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Stochastic modeling of a serial killer

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HIGHLIGHTS

- Serial killers' inter-murder intervals follow a power law with an exponent of ~1.5.
- We hypothesize that they murder when neuronal excitation exceeds a threshold.
- We model this neural activity as a branching process.
- Simulations of our model agree with experimental data.

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ABSTRACT

We analyze the time pattern of the activity of a serial killer, who during 12 years had murdered 53 people. The plot of the cumulative number of murders as a function of time is of "Devil's staircase" type. The distribution of the intervals between murders (step length) follows a power law with the exponent of 1.4. We propose a model according to which the serial killer commits murders when neuronal excitation in his brain exceeds certain threshold. We model this neural activity as a branching process, which in turn is approximated by a random walk. As the distribution of the random walk return times is a power law with the exponent 1.5, the distribution of the inter-murder intervals is thus explained. We illustrate analytical results by numerical simulation. Time pattern activity data from two other serial killers further substantiate our analysis.

1. Introduction

Fig. 1 shows a time-plot of the cumulative number of murders committed by Andrei Chikatilo (Krivich and Ol'gin, 1993) during his 12-year activity. It is highly irregular with long time intervals without murder interrupted by jumps, when he murdered many people during a short period. Such a curve is known in mathematics as a "Devil's staircase" (Mandelbrot, 1983). We can characterize the staircase by the distributions of step lengths. Fig. 2 shows such distributions for the staircase of Fig. 1 in log–log coordinates. A linear fit shows that the exponent of the power law of the probability density distribution (in the region of more than 16 days) is 1.4.

Recently Osorio et al. (2009) reported a similar power-law distribution (with the exponent 1.5) of the intervals between epileptic seizures. Soon afterward they proposed (Osorio et al., 2010) a self-organized critical model of epileptic seizures. They performed numerical simulations of their model and reproduced a power-law distribution of inter-seizure intervals. Almost simultaneously we proposed a stochastic neural network model of epileptic seizures (Simkin and Roychowdhury, 2010), which was very similar to that of Osorio et al. (2010). Unlike them, however, we solved our model analytically. Here we apply a similar model to explain the distribution of intervals between murders.

2. The model

We make a hypothesis that, similar to epileptic seizures, the condition, causing a serial killer to commit murder, arise from the simultaneous firing of large number of neurons in the brain. Our neural net model for epileptics (Simkin and Roychowdhury, 2010) and serial killers is as follows. After a neuron has fired, it cannot fire again for a time interval known as the refractory period. Therefore, the minimum interval between the two subsequent firings of a neuron is the sum of spike duration and refractory period. This interval is few milliseconds and we will use it as our time unit. Consider one particular firing neuron. Its axon connects to synapses of thousands of other neurons. Some of them are almost ready to fire: their membrane potential is close to the firing threshold and the impulse from our neuron will be sufficient to surpass this threshold. These neurons will be firing at the next time step and they can be called "children" of our neuron in the language of the theory of branching processes (Simkin and Roychowdhury, 2011). Since the

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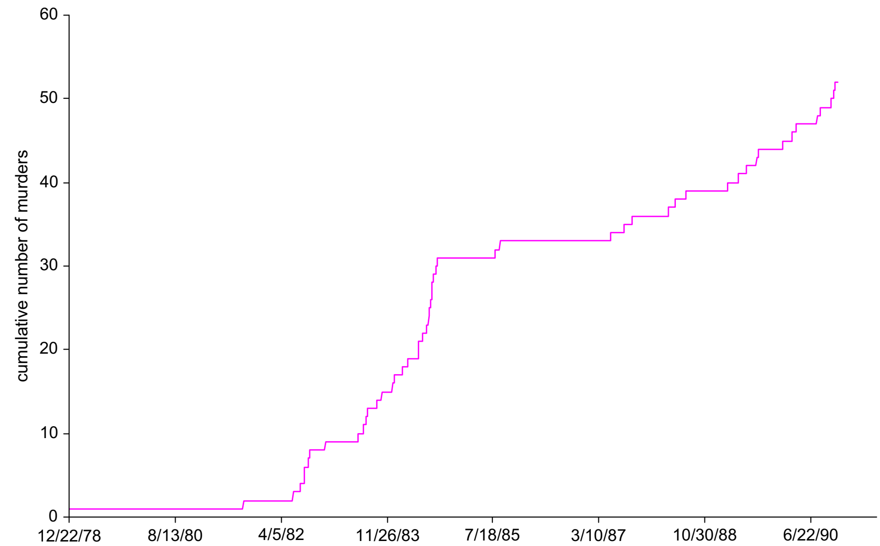

Fig. 1. Chikatilo's staircase shows how the total number of his murders grew with time. The time span begins with his first murder on 12/22/1978 and ends with his arrest on 10/20/1990. The shortest interval between murders was three days and the longest—986 days. The murder dates were determined based on the date on disappearance of the person in question.

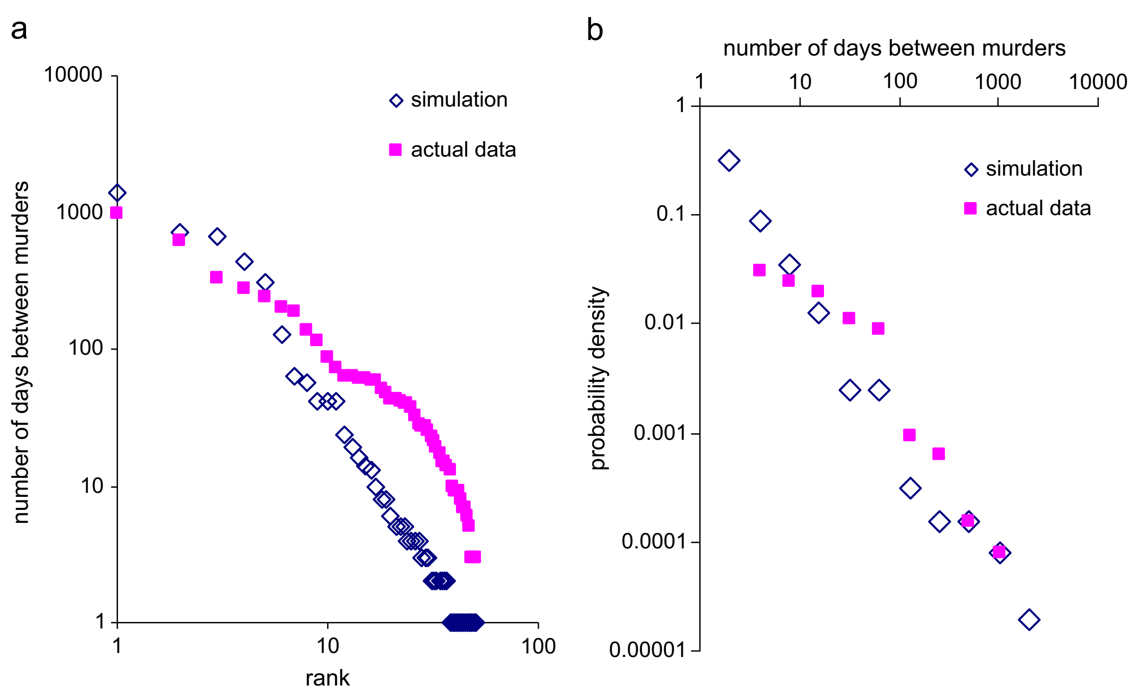

Fig. 2. Distribution of step length (intervals between murders) in Zipfian (a) and probability density (b) representations.

number of neurons connected to a given neuron is large and since each firing neuron will independently induce the firing of each of the neurons connected to it with a small probability, the number of firings induced by one firing neuron is binomially distributed with a large number of trials and a small success probability, which can be approximated by a Poisson random variable. In addition to induced firings, some neurons will fire spontaneously. We assume that the number of spontaneously firing neurons at each time step comes from a Poisson distribution with mean p.

Let us introduce the following random variables:

X_n=number of firing neurons at time n.
Y_n=number of spontaneously firing neurons at time n.
$Z_{n,j}$=number of firings induced by the jth firing neuron at time n.

Then, the process (X_n) defines a discrete-time Markov chain which we obtain by assuming that the two collections of random variables Y_n and $Z_{n,j}$ are collections of independent Poisson random variables with mean p and λ, respectively, and by setting

$$X_{n+1} = Z_{n,1} + \cdots + Z_{n,X_n} + Y_{n+1}$$

The above equation can be rewritten as (here $E(\ldots)$ denotes the expectation value)

$$\begin{aligned} X_{n+1} = {} & E(Z_{n,1} + \cdots + Z_{n,X_n}) + E(Y_{n+1}) \\ & + (Z_{n,1} + \cdots + Z_{n,X_n} - E(Z_{n,1} + \cdots + Z_{n,X_n})) \\ & + Y_{n+1} - E(Y_{n+1}) \end{aligned} \tag{1}$$