Human Travel Patterns

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Tropical forest in Yucatan, Mexico

“Lévy flight”

by a spider monkey
Fig. 1a–d Daily trajectories of spider monkeys. a, b Adult females. c Adult male, with the section of the trajectory within the lower-left square amplified in d. Note that some individuals, like the adult female in b, returned to sleep close to where they started their daily travel.
Animal Motion

Basking shark

Porbeagle shark

Random Walks

Lévy flights

\[ f(\Delta r) = C \]

\[ f(\Delta x) \sim \frac{1}{\Delta x^{1+\beta}} \]
Human Motion


\[ 0 < \alpha < 1 \]
\[ 0 < \beta < 2 \]
A real human trajectory
Mobile Phone Users

Sources: Nature; Albert-Laszlo Barabasi
Data Collection Limitations

We know only the tower the user communicates with, not the real location.

We know the location (tower) only when the user makes a call.

Interevent times are bursty (non-Poisson process—Power law interevent time distribution).
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Interevent Times

\[ P(\Delta T) = \frac{1}{\Delta T_a} \mathcal{F}(\Delta T/\Delta T_a) \]

\[ P(\Delta T) = (\Delta T)^\alpha \exp(\Delta T/\tau_c) \]

\[ \alpha = 0.9 \pm 0.1 \quad \tau_c \approx 48 \text{ days} \]


Two possible explanations

1. Each user follows a Lévy flight

2. The difference between individuals follows a power law

$\beta = 1.75 \pm 0.15$
Understanding human trajectories

Center of Mass:

\[ \vec{r}_{cm} = \frac{1}{n_p} \sum_{i=1}^{n_p} \vec{r}_i. \]

Radius of Gyration:

\[ r_g^a(t) = \sqrt{\frac{1}{n_c^a(t)} \sum_{i=1}^{n_c^a(t)} (\vec{r}_i^a - \vec{r}_{cm}^a)^2} \]
Characterizing human trajectories

Radius of Gyration:

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Scaling in human trajectories

\[ \beta_r = 1.65 \pm 0.15 \]
Mobile Phone Users
Scaling in human trajectories

$\beta_r = 1.65 \pm 0.15$

$\alpha = 1.2$

$\beta = 1.75 \pm 0.15$
Relationship between exponents

\[ P(\Delta r) = \int_0^\infty P(\Delta r | r_g) P(r_g) dr_g \]

\[ P(\Delta r) = \int_0^\infty r_g^{-\alpha} F\left(\frac{\Delta r}{r_g}\right)(r_g + r_g^0) e^{-r_g/\kappa} dr_g \]

\[ P(\Delta r) \approx \Delta r^{-\alpha-\beta_r+1} \int_0^\infty x^{-\alpha} F\left(\frac{1}{x}\right) e^{x \Delta r / \kappa} dx \]

\[ \beta = \alpha + \beta_r - 1 \]

Jump size distribution \( P(\Delta r) \sim (\Delta r)^{-\beta} \) represents a convolution between

*population heterogeneity \( P(r_g) \sim r_g^{-\beta_r} \)

*Levy flight with exponent \( \alpha \) truncated by \( r_g \)
Return time distributions

![Graph showing return time distributions for Users and RW](image)

- Users
- RW

![Graph showing the distribution of return times](image)

- 5 loc.
- 10 loc.
- 30 loc.
- 50 loc.

$P(L)$ vs. $L$ with a fit $\sim (L)^{-1}$
Mobile Phone Users

Sources: Nature; Albert-Laszlo Barabasi

THE NEW YORK TIMES
The shape of human trajectories
The shape of human trajectories

\[
\Phi(x/\sigma_x, 0) = \begin{cases} 
\sigma_x & \text{if } x/\sigma_x \leq 3 \text{[km]} \\
\sigma_y & \text{if } 3 < x/\sigma_x < 30 \text{[km]} \\
\sigma_z & \text{if } x/\sigma_x \geq 100 \text{[km]} 
\end{cases}
\]

\[
\sigma^x = \sqrt{\frac{1}{n_c} \sum_{i=1}^{n_c} (x_i^a - x_{cm}^a)^2}
\]

\[
\sigma^y = \sqrt{\frac{1}{n_c} \sum_{i=1}^{n_c} (y_i^a - y_{cm}^a)^2}
\]
Mobile Phone Viruses

Hypponen M. *Scientific American* Nov. 70-77 (2006).
Spreading mechanism for cell phone viruses

**Short range infection process**
(similar to biological viruses, like influenza or SARS)

**Long range infection process**
(similar to computer viruses)
MMS and Bluetooth Viruses

Social Network (MMS virus)

Onella et al, PNAS (2007)

Human Motion (Bluetooth virus)

González, Hidalgo and A-L.B.,
Spatial Spreading Patterns of Bluetooth and MMS virus
Spatial Spreading patterns of Bluetooth and MMS viruses

**Bluetooth Virus**

Driven by Human Mobility: Slow, but can reach all users with time.

**MMS Virus**

Driven by the Social Network: Fast, but can reach only a finite fraction of users (the giant component).
If the market share of an Operating System is under $m_c \sim 10\%$, MMS viruses cannot spread.
Mobile Phone Users
Collaborators

Pu Wang  Marta Gonzalez  Cesar Hidalgo

www.BarabasiLab.com