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ABSTRACT

Recently available high resolution cell-phone data from Rome provides a unique window into the dynamics of life in a large, complex city. Tracking this data, which describes the number of active cell phone calls as a function of position and time, shows a complex temporal and spatial pattern with a clear periodic signal. Our results show that cell-phone activity correlates strongly with location within the city—near transportation hubs, in commercial, office, and residential zones, and so on. It also reflects people's daily activities throughout the city—getting up, commuting, working, having lunch, eating dinner, sleeping, attending sports events, and the like. The preliminary data in this study suggests that cell-phone data can be used to characterize and map urban domains and the cultural signature of their occupants, implying that the proliferation of mobile communication devices has the potential to drastically change the way we view and understand the urban environment.

INTRODUCTION

Cities are complex fabrics of multiple domains, developed over centuries 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 provide us with a diagram of the static structure of cities and the relationships between their constitutive elements, but they are limited by what they cannot show: the dynamic activity of the people and vehicles that inhabit urban areas.

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 in 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 conventional map lets us track both activity and movement. Since cell-phone use is closely linked to events in our daily lives, we can 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 daily activities of millions of people leave characteristic signatures of cell-phone activity? And, finally, what conclusions can we draw about the character of different parts of the city and the daily rituals that define the lives of people who live or work in Rome.

CELL-PHONE DATA

The data presented here is normalized cell-phone traffic measured at 15-minute intervals from cell-phone towers throughout metropolitan Rome (Figure 1). To protect the privacy of cell-phone users, the data is anonymous, containing no information about the callers or the content of the calls being made. It shows only 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 normalized to a constant maximum and interpolated the data in between towers with a standard contouring algorithm to give a map of cell-phone activity over the entire metropolitan area. Units shown are *relative* call intensities and not absolute call volumes.

URBAN PATTERNS OF CELL-PHONE ACTIVITY

During a typical day in Rome, cell-phone activity varies according to position and time. Figure 2 shows call intensity at 3-hour intervals over the course of a 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 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. Clearly, some areas have higher call volumes than others. Additionally, the largest call volumes occur at specific locations within the city between the hours of 9:00 am and 6:00 pm (the regular workday). This pattern is repeated daily from Monday to Friday.

Figure 3 shows a larger view of one of the maps at 9:00 am. 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 variation of call activity over time. Two nodes, [4,1] and [2,3], were identified as areas where call activity was the lowest and the highest, respectively, over the course of a single day. Call activity for a single day along the eight 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, there are clearly defined areas of concentrated call activity that vary greatly over the course of on a given day. Where the curves are more tightly clustered (and 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 have higher call volumes. This could be due to a number of factors. For example, areas near transport hubs (like subway and train stations) might experience changes in call volume in response to the arrival and departure of trains, the assumption being that these callers are outside or inside the stations. Areas with concentrations of office buildings are likely to 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 in Figure 3, we begin to see periodic signatures of life in the city. Figure 5 shows call activity at each node during the month of November. The light and gray bands indicate different days, with data being available for only the first twenty-one days. Of the sixteen curves shown, the ones that correspond to nodes [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 points. There is a clear diurnal signal: the night has low call volumes and the daytime has high call volumes. The lowest call volumes are between the hours of 3 am and 7 am. This is the same at all sixteen nodes, but as is expected from the call intensity map (Figure 3), some areas experience a larger change in call volume than others. Weekdays have higher call volumes than weekends, with Sunday having the lowest call volumes of the 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 represent more residential areas, where daily schedules are less rigid than in offices. One exception to this is Wednesday, November 1. The call volumes then appear very similar to those on the weekends, making it very likely that this was a holiday in Rome. Areas with the largest changes in call volume are likely to be commercial or office zones. During the day when call activity is greatest, there is a temporary decrease in call activity around mid-day at all sixteen nodes. This change corresponds to lunchtime: people call less when they are eating. Finally, the decrease in call activity at the end of the day is more gradual than the increase at the start of the day, indicating that the time at which people go to bed is more variable than the time at which they wake up.

By 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. In Figure 6, the changes in cell-phone usage for these three days of the week (Sunday, a religious holiday; Monday, the first day of work; and Tuesday, the second day of work) are compared as a function of time. On Monday and Tuesday, a yellow band represents a probable 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 evident on workdays. A likely daily schedule for a Roman citizen is marked with vertical lines showing waking hours, the morning commute, lunch time, and dinner time. As in Figure 6, these data are more coherent in the early morning, since people tend to wake up at about the same time, but go to sleep at much more variable times. Call activity over the three days shows that even though call volumes are lower during the weekend, and the probable activity of people is different, the characteristic lunchtime dip in call activity occurs even on Sundays 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. This results from a greater contribution of residential call signatures than office call signatures, where lunchtime is more clearly defined and regulated.

FURTHER DIRECTIONS

This analysis represents only a first attempt to understand the enormous potential of high-resolution cell-phone data to understand characteristic patterns of life in Rome. In future, we will combine normalized *Erlang* data on cell-phone activity with high-resolution GPS tracking of buses and the actual movement of cell-phone users. We will also go back to the raw data to look more carefully at local signals at each cell-phone tower in order to establish characteristic signatures for different parts of the city and map out regions where the signals are the same. These can then be overlaid with information about neighborhoods and the location of different types of commercial activity. Data on the position of transport hubs (bus, subway, and train) and the schedules of public transport in and out of these hubs can be used to establish the signatures of different urban activities. Ultimately, these results should provide an analytical framework that can be applied to any city using local cell-phone data.

CONCLUSIONS

A preliminary analysis of high-resolution cell-phone call data in Rome allows us to identify characteristic domains of the city, with clearly defined spatial and temporal differences. The time signatures correlate strongly with the day of the week (workdays differing from weekends), the time of day (when people are awake, asleep, at work, at lunch, or at home), and the location (a commercial or residential area or a transport hub).

These results provide a new view of the city as a dynamic system that extends the static diagrams of traditional maps in a way never before possible. Not only can we characterize the overall activity and dynamics of different parts of the city, we can also observe the rituals and habits of daily life.

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