Point Process Models for Prospective Crime Analysis

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Aim:

Combine spatio-temporal modelling and statistical analysis with network theory to model the interactions between police activity, crime reporting, recorded crime and public perception of the police...

...to help improve local and city-wide policing.
Crime, Policing & Citizenship project (CPC)

Objectives:

- Identify emergent crime patterns;
- Analyse factors that accelerate or curtail crime ‘waves’;
- Develop different policy scenarios to migrate or prevent criminal activity and improve public satisfaction.
Crime, Policing & Citizenship project (CPC)
Overview

• Introduction to self-exciting point process models
• Application to Camden CAD data
• Conclusions and enhancements
Self-exciting point process models
Crime prediction based solely on past crimes

- Borrowed from seismology literature.
- Applied successfully to burglary and gang crimes in US. Underlying model in PredPol software (and others?)
- Crimes (earthquakes) occur with some background intensity that varies in time and space.
- Every crime (earthquake) may trigger ‘offspring’ events with an intensity that varies in time and space around the parent event.
Self-exciting point process models

Illustrative example
Self-exciting point process models

Why is this useful?

• Train the model (machine learning). Outputs:
  – Background intensity
  – Triggering intensity
  – Classification of each crime as parent / offspring

• Combining these, we have a predictive method:
Self-exciting point process models
Implementation details

• Background intensity $\mu(t,x,y)$.
• Trigger intensity $g(\Delta t, \Delta x, \Delta y)$.
• The conditional intensity gives the expected number of crimes per unit time and area, conditional on all data up to that point in time.

$$\lambda(t,x,y) = \mu(t,x,y) + \sum \{k: t \downarrow k < t\} \uparrow \bigotimes g(t - t \downarrow k , x - x \downarrow k , y - y \downarrow k)$$

• Our task is to infer the forms of $\mu$ and $g$ given some crime data. Once we have them, can compute $\lambda$ and use this for prediction.
Self-exciting point process models

Implementation details

\[ \lambda(t,x,y) = \mu(t,x,y) + \sum\{k : t^\downarrow k < t\} \uparrow g(t-t^\downarrow k, x-x^\downarrow k, y-y^\downarrow k) \]

- **Unknown parameters**: we don’t know the form of \( \mu \) and \( g \).
- **Missing data**: we don’t know which crimes are background/triggered.
- **Need to parameterise the SEPP model**.
- **Introduce the probability matrix** \( P \), with entries \( p_{\downarrow ji} \) giving the probability that event \( j \) triggered event \( i \).
Self-exciting point process models
The Mohler et al. (2011) algorithm

Expectation-Maximisation algorithm.
Initialise: Estimate $P^{↑}(0)$
1. Use roulette wheel selection to split the data into background and parent/offspring.
2. Estimate $\mu^{↑}(n)$ and $g^{↑}(n)$ using KDE.
3. Update $P^{↑}(n+1)$ from $\mu^{↑}(n)$ and $g^{↑}(n)$:

$$p^{↓}ii^{↑}(n+1) = \mu^{↑}(n) (t_{↓i}, x_{↓i}, y_{↓i}) / \lambda(t_{↓i}, x_{↓i}, y_{↓i})$$

$$p^{↓}ji^{↑}(n+1) = g^{↑}(n) (t_{↓i} - t_{↓j}, x_{↓i} - x_{↓j}, y_{↓i} - y_{↓j}) / \lambda(t_{↓i}, x_{↓i}, y_{↓i})$$
SEPP in CAD data
The evidence for SEPP in crime data is the same as that used to support the near-repeat victimisation phenomenon.


Violence against the person  
Burglary from dwelling  
Theft of/from a vehicle

Time differences between pairs of events occurring within 100m of one another.
Results

Burglaries from dwelling in Camden (1348 records)

- 1040 identified as background, 308 identified as offspring.
- Triggering intensity in time and space.
Results

Burglaries from dwelling in Camden
Results

Validation using Search Efficiency Rate

Divide Camden into grid squares 100m x 100m.
Predict 1 day ahead for each day in March 2012 (30 iterations).
Rank grid squares based on prediction.
Compute fraction of crimes ‘detected’ with the fraction of grid squares, picked in descending rank order.
Plot shows mean of all 30 runs.
Conclusions & discussion

• SEPP is a promising predictive method that appears to outperform a more simple heatmap approach.
• Because SEPP is based on a well-stated model, it is more interpretable.
• But the current validation method is overly simplistic.
• Policing does not involve dropping officers onto grid squares.
• Need to incorporate broader and more realistic metrics, such as area:perimeter ratio.
Enhancements and further work

- Parallel / GPU computing implementation.
- Local triggering.
- SEPP on road networks: crime does not diffuse through space.
Thank you!