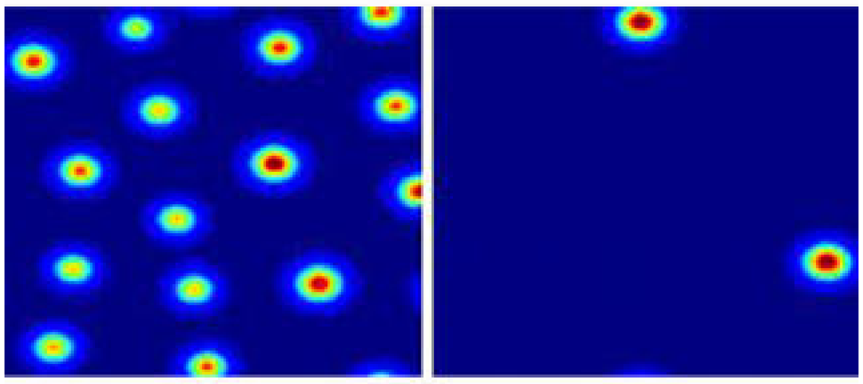
Mathematicians Tracking Criminal Activity Hotspots

Society for Industrial and Applied Mathematics



Philadelphia, PA — One way to study criminal behavior and predict a criminal's next move is by analyzing his or her movement. Several mathematical models have addressed this in detail, in particular, the UCLA "burglary hotspot" model, also the topic of a previous Nugget published by the Society for Industrial and Applied Mathematics (SIAM).

In a paper published last month in the *SIAM Journal on Applied Mathematics*, authors Sorathan Chaturapruek, Jonah Breslau, Daniel Yazdi, Theodore Kolokolnikov, and Scott McCalla propose a mathematical model that analyzes criminal movement in terms of a Lévy flight, a pattern in which criminals tend to move locally as well as in large leaps to other areas. This closely replicates daily human commute in big cities.

"The main goal of this study is to elucidate how various movement strategies of criminals affect the crime rate," authors Theodore Kolokolnikov and Scott McCalla wrote in an e-mail. "With our model, we can infer criminal movement patterns from burglary data, and thus gain information on how burglars explore possible targets."

The UCLA model studied the formation of hotspots of criminal activity based on the broken window effect, which proposes that localized regions of high crime activity can occur as a result of previous crimes in an area. For a brief period after a home is burgled it becomes a target for another burglary, as do other houses in the vicinity. This is observed in burglary data; previous crimes make homes more attractive to burglars for a variety of reasons, such as knowledge of how to break in, information about the valuables in a home, ability to navigate the neighborhood, and greater confidence in getting away with the crime.

The UCLA model, which uses a random walk with a bias toward attractive burglary sites to analyze criminal movement, can however, be restrictive. "The pioneering UCLA hotspot model assumed that criminals move locally, following Brownian (or random) motion. The model assumed that criminals only had access to information about burglary targets in their immediate vicinity, and that they were unlikely to travel large distances to access different neighborhoods with better targets," say Kolokolnikov and McCalla. "A much more realistic model of human locomotion allows for occasional 'big jumps'. This is typically modeled using Lévy flights."

Lévy flights are a modified form of the standard random walk; the latter uses random step lengths as well as a random direction. Lévy flights are similar, except that step lengths are chosen from a probability distribution, specifically, a power-law distribution, which allows the steps of a random walk to have large jumps. The use of Lévy flights thus enables more efficient exploration of a territory, hence extending the UCLA model to incorporate nonlocal movement.

It has been argued in previous literature that animal movement, including human movement, generates Lévy flights instead of random walks. This sort of movement — long jumps, interspersed with local random walks—is also seen in typical daily commutes in cities. The long jumps or "flights" correspond to long distances covered by perhaps a bus or subway to another part of the city. This allows criminals to move to distant, more attractive burglary sites as opposed to being confined to neighboring sites as in the previous model.

Data available on distance between criminals' homes and their targets shows that burglars are willing to travel longer distances for high-value targets, and tend to employ different means of transportation to make these long trips. Of course, this tendency differs among types of criminals. Professionals and older criminals may travel further than younger amateurs. A group of professional burglars planning to rob a bank, for instance, would reasonably be expected to follow a Lévy flight.

"There is actually a relationship between how far these criminals are willing to travel for a target and the ability for a hotspot to form," explain Kolokolnikov and McCalla. The authors calculate the likelihood of hotspot formation based on the distribution of step sizes (or lengths) in Lévy flights. "By computing the theoretical crime hot-spot distribution as a function of stepsize distribution, we found that the 'optimal' locomotion strategy for criminals is to occasionally take big jumps but otherwise follow a distribution which is close to Brownian motion," say Kolokolnikov and McCalla. "Taking an occasional big jump greatly increases the number of crimes. However, taking excessively many big jumps does no better than the regular Brownian motion. In the language of Lévy flights, there is an optimal exponent, which results in the maximum possible number of crime hot-spots, and that regime is actually close to the Brownian motion."

The underlying math model uses a system of two partial differential equations (PDEs) that define criminal density and attractiveness respectively. The resulting PDE for criminal density is nonlocal, whereas the attractiveness field remains local as in the UCLA model. The authors perform a linear stability analysis around a steady state of crime to illustrate the effect of non-locality on hotspot formation.

Kolokolnikov and McCalla explain that while the location and shape of burglary hotspots are extensively recorded and studied, criminal movements are not tracked, and are hence, not well understood. "In our research, we have seen a relationship between the dynamics of burglary hotspots and the way criminals move."

Such models can better instruct law enforcement efforts. "Certain policing efforts concentrate on known offenders' home territories as a predictor of future crimes," say Kolokolnikov and McCalla. "If the relationship between a burglar's movement and choice of targets becomes better elucidated, then the police will be better informed when they schedule their nightly patrols."

"The next major challenge is understanding how criminals move in different cities around the world," according to Kolokolnikov and McCalla. "Applying models like ours to reproduce the data is a strong first step, but there is clearly more work to be done. This would have clear implications for policing policy, and could have a significant impact on burglary rates."

"One of the surprising results in our model is that the criminals benefit very significantly by making a few big jumps while otherwise following a Brownian (or random) motion. It would be interesting to examine whether there are other situations, such as predator-prey models, where the optimal strategy is to follow nearly-Brownian motion with few jumps," they conclude.