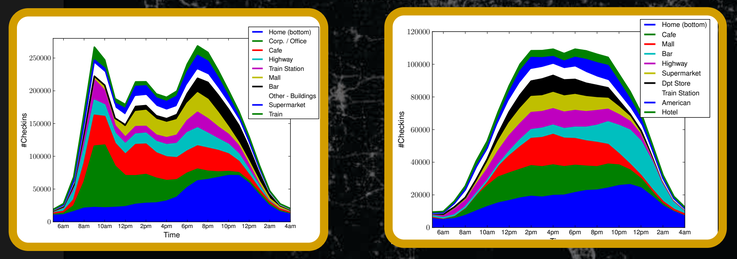
Human Urban Mobility in Location-based Social Networks: Analysis, Models and Applications

Mobile Users are The Stars

The constellations of the Milky Way have been guiding our ancestors for thousands of years. The stars have helped us to navigate, govern the seas and discover new lands. In the rise of the 21st century discovery, communication and navigation are still prominent to the advancement of our kind. The new means to humanity's eternal goals are smartphone devices powered with sensors, advanced software and cloud supported internet connectivity. A significant evolution in the past four years has been the rise of location-based social networks. Systems like Foursquare enable the crowdsourcing of unprecedented amounts and layers of information describing the location, activity and communication traits of millions of mobile users at a global scale. Not only they promise the large scale evaluation of past theories in fields of urban transport, social science and geography, but they offer the opportunity for novel applications for the computer sciences.In the era of the mobile web, the stars are the mobile users.

by Anastasios Noulas & Cecilia Mascolo

analysing the digital traces of mobile users

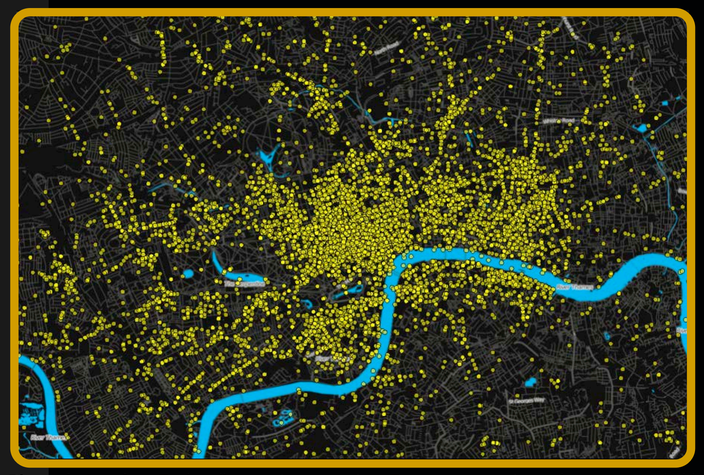


Temporal dynamics of user check-ins across the ten most popular venue categories observed during weekdays and weekends. Foursquare user activity is tracked with per second accuracy, live, via Twitter's Streaming API.

new york morning

new york night time

Urban activity comparison between morning and night hours in Manhattan. Each circle corresponds to a Foursquare venue. Colours are representative of different venue types: Arts (red), Education (black), Shops (white), Food (Yellow), Parks (green), Travel (cyan), Nightlife (magenta), Work (blue). The radius of a circle is proportional to the popularity of each venue.

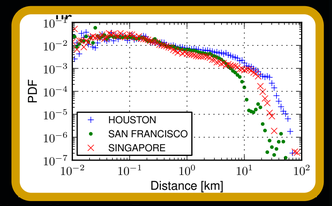


Places in London. Each yellow spot represents a Foursquare geo-tagged venue recorded in the capital city of England. Typically in a metropolitan area thousands of venues are being crowdsourced as mobile users voluntarily check-in and share their whereabouts. As of April 2013 Foursquare has registered approximately 40 millions users globally who have registered more than 3 billion check-ins across 50 million venues since 2009. These data has the potential to benefit research in social sciences or the development of applications for smartphone users.

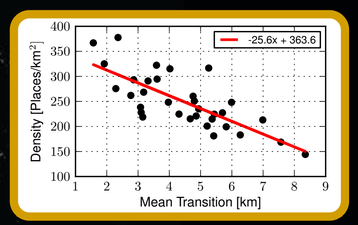
modelling urban movement

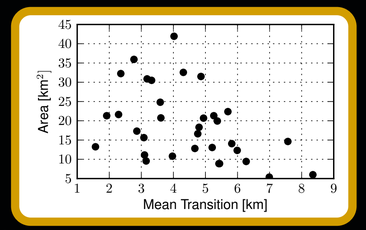
American Sociologist Samuel A. Stouffer (1900-1960).

Stouffer's **law of intervening opportunities** states, *"The number of persons going a given distance is directly proportional to the number of opportunities at that distance and inversely proportional to the number of intervening opportunities."*



Analysing Urban Movement. For every user we measure the geographic distance between successive movements. The probability density function plotted above for three cities shows that heterogeneities may exist across different urban centres.

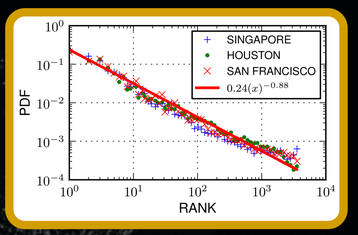




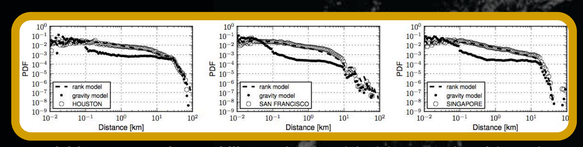
Urban Density and Area Size versus Movement. Scatter plot of the place density of a city, (left) and area size (right) versus its mean human transition in kilometres. Each datapoint corresponds to a city, while the red line is a fit that highlights the relationship of the two variables. A longer mean transition corresponds to the expectation of a sparser urban environment, indicating that the number of available places per area unit could have an impact on human urban travel. Stouffer's theory of intervening opportunities hints the key role of density in human mobility. This has been confirmed by our measurements that highlight a stronger correlation between density and mean movement length in a city.

$rank_u(v) = |\{w : d(u,w) < d(u,v)\}|$

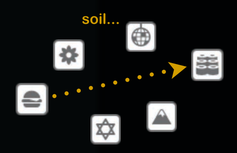
Rank-Distance. To shed further light on the hypothesis that density is a decisive factor in human mobility, for every movement between a pair of places in a city we sample the rank value of it. The rank for each transition between two places *u* and *v* is the number of places *w* that are closer in terms of distance to u than v is. The rank between two places has the important property to be invariant in scaled versions of a city, where the relative positions of the places is preserved but the absolute distances dilated.



Rank Universality. We observe that the distributions of the three cities collapse to a single line, when we measure movement in terms of the rank variable.



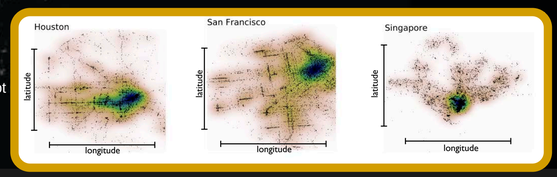
A Model for Human Urban Mobility. We have exploited the properties of the rank-distance variable to verify Stouffer's theory on thirty-four cities placed in four continents. Foursquare data has offered a unique opportunity to test the universality of the theory at such large scale. As shown above, the rank based model fits perfectly the empirically observed distribution of movements in all cities, outperforming a version of an alternative gravity based model.The model is comprised of two essential elements depicted on the right; foursquare places (soil) and the human cognitive factor (mind) that models the probability of transition from place u to place v.



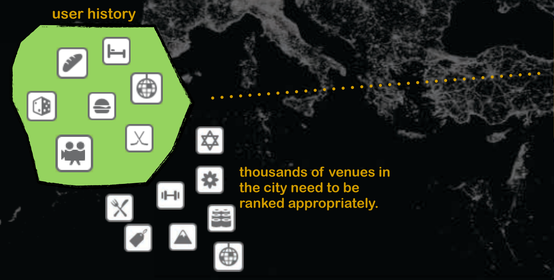
$Pr[u \to v] \propto \frac{1}{rank_u(v)^\alpha}$

and mind!

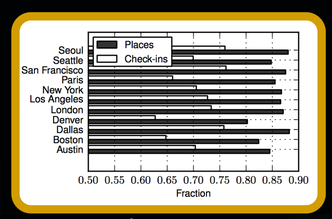
Kernel Density Estimation in three cities. Heterogeneities observed in human mobility are due to geographic variations. Cultural, organisational or other factors do not appear to play a role in urban movements. The rank model, although simple, can cope with the complex spatial variations in densities observed in urban environments.



recommending new venues to mobile users

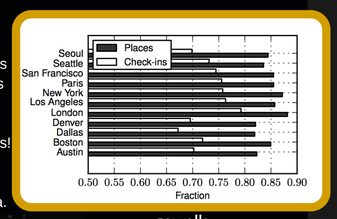


Application Scenario. Our mobile user, little Amy, has a historic record of previously visited places in the city. We would like to exploit this information in order to help her discover new, previously unvisited, venues in the city and recommend them to her.

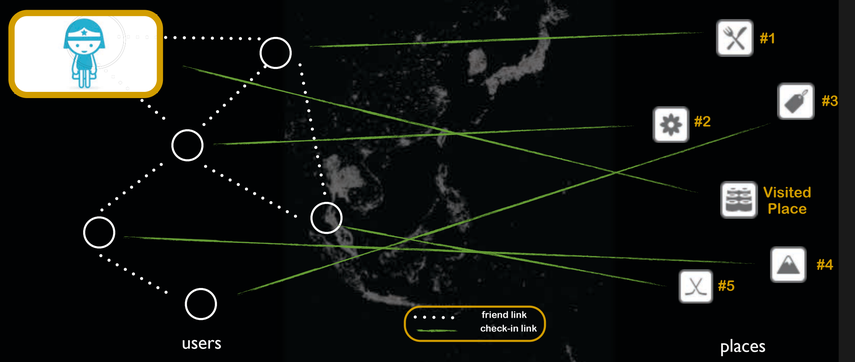


foursquare

The Thirst for Urban Exploration. In the Figures we depict the fraction of movements which correspond to new places in 11 cities. 80-90% of visited places are new places! 60-80% of check-ins occur at new places! The findings have been verified at two different location-based services; Foursquare & Gowalla.



gowalla



A Random Walk with Restart Model for Location-based Recommendations. We propose a new model based on personalized random walks over a user-place graph (example shown above) that, by seamlessly combining social network and venue visit frequency data, obtains between 5 and 18% improvement over other models in ranking new places to mobile users. Its performance has been compared with a number of baseline approaches, including ranking venues by popularity or by geographic distance from a users home location, and with state-of-the-art collaborative filtering algorithms, including latent space models. Our results (enlisted below) pave the way to a new approach for place recommendation in location-based social systems and highlight the need for the division of novel methodologies to efficiently deploy new computer science applications related to local discovery and search in domains where geography and user movement matters.

Recommendation Method	Average Percentile Rank
Random Walk Restart	**0.217**
Popularity	**0.228**
Content Filtering	**0.228**
Matrix Factorization	0.281
PlaceNet	0.337
Home Distance	0.383
Social Filtering	0.392
k-Nearest Neighbours	0.443
Random	0.500

powered by foursquare®

An Empirical Study of Geographic User Activity Patterns in Foursquare. Anastasios Noulas, Salvatore Scellato, Cecilia Mascolo and Massimiliano Pontil. In Proceedings of Fifth International AAAI Conference on Weblogs and Social Media (ICWSM 2011). Poster Paper. Barcelona, Spain, July 2011.
A tale of many cities: universal patterns in human urban mobility. Anastasios Noulas, Salvatore Scellato, Renaud Lambiotte, Massimiliano Pontil, Cecilia Mascolo. In PLoS ONE. PLoS ONE 7(5): e37027. doi:10.1371/journal.pone.0037027 . May, 2012.
A Random Walk Around the City: New Venue Recommendation in Location-Based Social Networks. Anastasios Noulas, Salvatore Scellato, Neal Lathia, Cecilia Mascolo. In IEEE Internationcal Conference on Social Computing, (SocialCom 2012). Amsterdam, The Netherlands, September, 2012.