

Urban Ritual in Rome: Characterizing the City with High-Resolution Cell Phone Data

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ABSTRACT

Recently available, high resolution cell phone data from Rome provides an opportunity to study and characterize the dynamics of life in a large, complex city in an unprecedented way. These data, which give the number of active cell phone calls as a function of position and time, show a complex temporal and spatial pattern, but with a clear periodic signal. Our results show that cell phone activity correlates strongly with location within the city (i.e., transportation links, commercial, office, residential zones etc.). In addition, the daily activity of people throughout the city is revealed (i.e. wake up, commute, work, lunch, dinner, sleep, sports events etc.). These preliminary results suggest that cell phone data can be used to characterize and map urban domains and the cultural signature of its occupants. Our study shows that the proliferation of mobile communication devices has the potential to drastically change the way in which we view and understand the urban environment.

Author Keywords

City, Rome, Cell Phone, Map, Dynamic.

ACM Classification Keywords

H5.0: Miscellaneous.

INTRODUCTION

Cities are complex fabrics of multiple domains, developed over centuries of time under competing cultural, commercial, and demographic pressures. Areas of residential, commercial, office, and public-use are linked by transportation networks that allow the flow of people and vehicles into and out of these domains on a daily basis. Conventional maps have long provided us with a diagram of the static structure of cities and the relationships between

the constitutive elements. But these maps are limited by what they cannot show: namely the activity and dynamics of people and vehicles that inhabit the city.

The proliferation of mobile communication devices, such as cell-phones and laptops, that are capable of transmitting and receiving data, provide an untapped resource for studying the dynamics of life within a city. In this paper, we analyze the number of (connected) cell phone calls as a function of position and time in Rome. Projecting these data onto a map of the city provides a time-varying view of activity and movement. Since cell phone use is now closely linked to our daily lives, this data allows us to ask the following questions: How does cell phone use change in different parts of the city as we wake up, commute to work, have lunch, go out for dinner, and eventually arrive home? Do the different daily activities of millions of people leave characteristic signatures of cell phone activity? We address these questions and present preliminary results from our analysis to characterize different parts of the city with these data and to identify the daily rituals and events that define the life of the people who live or work in Rome.

CELL PHONE DATA

The data presented in this study are normalized cell phone traffic data at 15 minute intervals from cell phone towers located throughout metropolitan Rome (Figure 1). To protect the privacy of cell phone users, the data is anonymous, with no information being given about the callers, or content of the calls being made. The data give the relative number of calls at any given cell phone tower, every fifteen minutes, over a two month period. This type of call traffic data is usually characterized in units termed *Erlang*, which is a measure of the total number of calls being made at any given time. In this preliminary study we used Erlang data, but normalized it to a constant maximum value and then interpolated the data in between towers with a standard contouring algorithm to give a map of cell phone call activity over the entire metropolitan area. Therefore, units shown are relative call intensities and not absolute call volumes.

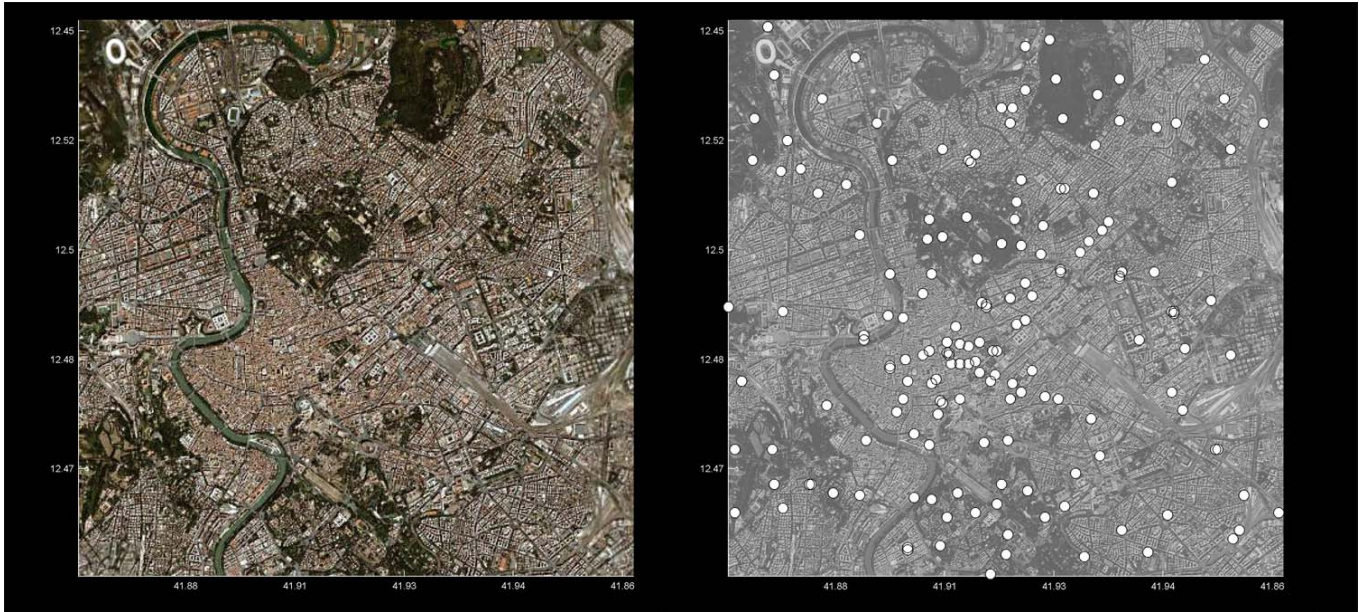


Figure 1: Aerial Photo of Rome showing study area and location of cell phone towers.

URBAN PATTERNS OF CELL PHONE ACTIVITY

During a typical day in Rome, cell phone activity varies according to position and time. Figure 2 shows a time series of call intensity at 3 hour intervals over the course of single day, overlaid on an aerial photo of the city. Changes in call intensity are represented by changes in color: yellow being the most intense and red being the least intense. Areas of the map where there is no color are areas where the call volume is either zero, or below the threshold of the color scale. It is clear from the time series that some areas show higher call volumes than others and that the largest call volumes occur at specific locations within the city between the hours of 9:00am and 6:00pm (the regular workday). This pattern is repeated daily from Monday to Friday. Figure 3 shows a larger view of one of the maps at 9:00am. Overlaid on this figure is a grid that establishes 16 nodes and 8 profile lines (four horizontal and four vertical). This reference grid was used to analyze the time variation of call activity. Two nodes ([4,1] and [2,3]) were identified as areas where call activity was lowest and greatest, respectively, over the course of a single day.

Call activity for a single day along the 8 profile lines of the reference grid are shown in Figure 4. Each plot shows curves at fifteen minute intervals, with a total of ninety six curves in each plot. As in Figure 3, these results have clearly defined areas of concentrated call activity that show

large changes in call activity on a given day. Where the curves are more tightly clustered together (and the curves appear darker), profiles of call intensity occur more often than where the curves appear lighter. Since the clustering of these profiles is different in each plot, different factors are influencing when certain parts of the city experience higher call volumes. This could be due to a number of factors. For example, areas near transport hubs (subway, train station, etc.) might experience changes in call volume in response to arrival and departure of trains. The assumption being that these callers are outside or inside the train/subway stations. Areas with concentrated office buildings likely operate on different schedules than areas with restaurants or residential areas. The same could be said for tourist areas, particularly in a city like Rome. The daily schedule of tourists is likely to be dramatically different than the daily schedule of people performing a normal day at work.

If we consider call activity at each of the sixteen nodes shown in Figure 3, we begin to see periodic signature of life in the city. Figure 5 shows call activity at each node during the month of November. The light and gray bands designate different days, with data being available for only the first twenty one days. Of the sixteen curves shown, ones that correspond to node [4,1] and [3,2] are highlighted. These two nodes represent the maximum and minimum values of call intensity, and are taken as end-member reference

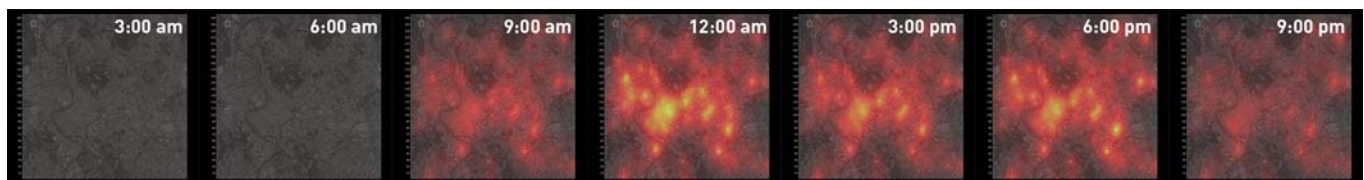


Figure 2: Time series of cell phone call intensity in Rome on Thursday, October 5, 2006

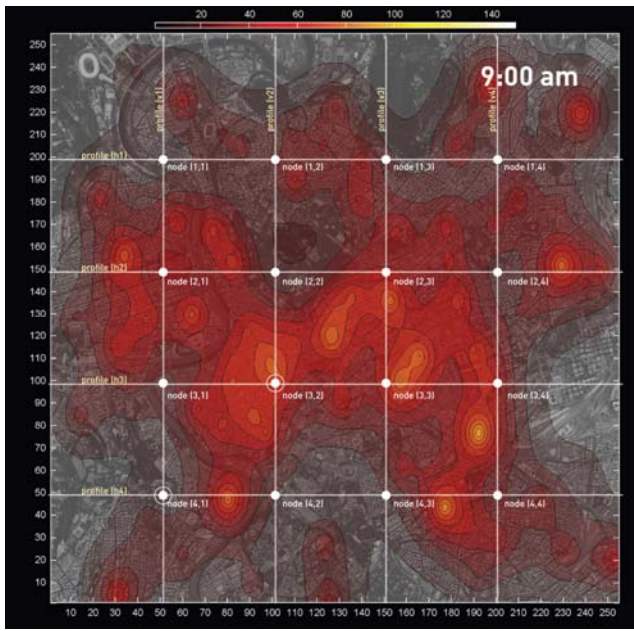


Figure 3: Contours of cell phone activity. The reference grid is explained in the text.

points. The data show a clear diurnal signal: night has low call volumes and daytime has high call volumes. The lowest call volumes are between the hours of 3am and 7am. This result is the same at all sixteen nodes, but as is expected from the call intensity map shown earlier (Figure 3), some areas experience a larger change in call volume than others. The second observation that can be made is that weekdays have higher call volumes than weekends, with Sunday have the lowest call volumes of the entire week. If we consider the nodes with maximum and minimum call activity, it is clear that the areas with the lowest call activity during the week also experience the smallest change in activity in going from weekday to weekend. It could be inferred from this that areas of low call volume likely represent areas with greater concentration of residential use, where daily schedules are less rigid than in offices. One exception to this is Wednesday, November 1. The call volumes appear very similar to that on the weekend, and so it is very likely that this was a holiday in Rome. Areas with the largest call volume changes are likely commercial/office zones. During the day when call activity is greatest, there is a temporary decrease in call activity that occurs around mid-day and is present at all sixteen nodes. This change corresponds to

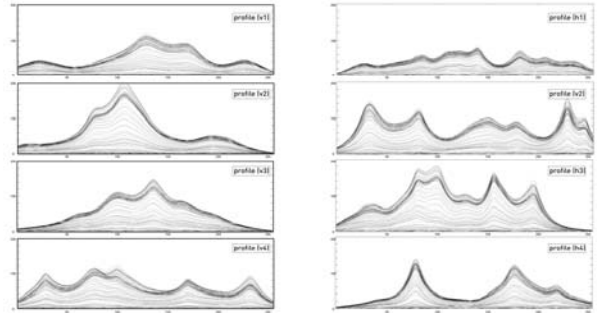


Figure 4: Profiles of cell phone activity along profile lines identified in Figure 3. Each curve along a profile line corresponds to a different time of day.

lunchtime: people call less when they are eating. Another observation that can be made is that the decrease in call activity at the end of the day is more gradual than the increase at the start of the day. In other words, the time at which people go to bed is more variable than the time at which they wake up in the morning.

Expanding the time scale for three days in November, beginning with Sunday, November 5, we can gain a better understanding of the time signature of call activity at the sixteen reference locations (Figure 6). The change in call activity for these three days of the week (Sunday: religious holiday, Monday: first day of work, Tuesday: second day of work) are compared as a function of time. On Monday and Tuesday, a yellow band represents a likely waking schedule for someone who lives and works in the city. Since this schedule is generally well defined during the week, but not during the weekend, it is only shown on workdays. Using available resources¹, one possibility of the daily schedule of a Roman citizen is marked with vertical lines, showing waking hours, morning commute, lunchtime, and dinnertime. As in Figure 6, these data show a more coherent beginning to the day, with people tending to wake up at the same time, but people go to sleep at much more variable times. The correlation of call activity over the three days shows that even though call volumes are lower during the weekend, and likely activity of people is different, the characteristic lunchtime dip in call activity occurs even on Sunday and correlates well with the regular work week. However, at the reference location [4,1], where call activity is lowest, the change in activity at lunchtime is less dramatic, as is also evident in Figure 5. It is likely that this

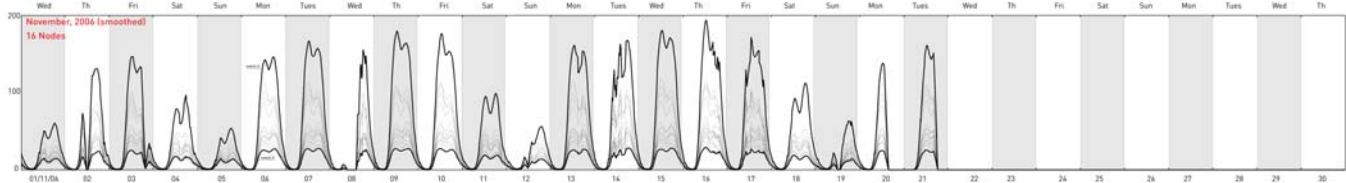


Figure 5: Cell phone activity at nodes identified in Figure 3 during the month of November. Alternating white and gray bars indicate different days.

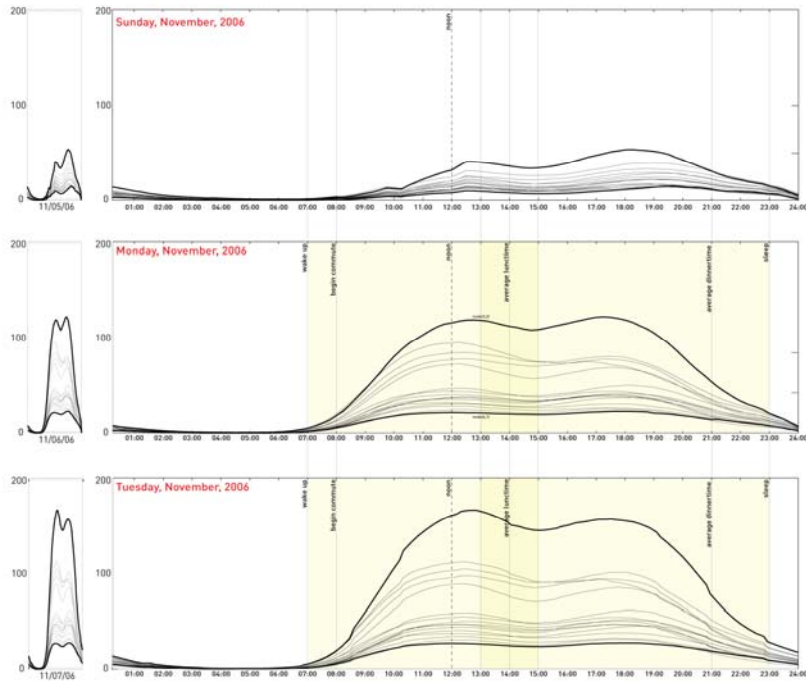


Figure 6: Comparison of cell phone activity for three days in November. See text for details.

results from a greater contribution of residential call signatures than office call signatures, where lunchtime is more clearly defined and regulated.

FURTHER DIRECTIONS

The results presented in this study represent only the beginning of our efforts to understand the enormous potential that this high-resolution cell phone data can give us to understand the characteristic patterns of life in Rome. In this study we have used only data on cell phone activity (normalized *Erlang* data), but in future work we will combine this with high resolution GPS tracking of buses as well as the actual movement of cell phone users. Our current analysis uses normalized data that has been averaged over the entire study region (Figure 1). After identifying the patterns in this dataset, we will go back to the raw data and begin to look more carefully at local signals at each cell phone tower. The goal of this will be to establish characteristic signatures of different parts of the city and to map out regions where the signals are the same. These will then be overlaid with known information on neighborhoods and locations of different types of commercial activity in the city. Combined with the position of transport hubs (bus, subway, and train), and the schedules of public transport in and out of these hubs, we

will be able to establish the signatures of different activities in the city. Ultimately, we anticipate that these results will provide a framework that can be applied to any city, so that cell phone data can be used to characterize the spatial elements of a city and to describe the activity that is occurring within.

CONCLUSIONS

We present the results of a preliminary analysis of high resolution cell phone call data in Rome. The data allows us to identify characteristic domains of the city, with clearly defined spatial and temporal differences. The time signatures correlate strongly with day of the week (workday/weekend) time of day (sleep/awake/lunch) and location (commercial/residential/transport hub). These results provide a new view of the city as a dynamic system that extends the static diagram of the traditional map in a way that has never before been possible. Not only is it possible to characterize overall activity and dynamics of different parts of the city, but it also possible to observe the rituals and habits of daily life.

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