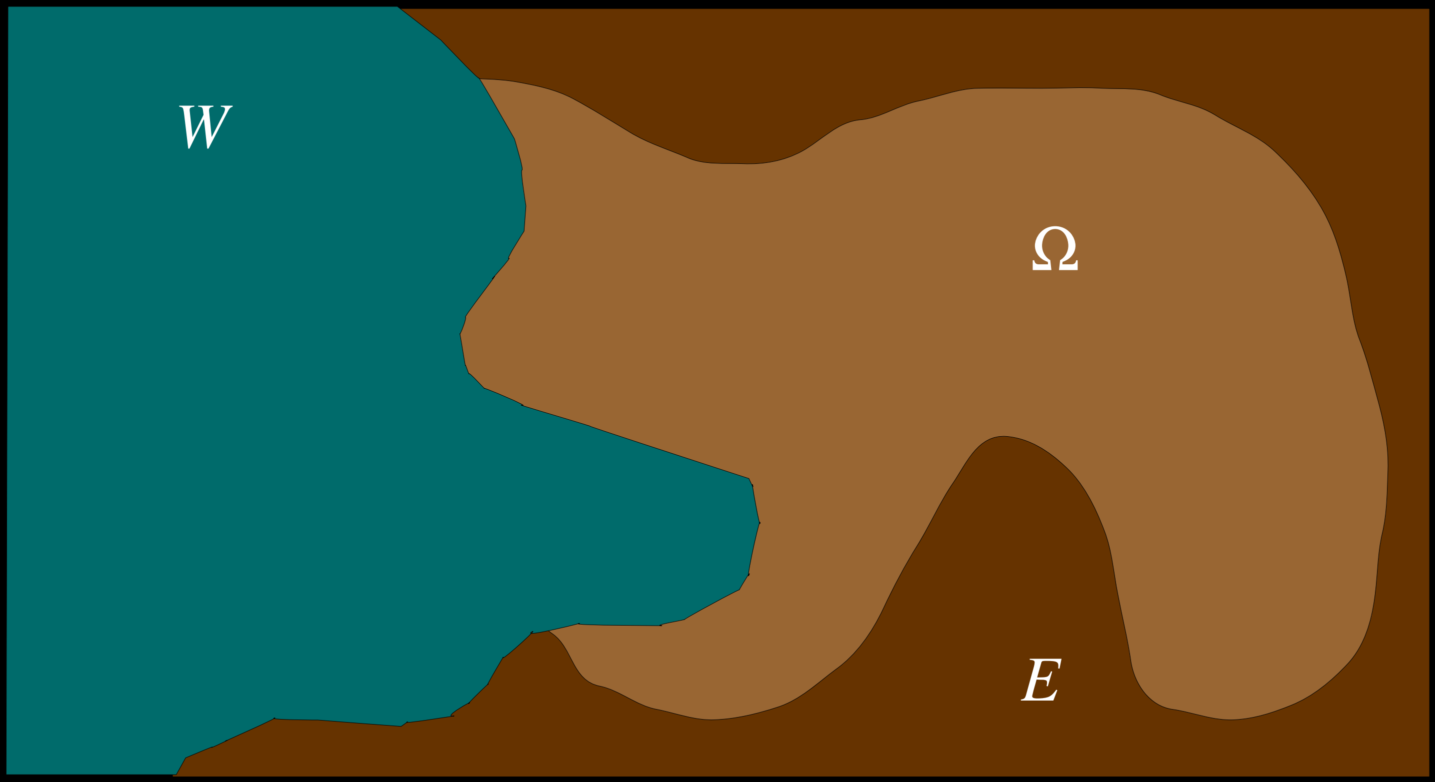
Dispersion kernel

Geographic factors

Normalization

The Simplest Case

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



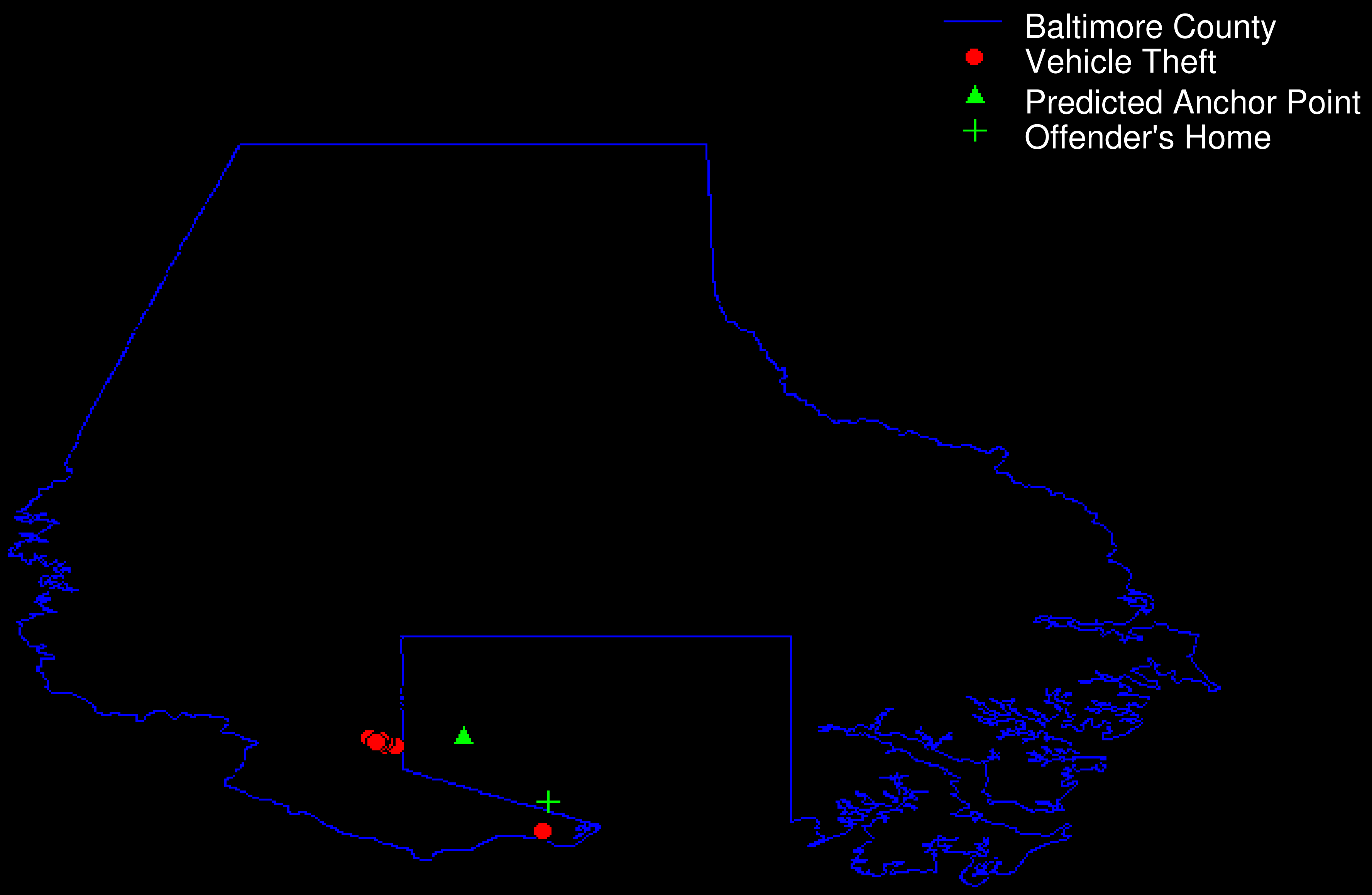
The Simplest Case

- Regions
  - Ω: 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 $P(\boldsymbol{x}; \boldsymbol{z}) = 0$ if $\boldsymbol{x} \notin \Omega$.
- We set
$$G(x) = \begin{cases} 1 & x \in \Omega \\ 0 & x \notin \Omega \end{cases}$$
We choose an appropriate dispersion kernel; say
$$K(\boldsymbol{x}; \boldsymbol{z}) = \exp(-|\boldsymbol{x} - \boldsymbol{z}|^2 / \sigma^2)$$
- The required normalization function is
$$N(\boldsymbol{x}; z) = \left[\iint_{\Omega} \exp\left(-|y - z|^2 / \sigma^2\right) dy_1 \, dy_2 \right]^{-1}$$

Sample Results



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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