

One to Many: Opportunities to Understanding Collective Behaviors in Urban Environments Through Individual's Passively-Collected Locative Data

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Abstract. Walkable cities are of increased interest for urban planners and active transportation professionals, where a greater understanding of pedestrian behaviors is needed. This presentation discusses an approach for measuring spatiotemporal macro-behaviors of walking activity in urban environments using anonymized, individual, locative, passively-collected data recorded by popular physical activity mobile applications. With this data, we explore the characteristics of aggregated pedestrian activity within the physical and social milieu of the city at scale, with temporal detail, and in consideration of the infrastructural and urban characteristics influencing individual activity.

Keywords: Urban planning · Mobile applications · Locative data · Spatiotemporal data · Physical activity

1 Introduction

With ever increasing frequency, the digital devices that sustain our contemporary way of life communicate back to servers and networks, leaving traces of our physical life. This pervasiveness of mobile devices is also increasingly becoming individualized, with a machine (or more) for every person, especially as the locative technologies document our activities in space and time. This data can be used to make apparent the individual dynamics and flow of materials, capital, and information resources and the individual human behaviors within a city [1]. At this scale the emphasis is increasingly on locative data, concerned with the positional coordinates of human activity, being produced by mobile applications and the devices themselves. We now move ever closer to fully understanding people in place through the analysis of this data, with an ever increasing ability to contextualize activities and behaviors at the urban scale. In a sense, digital interfaces are availing better understand the previously opaque relationship between people and place [2, 3].

Like Geertz's interpretations on a common eye wink [4], the interpretation human activity in urban space must be contextualized. This has been incredibly difficult in the

context of urban history—how do we understand the public behaviors of urban dwellers at the scale of their city, particularly the elements of the city that are within the purview of the urban planner? The question of “good city form” has been of long pursuit, but without a means of quantifying the relationship between inhabitant and the public nature of urbanism. Jane Jacobs describes the importance of this public life:

Streets are almost always public: owned by the public, and when we speak of the public realm we are speaking in large measure of streets. What is more, streets change... If we can develop and design streets so that they are wonderful, fulfilling places to be, community-building places, attractive public places for all people of cities and neighborhoods, then we will have successfully designed about one-third of the city directly and will have had an immense impact on the rest [5].

In a similar vein, Jan Gehl [6] calls attention to the life between buildings. It is in the spaces between architecture where the social connections of inhabitants are created and reaffirmed, and where the space of movement coexists with the social life of the city. These aspects form inter-related patterns of movement and activity to which buildings in turn respond. To Lynch, this life also imbues these spaces with meaning. Imageable paths contain characteristic spatial qualities that are able to strengthen the attention and meaning of the street to its users [7]. Such paths set up relationships among buildings, spaces, and urban features arrayed along them, due to their proximity to one another, or the geometric configuration of the street itself. For instance, the distinctively articulated facades, the greenway, and the width of the Champs-Élysées give the boulevard prominence in Paris, inviting people to ambulate along it.

With the prevalence of digital technologies, particularly locative technologies embedded in our mobile devices, we are now able to dynamically sense, analyze and understand these urban dynamics more quickly and to accumulate detailed knowledge over time to see patterns and trends. This technological approach – having access to large volume datasets to study a phenomenon and its dynamics – augments the process by which urban space is designed, developed and evaluated, and offers opportunities for data-driven analysis and design of the built environment. McLuhan foresaw technologies serving as civic thermostats “to pattern life in ways that will optimize human awareness” [8]. He said, “already, it’s technologically feasible to employ the computer to program societies in beneficial ways.” He stressed that “the programming of societies could actually be conducted quite constructively and humanistically.” Greenfield comments that “the final intent of all this... is to make every unfolding process of the city visible [...], to render the previously opaque or indeterminate not merely knowable but actionable” [9].

2 Devices and People, in Place

The pedestrian realm has long been a focus of research. William H. Whyte [10] used Super 8 film to record the use of plazas and other public spaces in New York City, created in the construction of large, office buildings taking advantage of new zoning incentives. Whyte used a variety of observational methods, including time-lapse films, to assess variation and regularity in pedestrian behavior and the use of designed elements in these

small urban spaces. Whyte's research is an example within a longer tradition of using a snapshot of or creating a simulacrum of urban life, in an attempt to reveal the essential nature and predictable character of activities in the built environment.

Of course, these efforts were not new [11]. To reveal activity patterns, there are many mechanisms by which we can understand how individuals move through space and the motivations why. Traditionally, observations and surveys have been used to investigate values and attitudes towards different attributes of the pedestrian experience along a route. Increasingly, technology has been augmenting these efforts. Computer-based models and "on the move" surveys using mobile technologies are now common research tools [12]. These efforts can reveal how pedestrians behave, in regular and repeatable patterns, in space. This re-creation (modeling) is fundamental, as designing pedestrian environments requires assumptions about how individuals will respond to characteristics of the environment as they create and enact their walking itineraries. Fundamental, the patterns of travel have incredible regularity; despite the diversity of travel history overall, humans follow simple reproducible patterns [13]. Many of these regular decisions are made internally as a series of on-the-spot responses to social, economic and physical stimuli from the urban environment around the individual [14]. The quality of the pedestrian environment can significantly affect the utility of walking along a path [15].

Relationships between urban space and travel behavior have long been a focus of research by studying how people, place, and activity influence the creation of walking itineraries. These itineraries are closely tied to the mental imageability of a place. Lynch, notably, studied individuals' perceptions of the urban environment to formulate a conceptual basis for good urban form [16]. He ascertained that certain spatial elements and sequences tend to be remembered ("imageability"), suggesting that reference points (landmarks, edges, etc.) are important to spatial cognition [17]. These points provide an organizational structure that facilitates the location of subsequent points when individuals move through space.

Ultimately, the intent is to understand behaviors within the context of the intent [18]. This ethnography seeks to reveal the reveal technical, social, organizational, and physical factors that drive the decisions made by an individual, or the aggregated decisions of a population. With the democratization of access to digital technologies and information, these spatially-oriented studies have begun leveraging data as a means of scaling these ethnographies to the breadth of an urban region. The pervasiveness of mobile phones lent an opportunity to coarsely study the aggregated mobility patterns of entire cities through the metadata produced [19]. Online access to street-level photographs has been used to understand how the visual appearance of an urban environment can have strong effects on the perception of safety. Streetscore used a scene processing algorithm to predict the perceived safety of a streetscape, using training data from an online survey with contributions from more than 7000 participants and over 1 million online images [20].

Similarly, locative technologies may be used to understand human dynamics within an architectural or room scale. Several projects leverage Bluetooth sensors to record human dynamics within space. They leverage the unique MAC address assigned to each mobile device (and most likely, one person carrying these devices). When two Bluetooth

equipped devices are in close proximity, the MAC address is shared between and a log may be kept of that interaction. *Bluestates*—by Mark Pesce and John Tonkin—sought to measure the social interactions between individuals equipped with Bluetooth-enabled mobile phones in order to see how social life in space is created between individuals: who talks to whom, for how long, and in what order? A comparable study conducted in the Louvre sought to delineate patterns of movement of visitors to the museum, finding little difference between short and long duration visits [21].

The use of public space and its dynamic characteristics has long been of interest with regard to technological culture. Keith Hampton has used Wi-Fi and data usage patterns with observations to ethnographically understand how Wi-Fi use influences the use and presence of individuals in urban public spaces [22]. Similarly, Ito et al. [23] created ethnographic profiles of Japanese youth in public spaces that used their mobile phones in the public realm. These profiles, again, are in a lineage of trying to understand patterns of social behavior in public space, but the use of the digital breadcrumbs from these engagements can now create more robust profiles of use and activity.

The potential to create thick descriptions is where the power of locative data lies. Especially through passive observation and documentation, we begin to answer this question with the natural behaviors of individuals. These behaviors carry with them significant implications for the design and planning of these spaces, the structure of a community, and the social networks among people. This prevalence of data from activities in public spaces may in turn reshape the public realm.

These projects use information and communication technologies to generate a map of human routine. These technologies are enabling a big data approach to Paul-Henry Chombart de Lauwe's 1957 idiosyncratic map tracing the movements of a single individual, a young woman studying at the school of political science. Today, such maps are now routine; we generate them involuntarily everyday as the devices we carry with us leak this locative data that include our locations and social connections through our voice calls, IP pings and messages sent. If we engage in certain kinds of online behavior – checking in via Foursquare, posting to Twitter with geolocation – we may be generating maps visible to the general public.

With the introduction and rapid adoption of personal mobile devices, such as mobile phones, smart watches, and wearable sensors, the amount of data about the minutia of personal activities is increasingly available [24]. This data is also increasingly geospatial, with activities located in the environments around us. This figurative overlay of digital information in our everyday lives has added a virtual connection between everyday reality, people, and devices. People are increasingly (and romantically) “immersed in a twitching, pulsing cloud of data” [25] with the introduction of pervasive sensing technologies. Taking a narrow view on Thrift and French [26], the use of digital technologies also automatically creates a virtual representation of physical space—an “automatically reproduced background” of data “found in the spaces of everyday life”. Here, the digital “reproduces everyday life”. The technological reality is that the space of the street is also becoming a platform for technologies logging detailed patterns of behavior, and allowing for new possibilities within them (Fig. 1).



Fig. 1. Paul-Henry Chombart de Lauwe’s 1957 map of a single woman’s journeys through Paris

This new capacity, therefore, allows us to imagine new opportunities for urban planning, policy-making, and design by understanding the collective population within their specific urban milieu. Rather than a conceptual outcome, as Koolhaas imagines, wherein “apocalyptic scenarios will be managed and mitigated by sensor-based responses; mundane issues, hidden from view, will be brought to our attention and redressed automatically” [27], the potential of leveraging digital data is to serve as being supplemental to the intuitive process of design—theories within a designer’s toolkit. In other words, the analysis and sense-making of digital data can reshape theories and practices of city-making towards a new paradigm rooted in the use of these massive, real-time sets of data.

3 One to Many: Toward an Urban Understanding

The design of the built environment to achieve social, cultural, environmental and economic goals entails assumptions about the function and performance of urban spaces. Understanding how individuals respond to the characteristics of existing urban spaces will allow creators of new public spaces to specify their context and design with more detail and greater certainty as to how they will actually perform. Fundamental to the creation of urban space is an understanding of how individuals are likely to behave within it. Gaining this knowledge requires “well-validated, durable criteria for successful outcomes” [28]. The difficulty, however, is that the generation of these criteria has long relied on surveys with small numbers, or anecdotal studies using proxy data. Campanella [29] similarly calls for a return to the planning of the physical city concentrated on people and place.

Such an endeavor would have to “deal with the complexities of aesthetic, ethical, and political theory to secure its foundations.” This search has thus far been quixotic. Christopher Alexander, Leslie Martin, Kevin Lynch, John Habraken, Konstantinos Doxiadis, and many others have searched vigorously for theories that ascribe physical attributes and configurations with the quality of experience in urban spaces by those who inhabit it [7, 29–32]. This is made particular true, yet more challenged, in that people’s work and social habits are changing because of new technologies—activities that once required fixed locations and connections can now be done with more location and temporal flexibility.

Here, the technology allows for such definitions to begin with the individual, through his or her natural choices. Rather than surveys or diaries where the person must unnaturally recall the minutia of daily life, locative technologies can document the eccentricities of those mundane choices. Cumulatively, these collective behaviors represent a truer picture of Campanella's complexity especially as the ubiquity of smartphones incorporate more and more locative technologies. Across the demographic spectrum, smart devices are being consumed and used with increasing numbers. Despite smartphone users tend to skew younger, a majority of Americans in their mid-forties/fifties now own smartphones [33].

For this study, we begin with the example of Boston, Massachusetts in the United States. The dense and non-orthogonal grid configuration has long made Boston known as a city amenable to walking. Morphologically, it is a unique case in the United States due to the lack of an orthogonal grid in much of the city. The city of Boston has the seventh highest rate of commuting trips done on foot, with neighboring Cambridge ranking first. The urban area of Boston has 15.1 % of commuting trips to work done on foot, the highest of any large city in the United States. Further, with the high ownership rates of mobile devices, it serves as a rich laboratory to investigate these human-device-city interface potentials.

3.1 Data

Traditionally, surveys have been the most promising tool for studying the link between the built environment and pedestrian behavior [34]. With new technologies now available, we are able to gain greater clarity in movements without the need for surveys or manually completed travel diaries. This project leverages anonymized data created on walking behavior by individuals using popular physical activity mobile applications. The scale and precision of this locative passively-collected, mobile phone data offer an opportunity to move beyond the limitations of previous studies. By not limiting the physical scale to a small area, but enlarging it to multiple cities, this study can span and assess distinct neighborhood typologies and help to mitigate issues of neighborhood self-selection. This allows for a novel awareness of aggregate pedestrian behaviors and risk exposure that speaks to the social and physical characteristics unique to a street, city or region as a whole, with insight into behavior influenced by dynamic conditions (Fig. 2).

This research employs anonymized data created on walking behavior by individuals using a popular physical activity mobile application company. First, an exercise-oriented application (EOA) collects data when users opt to track their fitness activity, and its' activity-oriented application (AOA) takes count of how much, and where, users walk. The AOA, utilizes the phone's motion coprocessor, which constantly documents movement data in the background processes of the device. Combined with GPS locations from the mobile device, the data reveals the walking locations and durations of users throughout the day. As a result, the data incorporates both recreational and utility (e.g., commuting) trips made by the user. With behaviors differing based on intention [35], a distinction is made between recreational and utilitarian activities.

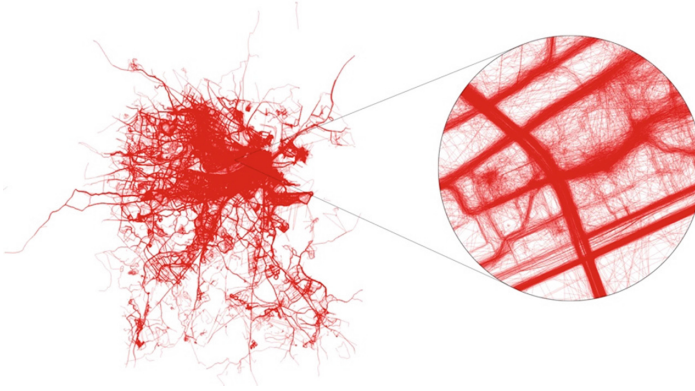


Fig. 2. A map of the Boston metropolitan area drawn from the individual pedestrian tracks in the dataset. The area around the MIT campus is called out (right) to show the detail of the geospatial data.

The data went through a process of anonymization before being shared with the researchers. First, profile information was anonymized and given hashed user identification numbers. Basic categorical demographic profile information was made available for EOA trips, but unavailable for the AOA trips. Further, a random distance of 0-100 m was removed from the start and end of each trip to further anonymize the user's frequently visited locations. The resultant data was again filtered to eliminate errant activity traces due to inherent errors in the device's various locationing methods [36].

3.2 Boston as a Case Study

In this study, we analyzed over one million trips from over 60,000 unique users in Boston from two mobile applications made by the application company bound within 42.2284° N, 71.1895° W and 42.3979° N, 70.9852° W. From the EOA, we analyzed data from January 2010 – May 2016 and from the AOA, May 2014 – May 2015. The use of these datasets offers an ability to assess walkability factors beyond “active living” or recreational purposes. With behaviors differing based on intention [35], a distinction is made between recreational and utilitarian activities. As users have to initiate trip recording with the EOA, that application is more inclined to document recreational activities when users wish to track their activities. As the AOA records all movement activities of the user, and increasingly users are always carrying their mobile device, the data is more representative of utilitarian, natural movement activities. This avails an opportunity to analyze utilitarian pedestrian activities as well as activities in residential or less central areas of these communities (Fig. 3).

However, inherent in this study (and the choice of case city) is a chicken and egg problem between the prevalence of walking and prevalence of data: without pedestrians, there is no data. This is particularly true of Boston, with its strong cultures of walking and with more pedestrian-oriented infrastructure than many other cities in the country. The approach of using data to extract these patterns is predicated on the availability of

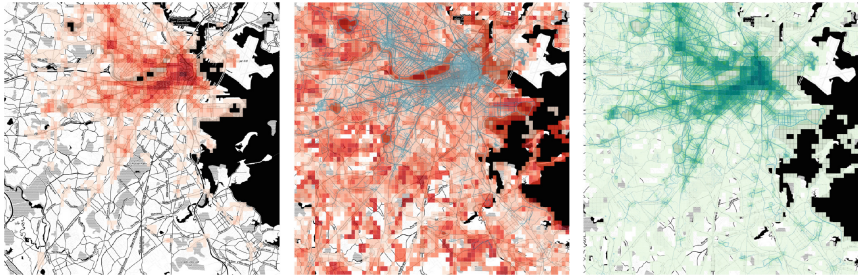


Fig. 3. Three heat maps of Boston and walking activity from the AOA. The first image (left) shows the density of trips is primarily focused on the downtown and Back Bay neighborhoods. The second shows the average time spent in each spatial unit of the city, where the activity is centered on recreational areas in the city including waterfront walks and parks. The third (right) illustrates the paths taken by individuals overlaid on the urban tree density of Boston, with apparent correspondence between the two.

data. As such, there is a lack of a clear case study that offers a null scenario, where little walking occurs. However, the framing of the research questions is oriented toward understanding patterns of behavior in places where walking occurs, rather than what spatial factors compels walking generally.

For utilitarian trips, pedestrians can choose from any path within the urban grid to travel from origin to destination. Despite the abundance of options, pedestrians tend to favor a small subset of potential paths, of which several factors play a role. In particular, trips along streets purposefully designed with a pedestrian in mind do carry more passengers. This is especially true with tree-lined paths, which has a strong correlation to quantities of pedestrian trips. In this context, pedestrians do choose the utility of the street over pedestrian parkways for different mobility purposes, as velocities and elapsed time in these different spaces differ—pedestrians spend more time in, and traverse slower through, paths through parks or green spaces than on the sidewalks. Despite trees in both locales, pedestrians do behave differently in each of those spaces.

This type of analysis offers a new means of population-level categorizations of space that may transcend the typical approach to Euclidean planning, in the nuanced categorization of spaces through its use by the inhabitants themselves. The narrative analysis, in this example, reveals nuances that would otherwise remain invisible through traditional methods. Equivalently, through the analysis of actual activities may reveal behavioral patterns in time, as well as space.

3.3 Boston Marathon Bombings

Although an anecdote, the recent bombing tragedy at 2013 Boston Marathon offers a lens to understand how this data may begin to tell population-level behavior overall. In analyzing the characteristics of trips made during the week of the marathon, we were able to gain a perspective on how the citizens responded during the tragedy and confusion surrounding the attack in this unique and shocking event. Surprisingly, there few impacts noticed during that week—perhaps affirming the local rallying call to be “Boston

Strong”. Compared to the week prior, there was a very noticeable drop off in trips after the bombings occurred in Back Bay on Monday, April 15. Although there is a general trend of fewer trips on Marathon Monday, largely due to the closure of streets for the Marathon, the decline in trips was significant, perhaps due to the police cordons and the strong mood of uncertainty in the city.

There was little difference in the number of trips being made by the application users, despite the safety concerns throughout the week of the manhunt and investigation. This is no more apparent than the little difference in the number of trips between Friday, April 19 and the week before, in defiance of the request by the Governor of Massachusetts to shelter-in-place in the cities and towns of Allston-Brighton, Boston, Belmont, Brookline, Cambridge, Newton, and Watertown, which lie within the study area. Even though that request was made, and the confusion surrounding the manhunt and subsequent shootout in Watertown, there was little overall difference in the hourly quantity of recreational trips between the two weeks, especially in areas farther from Watertown. Although to the likely chagrin of public safety officials, this glimpse into the activities at the city scale speaks to a narrative about the social resiliency of the population that would have otherwise been difficult to ascertain through word of mouth or observational narratives (Fig. 4).

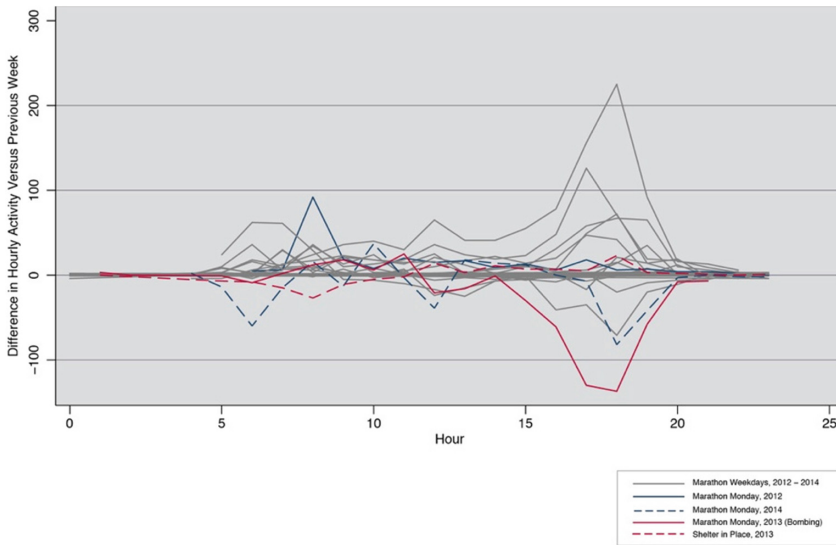


Fig. 4. The hourly count of weekday EOA (recreational) trips during the week of the Boston Marathon for 2012–2014. Although there is a noticeable drop in the number of trips after the blasts on Marathon Monday, 2013, the impact of the shelter in place order on the following Friday was not as apparent. The remarkable higher-than-average number of trips in the evening of April 22, 2014 is likely attributed to the ideal spring weather conditions in the city.

4 Discussion and Future Work

These narrative findings offer an initial lens by which we understand the city in new ways. While there are still many analyses to perform with this rich data, these results open new lines of human-computer interface research, particularly as it relates to the relationship between cities and individuals. In Michael Batty's words, "we delight in approaching the city in terms of its morphology but morphology is not enough. It must be unpacked and the only way to unpack it is through dynamics." [37] These results summarize and example a larger course of research.

Recent research efforts in urban planning have focused on the idea that land use and design policies can be used to promote non-motorized mobility such as walking. The development of appropriate measures for the built environment and for travel behavior is an essential element in the search for "good urban form". Neighborhood design has an important role in fostering walkability. Already, there is relatively strong evidence of an association between site design and pedestrian activity, particularly with compact development patterns and the promotion of walking behavior and may further this research.

Due to the imperative for user privacy, the challenge of the uncertainty as to the representativeness of this population across the breadth of descriptors for the larger population remains. Among them are questions of socio-economics, especially with this project's reliance on smartphones. A factor exacerbating these differences in pedestrian activity is accessibility—how different locations within a city are spatially linked to surrounding economic opportunities. Walkability is connected to larger considerations of socioeconomic conditions within the city and the generation of social capital: is walkability accessible to or enjoyed by all equally? This question, although broad and fundamental, touches upon the experiential potential differences in the character of urban space and the access, or lack thereof of these spaces as places to live work and play by those of differing socioeconomic groups across the breadth of the city. As walkability and traditional neighborhood design are en vogue in many areas, the concern is that pedestrian-friendliness may exacerbate societal divisions in their economic and physical inaccessibility. The generation and maintenance of social capital are other important components of quality of life that may be facilitated by living in a walkable community.

Of great interest as well is the use of this data to move beyond traditional measures of transportation that are often concerned with metrics of efficiency—velocity, speed, quantity. With the resolution of this data, there exists a potential to generate new measures drawn from the social behavior of individuals such as "shoaling", analogous to fish behavior. In the same vein as Whyte generating catalogs of behavioral typologies in public plazas, the precise locative data may allow for a cataloging of behaviors related to traversing the city.

Within the course of this study, this paper and presentation sought to encompass two parts of this urban-focused discourse. First, it established a theoretical context, rooted in the conversations of urban planning development as a foundation for HCI interventions, rather than those of technology (or worse, the rhetoric of "optimized" cities). It began as a literature review of that potential that exists with a new paradigm of big, locative data, that despite having been written within the context of situated computing,

pervasive computing and smart cities for years, has only recently been made possible. The second half sought to be illustrative of that same potential, by seeking to example a new understand the relationship of people in place (with emphasis on both). Although there is more to be done, we hope it offers a figurative light at the end of the tunnel about the use of locative media at scale.

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