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Commentary

Sensing human society

Although the commercial use of cellular communications began as far back as 1983, owing to the high price of both the service and the devices used, it was limited primarily to business purposes. Cellular phone prices began to drop drastically in the mid-1990s, and today, in the developed world, cell phones are owned by people of all ages, professions, and income levels, with cell phone penetration in the developed world recently passing the 80% mark (Eurostat, 2005). In 2005 the United Kingdom had a 102% penetration rate, second only to Israel with a penetration rate of 106% and Sweden with a rate of 103% (World Bank, 2006). In recent years the penetration of this communications technology has accelerated also in many parts of the developing world. It is expected that, by 2010, more than 50% of the world's population will own a cellular phone, at which time we will be able to refer to human society as a whole as a *cellular society*.

The operation of a cellular phone network requires the network operator to be able to constantly detect the subscriber's proximity to a specific antenna ('cell'). This enables the operator to transmit incoming and outgoing calls to and from the user's handset. This feature allows the tracking of the device. However, it is clear that there are more accurate tracking technologies currently available—such as global positioning systems (GPS), for example (Shoval and Isaacson, 2006)—that are increasingly being embedded into cell phones nowadays. The fact that an ever-increasing proportion of human society constantly carries a tracking device at all times and in all places creates new possibilities for spatial research. If all the phones that belong to the network are tracked at specific periods, cell phone location data can be used for the aggregative analysis of human activity, and, in practice, this enables the *human sensing* of entire populations. The application of this aggregative approach makes it possible to take a synoptic view of the time – space activity of hundreds of thousands of people in urban and metropolitan areas, or even the time – space activity of millions of people at a national level. This fact, coupled with the considerable progress in the field of GIS, currently places us on the verge of a veritable revolution in human time – space activity research.

Aggregative cell phone location data for spatial analysis

There are two main ways of analyzing the aggregative location data of cell phones. One is to analyze the statistics of antenna activity at certain time periods, information that the operating companies routinely collect and utilize to manage the network. The other possibility is to detect the location and migration of a group of devices over a given period of time on the different antennas of the network. This information is not collected routinely by the operating companies, therefore making it more complicated to obtain, and, as will be mentioned later, this analysis could entail issues of privacy, unlike the first approach.

In the first method the number of devices that are associated with each antenna of the network during a certain period of time is counted. In this method there is no problem of privacy because there is no tracking of specific cellular phones, but rather a statistical analysis of the activity in the different antennas of the network. This method enables the researcher to sense the vitality of cities and regions, and to analyze, for example, daily activity patterns in the region and its cities. It also enables the researcher to integrate the data on human activity with other databases, such as weather radars, and in that way to analyze, for example, the impact of weather on human activity. These data could also be used by the relevant public sector agencies for real-time control and management of large metropolitan areas in case of catastrophic events: for example, evacuations before major hurricanes, rescue operations after major earthquakes, etc.

Janelle (2004) suggested that such data should be analyzed by the 'synoptic analysis' approach, which relies on measures from data across a wide area to identify simultaneously space–time patterns and to forecast changes in relationships among these patterns over time. This analysis would provide a basis for automated real-time synoptic visualization of movement behavior in cities over certain periods of time (Janelle, 2005).

The second method of analysis is to detect the location and migration of a group of devices over a given period of time on the different antennas of the networks—for example, the location of devices registered with the residents of a particular statistical district over a certain period of time. The aggregate data concerning the human spatial activity can then be associated with certain types of spatially referenced data. Such activity could, for example, breathe new life into the census, making it possible to conduct a *dynamic census*. This approach may entail a privacy issue; however, if sufficient aggregation levels are maintained, privacy will also be ensured.

Geographical distribution of antennas

Aside from the two aforementioned ways to analyze the aggregative data of cell phone location, there could also be value in analyzing the geographical distribution of cell phone antennas in cities and regions, since they could serve as a proxy for human activity. A cell phone antenna typically serves around 150 calls simultaneously and therefore the cellular providers are constructing more antennas in areas where they expect a high potential of users. Observing maps of cellular antenna densities could give us a general idea about the main nodes of activity in cities, such as concentrations of business activities, shopping, and leisure, etc. Figure 1 is an example, created by Adi Ben-Nun from the Hebrew University GIS Centre, of a density map of around 1300 cellular antennas in Manhattan. The concentrations of activity around the financial center of Wall Street in the southern tip of Manhattan and the central business district of midtown are highly visible in this map.

Optimal scale for analysis

Cell phones have relatively low accuracy as a tracking method. Mateos and Fisher (2006) found in tests that the average accuracy was 3625 m (with a minimum of 500 m and a maximum of 5000 m); other researchers found higher accuracies, between 150 m to 1500 m (Shoval and Isaacson, 2007). The different results originate mostly from differences in the geometry of the networks and the density of the cell towers.

This suggests that the technology is appropriate for studies of relatively low geographical resolution, such as at the metropolitan level, and not for high-resolution interurban analysis, in which case it is better to use GPS to track subjects (Shoval and Isaacson, 2006). In addition, it should be noted that the suggested methodology is better suited to research in cities and metropolitan regions, where the cellular network is denser, than in suburban and rural areas.

Challenges for implementation

The use of data from many cell phones at the same time for traffic monitoring has already been implemented in various places by private companies that use aggregative cell phone data to monitor traffic in several cities worldwide (Richtel, 2005). These companies usually sample phones that are connected to antennas along highways and

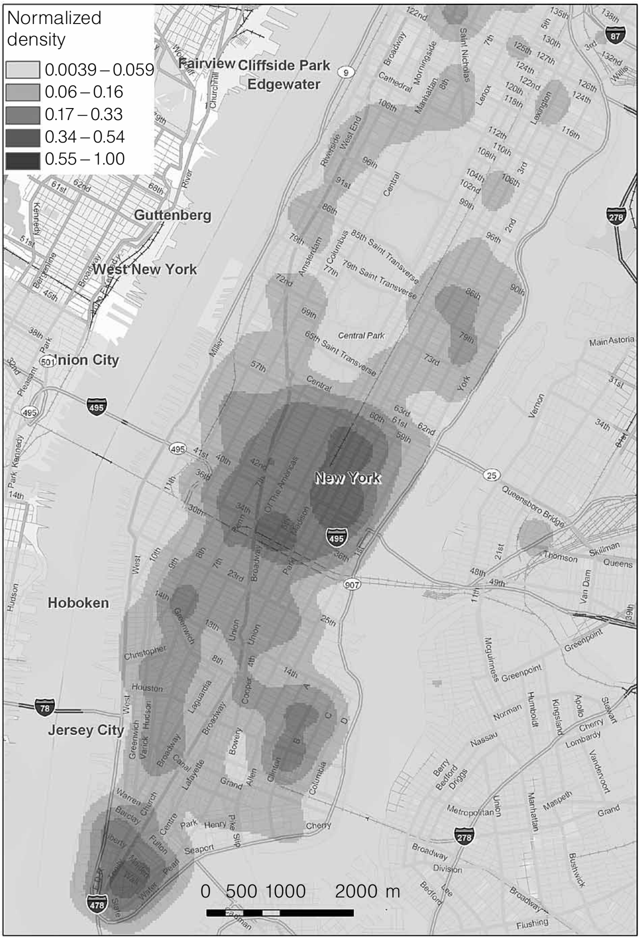

Figure 1. Cell phone antenna densities in Manhattan. A colour version is available at http://www.envplan.com/misc/b3402com/

not whole networks. However, so far there have been only a few efforts to try and implement this concept for academic empirical research. The explanation lies first in the fact that this is a relatively new research area, and second in the fact that that there are significant problems in acquiring the data. The first effort to map human activity using aggregative data from cellular phones was done by a group from Tallinn. Ahas and Mark (2005) made several studies with samples ranging from 30 people to 117 people carrying cell phones for short periods of time. The first, and so far only, researchers to analyze a whole network of cellular phones on a large scale are a group of researchers from the MIT Media Lab headed by Ratti. They used cell phone data to present the feasibility of using aggregative data for urban analysis in the metropolitan area of Milan (published in this journal by Ratti et al, 2006) and in the city of Graz in Austria (Ratti et al, 2005).

There are currently several significant challenges that need to be dealt with before a widespread adoption of this methodology by researchers will be possible.

(1) "In the future our cell phones will tag and track us like FedEx packages, sometimes when we are not aware" (Levy, 2004, page 81). Indeed tracking technologies raise serious concerns regarding infringements on privacy (Fisher and Dobson, 2003)—they add a

geographical dimension to the 'surveillance society' (Lyon, 2001) and they create the abilities to track better the 'digital individual' (Curry, 1997). However, in the first approach presented in this commentary, the data derive from statistics regarding activity in antennas and not regarding the locations of the phones themselves—therefore there should not be any privacy considerations in this case. The issue of privacy is relevant regarding the second approach only, but the challenge could be reduced significantly by creating a 'firewall' between the data supplier and the researcher in a way such that the individuals' privacy will be kept. The solution could be similar to that in the case of censuses: detailed census records at the individual household level are not usually available to researchers. Data are available only in aggregated forms at a level of detail intended to prevent the ready association of demographic information with individual households.

(2) Another barrier to the wide implementation of this concept may be a lack of willingness on the part of commercial enterprises to share their proprietary data. These data are legally the property of the corporation that collects them, and are not freely available. This means that such data are available only on terms and for purposes approved and agreed by the owner. However, as mentioned above, there are already commercial companies and researchers that have received access and permission to use this kind of data.

(3) Even in societies with a high percentage of cell phones, not everyone owns such a device, and even those who do, do not always take the device everywhere with them. Thus, representation of the population may be a problem, although such issues must be addressed in any other research method as well.

Conclusion

In recent decades the government sector in developed countries has invested considerable resources in launching satellites into space, thereby spurring the development of remote sensing. In the *physical* geographic domain, continued rapid developments in remote sensing have dramatically increased the availability of data describing earth surface processes such as climate, changes in land cover and land use, deforestation, and urbanization (Longley, 2002). Each of these new sources of physical geographic data is related to aspects of human spatial activity, but none of them can be thought of as materially augmenting more traditional social scientific data that describe the social characteristics of individuals and groups. At the same time, the private sector has established a global infrastructure for the operation of cellular phones in many parts of the world.

In this commentary I propose referring to the possibility of the aggregative use of cell phone spatial data as *human sensing*. Remote sensing is defined usually as: "the acquisition and recording of information about an object without being in direct contact with that object" (Gibson, 2000, page 1). It might seem that the suggested approach could fall within this definition. However, this new approach is distinct because it enables us to sense people directly, in contrast to remote sensing, where the information obtained regarding human activity is indirect.

Only time will tell whether the contribution made to human geography and the social sciences with this methodology will be on a par with the revolution generated by remote sensing in the field of physical geography and related geosciences.

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