Pulse of the city:
Visualizing Urban Dynamics of Special Events

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ABSTRACT

How does a city perform during a special event? How can we inform local authorities and urban dwellers of public happenings? Until today it has been difficult to monitor urban dynamics in real time. Traditional methods, like head counts, surveys, and aerial inspection, are costly and limited. In this paper we present our twofold approach to the processing and visualization of real time information gathered from the telecommunication infrastructures that percolate modern cities.

This paper presents visualizations for a popular audience that examine the social psychogeography of the cityscape. Our work is a step towards understanding the functions of the city through digitally-enabled urban functions such as the pervasive telecommunications network. Based on an analysis of data from a telecom network, we illustrate how special events influence the normal rhythms of the city, and how crowds move and respond to large-scale public events.

This paper also discusses the potential of realizing an interface aimed at informing urban dwellers in real time of the dynamics that occur in the very place they find themselves. We contend that this type of public intervention could enable local authorities, service providers, businesses, and citizens themselves to function and behave more efficiently, making the places they inhabit more livable and sustainable.

This paper presents the two approaches, compares them to similar recent projects, and discusses the design choices that drove our implementation and the insights that we gained by their implementation.

Categories and Subject Descriptors

H.5.1 [Multimedia Information Systems]: Animations; [J.4 Social and Behavioral Sciences]: Sociology.

General Terms

Design, Human Factors.

Keywords

Urban Dynamics, Urban Informatics, Urban Interaction Design, Visualization for the Masses.

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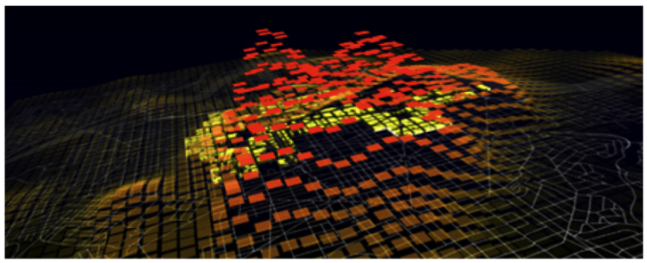

Fig. 1. *Obama* | *One People* [15] visualizes cell phone call activity during the Inauguration of President Barack Obama as a way to understand the urban dynamics of special events.

1. INTRODUCTION

Over the past decade there has been an explosion in the deployment of pervasive systems like cell phone networks and user-generated content aggregators on the Internet that produce massive amounts of data as a by-product of their interaction with users. This data is related to the actions of people and thereby to the overall dynamics of cities, how they function and evolve over time. Electronic logs of cell phone calls, subway rides, GPS-enabled buses, and geotagged photographs are all digital footprints [6] that today allow researchers to better understand how people flow through urban space, and could ultimately help those who manage and live in urban areas to configure more liveable, sustainable, and efficient cities [2].

At the same time, these pervasive systems present the possibility of extracting and inserting real-time information about social dynamics into the built environment. The possibility of establishing this dynamic feedback loop of information about how a city functions has the potential to influence many aspects of

urban management by assisting local authorities, service providers, enterprises, and even citizens themselves to make more accurate decisions and thereby create a more efficient urban environment. In order for this to happen, we contend that it is necessary to first educate the public in understanding how individual choices build up to form emerging urban processes that affect the city and its inhabitants as a whole.

Obama | One People [15] employs digital footprints from a major telecom operator's cell phone network to examine how people occupy urban space during a major special event. The project consists of two visualizations, The City and The World, which are aimed at a popular audience and represent the event from both a local and an international perspective. We chose President Barack Obama's inauguration day in Washington D.C. as a case to develop the special event visualizations and we partnered with a major telecom operator to use cell phone data as proxy of social activity. We designed and implemented the *Obama | One People* visualizations to provide aesthetically compelling answers to questions like: How does a city perform during a special event or, analogously, a sudden emergency? Where do people congregate and how does this vary over time?

It should be noted that there are many projects that focus on specific aspects of urban pervasive systems and the study of digital traces like cell phone calls, text messages and geotagged photographs [6, 13, 7] and the implementation of new mobile services [12, 1, 9] and interfaces [8, 14, 5]. Our approach in *Obama | One People* is slightly different. The goal of our visualizations is to translate the invisible digital traces of cell phones and relate these to urban space so that people can grasp the large-scale dynamics that occur within a cityscape. The ultimate intent of this work is to envision a future where urban actors can process existing information in real time directly from the city's digital infrastructure and make more informed decisions about their social behavior within the city.

The data presented in *Obama | One People* consists of hourly counts of cell phone calls per each base transceiver station serviced by a major telecom operator in the Washington, D.C. metro area along with the location where those phones are registered, by state for American phones and by country for international phones. The data set provided covered the period from January 10, 2009 to January 28, 2009, out of which we chose to represent the three days before and after the event, from the 17 to the 23. To ensure the complete privacy of the telecom provider's customers, the data is in accordance with the provider's privacy policies and we performed our analyses in compliance with the 2002 Directive of the European Parliament and Council on Privacy. Our use of aggregate data implies that we cannot identify individual callers, and we hope that our project might stimulate a dialogue on the responsible access to digitally-generated urban data and on how it can provide value-added services to local and regional communities.

This paper first reviews the relevant design works in the field of urban informatics, then discusses the design requirements we sought to achieve in *Obama | One People* and describes the visualizations themselves and their results, reviews the architecture designed to implement the project, and finally considers the limitations and practical applications of this type of work. All in all, we believe *Obama | One People* offers the following contributions to the field:

- It presents two visualizations that use existing digital footprints to create an aesthetically compelling representation of the temporal and spatial aspects of a public event in a major urban area.

- It proposes how such visualizations can be accessed through digital interfaces to support real-time decision-making in the urban environment.

2. RELATED WORKS

Urban space and cartographic space are inseparable: from the grid to the aerial perspective to contemporary digital mapping technologies, the experience of urban space is always an important component in people's mental map of the city. The map has become a popular interface in illustrating data sets drawn from our increasingly digitally enabled urban infrastructures: from GPS [18, 17, 4] to cell phone networks [13, 11] and other objects equipped with radio frequency ID tags [4, 3]. The purposes behind these types of visualizations vary: from purely artistic endeavors to traffic monitoring to the uncovering of emerging patterns of urban activity.

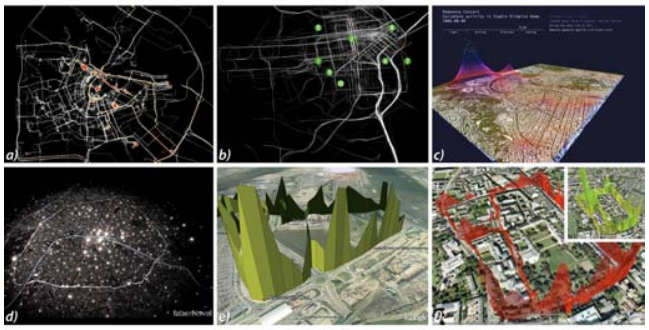

Fig. 2. Examples of visualizations of urban dynamics.

There seem to be four distinctive elements in the visualization of urban digital footprints:

Infrastructure and scalability. The type of data being used in the visualizations are generated by digitally-operated urban infrastructures in the course of the everyday functions of the city (RFID, WiFi hotspots, GPS, cell phones).

Flows and contexts. The data are displayed dynamically over time and in geographic space in order to represent flows of activity (i.e. pedestrians and cars). Some visualizations attempt to represent activity in almost real-time, often with a slight time lag for processing, such as a 15-minute delay.

2D and 3D perspective views. Depending on the objective of the visualization, some perspectives are in 2D, such as in representing traffic flows, and others are in 3D to present concepts like the volume of activity in urban space.

Levels of data aggregation. The scale at which the data is presented varies in detail and aggregation, such as in the case of sensitive information about individuals.

The following is a discussion of precedent projects that exemplify the most notable approaches to mapping urban dynamics and that offer starting points for illustrating the city-wide special event for *Obama | One People*.

Amsterdam Real Time (2003) by the Waag Society and Esther Polak [18] (Figure 1.a) focused on visualizing the connection

between the structure of the city and the movements of Amsterdam's inhabitants.

Fig. 3. Distinctive elements in the visualization of urban digital footprints.

By examining people's mobility through GPS, the project uncovered a map of the city defined solely by people's activity in space. Only GPS trajectories were recorded in the visualization and this urban flux revealed Amsterdam's urban form only by capturing the digital traces of people's movements (Figure 2.a). Similar to Cabspotting in San Francisco [17] (Figure 1.b) this visualization employs the flow information to structure the geographic space of the city, highlighting thoroughfares of movement but leaving out buildings and public spaces. Because of a lack of geographic references, it is difficult for those not familiar with the map of Amsterdam to understand the connection between the form of the built environment and the flows of people. Nevertheless (Figure 2.b), using GPS systems to visualize urban dynamics is a powerful way to detail (Figure 2.d) the movements of large numbers of people. Though as in all projects that use GPS, extending this kind of mapping to include larger number of individuals involves a high cost and a major organizational effort.

As mentioned previously, Cabspotting is similar to Amsterdam Real Time [18] in visualizing movement within the city and in its design approach. Directed by Scott Snibbe [17], Cabspotting uses GPS technology Figure 2.a in San Francisco's taxicabs to trace their movement in real time through the city. The patterns traced by each cab create a dynamic sense of traffic flows through the city's arteries, revealing where traffic is moving quickly and where it is congested.

Real Time Rome [13] (Figure 1.c) and UrbanMobs [11] (Figure 1.d) introduce a 3D perspective view (Figure 2.c) and provide a sense of the collective emotions of a city. As the MIT SENSEable City Lab's contribution to the 2006 Venice Biennale, Real Time Rome took aggregated data from cell phones and mapped these calls onto the geography of the city during two special events over the summer of 2006: the World Cup finals match between Italy and France, and a Madonna concert. The visualizations show peaks in the volume of calls during stirring moments (such as Italy scoring a goal during the World Cup match) in a sense revealing the emotional signature of the city as well as where people are congregating. Similarly, Orange Labs and Faber

Novel developed UrbanMobs as a tool to showcase popular emotion cartography through the analysis and visualization of citywide cellular network traffic activity. Both examples signal a shift in both the aesthetic qualities of visualizing dynamic urban data and in the methodology of positioning cell phones within urban space according to the location of cell phone towers that service those calls. This methodology may lose the detail of GPS data but in tapping into the network infrastructure of cell phones, it can harness vast amounts of data representing large swaths of the city, thus increasing the scale of representation.

Measuring and mapping people's emotional responses to the built environment itself is the goal of BioMapping by Christian Nold [4] (Figure 1.e). This is a community-mapping project that utilizes a GSR (Galvanic Skin Response) device to measure how people react psychologically to different areas of the city. Over 1,500 people have contributed to this exercise in various cities to produce these communal emotion maps. Presented in a 3D view, the visualizations use Google Earth to relate people's emotional arousal as measured by the GSR device to the geographic locations they traverse. BioMapping clearly presents the urban context of people's reactions to the built environment, and the GSR sensors and GPS scale the visualizations down to show individuals' responses; however the number of people involved limits the extent to which these maps may present a collective psychogeogaphy of the city.

Another project that visualizes data gathered directly from consenting individuals is CamMobSense in Cambridge, UK [3] (Figure 1.f). Using sensors mounted on pedestrians and cyclists, CamMobSense monitors pollution in the city and relays the collected data to a website in real time. It presents a low-cost, distributed sensor model where people themselves collect data that can be then visualized to better understand the environmental impacts of urban functions such as transportation, and in turn this can help those who manage urban regions make more informed decisions.

Building upon these precedents, *Obama | One People* utilizes aggregated data from cell phones and overlays the call dynamics onto an aerial photograph of Washington D.C., which highlights the event spaces of the Presidential Inauguration such as the Mall and Pennsylvania Avenue. We present the visualization in 3D to highlight the peaks and troughs in cell phone activity before, during and after the special event itself, totalling a week's time of data. While the aggregated data does not reveal details of individual movements, it does reveal collective dynamics over the course of a week in large swaths of the Nation's Capital. We have thus created a scalable system that is able to capture the call activity of large numbers of cell phones resulting in a visualization that highlights the communications flows of a crowd and how these relate to geographic locations within the city.

3. DESIGN REQUIREMENTS

In light of the above discussion, we identified the following specific design requirements to guide the design of *Obama | One People*. The visualizations should create a "digital skin" of urban spaces, with a simple and clear visual language system. They should convey the social dynamics of a crowd, which are real phenomena, using informational data. The user should perceive the former, not the latter. They should establish a strong relationship between the crowd and the urban landscape. For this reason, we considered the spatial representation of the information as a given, reflecting the geographic nature of the data.

The visualizations should be interactive but simple, allowing the user to explore the evolution of the event in space and time. However, they are not meant to be visual analytics tools, so they should not provide quantitative details on the data. To achieve this, there should be a good balance between aesthetics and functionality. Inspired by Norman's work [10], we should use color, saturation, and luminosity to improve the aesthetic and emotional impact of the project.

Finally, from a technical perspective, *Obama | One People* should ideally run on a real-time stream of data. However, due

restrictions on the time required to collect the data from the telecom provider's network it was not possible for represent the event as it occurred.

4. OBAMA | ONE PEOPLE

On January 20, 2009, Washington D.C. hosted the largest crowd in its history for a very special event: the Inauguration of President Barack Obama. This crowd presented great challenges to both federal and municipal authorities in terms of management, transportation, security, and emergency response. Where would people congregate? How would they get there? When would they arrive and depart? From where were they coming? The authorities even had difficulty in estimating how many people would attend the event. Early predictions called for over 3 million people, and it was only after the week of the Inauguration that the City was able to release an official estimate of 1.7 million people. The 2009 Presidential Inauguration offers perhaps one of the most extreme cases of the value of gathering data about large crowds in real time so that decision makers can understand and manage special events as they occur.

In considering the volume of mobile phone calls at any given momentas indicators of a crowd's geographic distribution over time, our access to aggregated cell phone data from a large telecom operator presented us with the opportunity to explore the possibilities of using such data to understand the dynamics of large-scale special events such as the Presidential Inauguration. The *Obama | One People* visualizations sought to explore such questions as: Who was in Washington, D.C. for President Obama's Inauguration Day? When did they arrive, where did they go, and how long did they stay? The nature of interpersonal communications also allows us to interpret the resulting visualizations of call data as revealing the psychogeography of the city during a special event. Guy Debord, a French theorist, defined psychogeography in 1955 as the "the study of the precise laws and specific effects of the geographical environment, consciously organized or not, on the emotions and behavior of individuals." [TODO Guy Debord. 1955. Introduction to a Critique of Urban Geography (essay)]

Thus, another question *Obama | One People* explores is: when and where did the crowd in Washington D.C. sense the need to share thoughts, information, and feeling with others who were not co-present? Not only does *Obama | One People* map the invisible flows of communications over the geography of the city, it also begins to gauge the collective emotional pulse of the city at a large scale and over time. Below we discuss the two visualizations produced to present our analyses of aggregated phone calls in Washington D.C. during the week of President Barack Obama's Inauguration: The City and The World.

4.1 The City

The City illustrates two pieces of information about the Presidential Inauguration: 1) where the crowd came from and 2) the emotional flow of the massive event in Washington, D.C.

The City summarizes this information by relating call activity to the geography of Washington D.C. We overlay the map of the Nation's Capital with a 3D color-coded animated surface of square tiles, with one tile representing a geographic area of 150 x 150 meters. Each tile rises and turns red as call activity increases and likewise drops and turns yellow as call activity decreases. On the left side of the screen, a dynamic bar chart breaks down the call activity by showing the normalized contributions of calls from the U.S.'s fifty states and 138 foreign countries grouped by continent. The timeline at the bottom illustrates the weeklong trend of call activity in Washington, D.C., which follows the 3D square tiles that rise and fall on top of the map of the city.

In visualizing the volume of calls served by a large telecom network in Washington DC, it is possible to see peaks of call activity as the crowd anticipates Obama's oath, a drop in call activity as the crowd listens to Obama's address, and peaks again as the crowd celebrates the inauguration of the new President. Through their cell phones, those present at the historic event share their impressions with friends and family in vast numbers: on the morning of January 20th, call activity is two to three times stronger than usual, and it rises to five times the normal levels after 2 pm as President Obama takes his oath and people begin to celebrate.

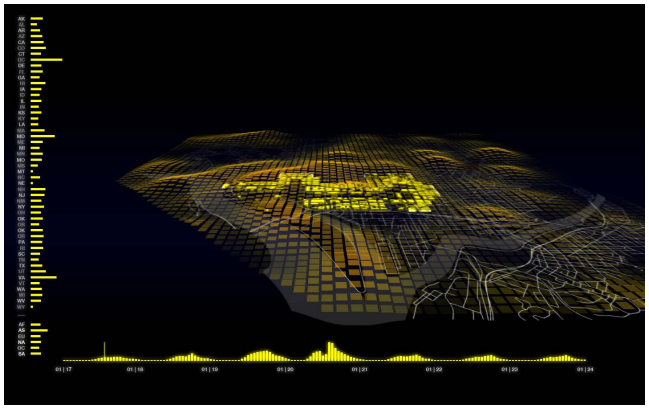

Fig. 4 The City visualizes call activity in the week of the inauguration. Superimposed on the map of Washington, D.C. is a 3-D color-coded animated surface of square tiles (1 tile represents an area of 150 x 150 meters). Each tile raises and turns red as call activity increases and likewise drops and turns yellow as activity decreases. On the left, a bar chart breaks down the call activity by showing the normalized contributions of calls from the 50 states and 138 foreign countries grouped by continent. The timeline at the bottom illustrates the overall trends of call activity in the federal areas of Washington, D.C., which are represented with 3-D yellow models on the map at the center of the screen.

4.2 The World

The World reveals the international nature of Inauguration Day. By using the area codes and country codes of the cell phones present in Washington D.C. during the week of the Inauguration, this visualization traces the trajectories of people travelling from all over the U.S. and the world. We interpret the variations in call activity as flows of people arriving in Washington, D.C. and then departing the capital to go back home. The visualization employs a world map to link the city of Washington to US states and countries abroad. Packets of information representing 100 calls for US states and 10 calls for foreign countries move to and from Washington depending on whether call activity increased or decreased in relation to the previous hour. The timeline on the bottom of the screen shows the overall trend of call activity in Washington, D.C., relating the flows of people with events in the city.

This visualization shows that people from almost every corner of the world and almost all fifty states attended the Inauguration of

President Barack Obama. The aggregated call data indicates that, at the least, there were people present from 138 countries, totaling over half of all the countries in the world. This is likely a low estimate since the data represents only one domestic telecom carrier. Among the foreign countries represented, the main international callers are from Canada, Great Britain, France, and Puerto Rico, which register a five-fold increase in call activity. In the U.S., the top calling states are also the country's most populous: California, Florida, New York, and Texas. Notably, Georgia also figures in the list of top five callers on Inauguration Day, even though it ranks ninth in US population.

4.3 Implementation Choices

In the previous section we described the design requirements of the two visualizations. Here we explain the thinking that motivated our implementation choices with respect to the those requirements.

First, we chose to represent the data from two perspectives. The City shows the evolution of the event within the context of Washington D.C. and allows users to see the build up in anticipation of the Inauguration, and how the crowd faded out after its conclusion. The World represents the international nature of the event and aims to convey the idea of a global pilgrimage to the American capital by displaying a map of the world and showing how people from near and far gathered in one city for one reason. In both visualizations, one aim is to represent the social dynamics that enveloped the city before, during, and after the President's Inauguration. Another aim is to help users understand how participation in a public event, like other individual choices in the context of the urban environment, builds up to create a collective social dynamic that affects the city as a whole. For this second reason, we purposefully deemphasized the quantitative nature of the data by using the visual metaphors of waves and packets.

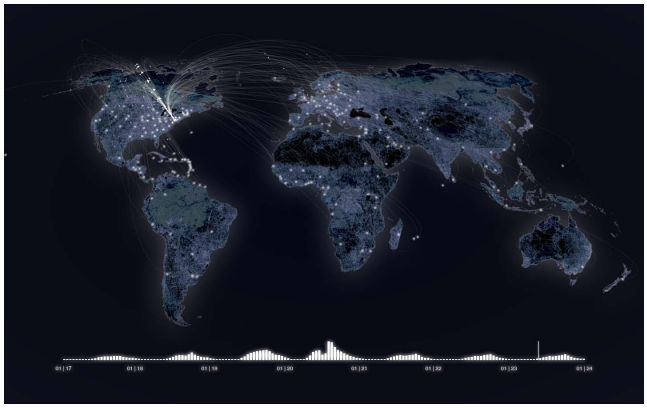

Fig. 5. The World visualizes call traffic to and from the capital. Variations in call activity are represented here as flows of people coming to Washington, D.C. and then leaving the capital to go back to their home states and countries. The world map links Washington, D.C. to capitals abroad. Packets move to and from Washington depending on whether call activity increased or decreased in relation to the previous hour. The timeline on the bottom of the screen shows the overall trends of call activity in the federal areas of Washington, D.C., allowing to associate the flows of people with the events highlighted in The City.

In formulating how the data representation would occur, we considered more abstract visualizations of the flow of phone calls but instead decided to use maps given the inherently geographic nature of the data and the message we aim to convey about the influence of special events on urban space. Moreover, we employ map details to assist users in orienting themselves within the context of Washington D.C. without overloading the visualization with unnecessary details. For this reason, The City visualization highlights only the major roads of Washington D.C. and the Potomac River, while The World simplifies the representation of flows by showing only connections between Washington D.C., US state capitals and the countries around the world.

While we simplified the representation Washington's geography, we decided to represent call activity in The City with some redundancy along different features of the visualization: we used color, opacity, and position of the tiles to represent the intensity of activity within each cell. The combination of these three features makes for a strong representation. Color varies from unsaturated yellow to saturated red to represent the volume of activity (a feature sensitive to color blind users). The use of opacity hides those tiles where activity is low and highlights those where it is strong, thus guiding the user through the evolution of the event. Finally, the third dimension recreates the wave metaphor mentioned above and further helps to convey the idea of the city as a living system.

In The World visualization we represented the origin of the callers' phones only using packets of information. In this case, employing multiple features as in The City would have focused attention on those connections with the strongest activity, whereas in this case we sought to highlight the overall exchange of inflows and outflows happening in Washington D.C. For this, identical packets are a strong solution as their movements alone create denser or thinner flows emerging from Washington D.C.

The timelines placed at the bottom of the screen unify the two visualizations and highlight the weeklong trend of activity in the areas of the Washington D.C. where the Inaugural events took place. This common element is intended to help the user associate the information represented in one visualization with that being represented in the other. The two visualizations also share a minimalist interaction system that allow the user to navigate the 3D space with the mouse, using left and right clicks to rotate and span, and the mouse wheel to zoom in and out. Keyboard arrows can be used to pause and play the animation, and to move backward and forward in time.

4.4 Results

The visualizations of aggregated call activity during the Presidential Inauguration we created for *Obama | One People* have provided insights into the dynamics of a remarkable special event in Washington D.C. in terms of the composition of the crowd and its emotional behavior in space and over time.

By examining the relative increase in call activity during the week of the Inauguration as compared to a normal week of call activity in the Nation's Capital, it is possible to get a sense of who travelled to Washington to attend this special event. The states with the strongest increase in calls were the southern states of Alabama, Georgia, Kentucky and Tennessee, with calls up to twelve times the normal levels. These are states that played a prominent role in the Civil Rights movement and notably are also red states whose voting population went for the Republican

candidate, John McCain. Other states with a ten-fold increase in call activity were Illinois, Barack Obama's home state, and Michigan, Ohio and Indiana, swing states which went blue, voting for President Obama. These results illustrate that participation in the event from each U.S. state did not depend on its political leaning or geographical proximity to Washington, D.C.

As the visualizations show, call activity in the days before and after January 20 reveal that the Inauguration was a multi-day event as traffic increased markedly throughout the week. On Sunday, January 18th call activity began to increase and, further analysis reveals that on Monday it was already two to three times what it would normally be on a Monday in January in Washington D.C. On the day of the Inauguration, call activity reached unprecedented levels throughout the day and the telecom provider's network served six times more SMS than normal levels. In the morning, call activity was two to three times stronger than normal levels as the crowd anticipated Barack Obama's oath, then dropped as the crowd listened to President Obama's inaugural address and peaked to five times the normal levels after 2 pm as President Obama took the oath and people celebrated.

Geographically, The City visualization reveal how the Inaugural visitors spread beyond the confines of the Federal areas of Washington, D.C. - such as the Mall and Pennsylvania Avenue - into the neighborhoods of the city. The hotspots of activity were clustered in the Northwest neighborhoods of the city, around Downtown, Adams Morgan and U Street. The historic inauguration of President Obama offered people from all over the United States and the world the occasion for a truly urban celebration. While these results are not surprising in themselves, our analyses allow for the first time to quantify and compare the presence of people in different areas of the city and to reveal their dynamic movements and, to a certain extent, their emotional reactions through time.

In post-project discussions with the telecom provider we learned that while the origin of the crowd is not a key factor driving capacity planning decisions of network operators, the remaining questions are relevant. The visualization capabilities presented in this paper made it possible to understand that the Inauguration was a multi-day event that began two days before January 20th and which did not end immediately, stretching visitors' presence in the Nation's Capital through the middle of the week. The telecom operator appreciated the visualizations' simplicity and their ability to summarize vast amounts of data, both temporal and geographical. *Obama | One People* also convinced network engineers of the benefits of collecting, analyzing and visualizing digital footprints of telecommunications flows. This in turn led to a new partnership with the radio access network engineers to get access to more data and to get the support of their management for further analysis.

Future user studies should include those who manage municipal services during special events who often must make educated guesses about crowd capacity in the city's public spaces. Moreover, it would be valuable to gauge how the information transmitted through these visualizations could alter the behavioral decisions of the participants of special events themselves. Would they decide to arrive at the event earlier or later? Would they choose to reorganize themselves in the public spaces of the as they learn the real time dynamics of the crowd? Ultimately, what these visualizations aim to do is to create a feedback loop that provides real time information about urban dynamics back to people so that they can adjust their decision-making as they go about their daily activities.

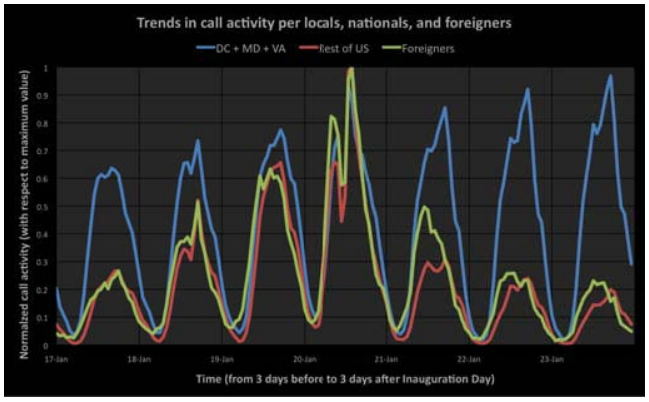

Fig. 6. Trends of normalized call activitity before, during, and after the event.

5. SYSTEM IMPLEMENTATION

We developed *Obama | One People* on top of an agile architecture that supports the operations of data gathering, storage, and analysis. These three operations exist in three separate layers and we implemented the system in the Python programming language, using the open-source PosgreSQL database system and the PostGIS geospatial extension. Figure X details the workflow between the layers, which we describe below.

5.1 Data Gathering

This layer provides standard tools for uploading urban data. It consists of a secure FTP server and a server daemon. The server allows the telecom operator to upload CSV files containing data on the network activity in the last 60 minutes. The daemon detects when a new file has been loaded, then parses it and loads the data in the Data Storage layer.

We chose not to implement more advanced data streaming technologies to simplify the interaction with the telecom operator. This solution allowed us to obtain data in different formats and resolutions and to rapidly restructure it in a form that is compatible with the data storage layer. However, this solution did not allow us to visualize network activity in real time. Nevertheless, we were able to access the data and complete the visualizations within a couple of weeks of the Inaugural event.

5.2 Data Storage

This layer stores the network activity data into a geospatial-enabled database, which also stores information about the location of the base transceiver stations and on the geographical structure of the spatial grid used in The City visualization. Each data point has a time reference and a geographic reference to the country or state where the phones making calls are registered, which allows inter-country normalization and continent-scale aggregation of the data.

Since in this dataset the activity generated by U.S. phones is on average two orders of magnitude higher than that generated by foreign phones, we chose to normalize all time series in the range [0; 1]. To do this, we divided the activity by the maximum reached by each state or country within the time span of our data set. In most cases, the maximum was right after President Obama's Inaugural speech (see Figure 6).

5.3 Data Analysis

This layer accesses data from the Data Storage layer and performs geospatial operations that redistribute the punctual information on network activity over the two-dimensional Washington, D.C. area. The Data Analysis layer is also in charge of performing pre-processing operations on the data, like correcting missing values and normalization. The geospatial operation adopted to redistribute the network activity visualized in The City was based on a discrete grid of 150x150 meter cells that cover the Washington, D.C. area. The activity in each cell is estimated by summing the contributions of all the base transceiver stations weighted according to the distance between the cell and the station. The weighting factor is defined by the exponential decay function $w=\exp((-dist(cell,bts)^2)/0.2)$ which causes the weighting factor to become insignificant at the reasonable distance of 1 km from the station. The operation chosen to estimate the flows visualized in The World was based on the gradient of the network activity generated by each US state or country. Under the assumption that the average number of calls per person does not change radically over the course of the special event, we estimated a larger presence of people from a given state or country when the related call activity increased from one hour to the next. To account for normal daily fluctuations, we subtracted the average variations and represented only unusual fluctuations.

The main objective of our analyses was to summarize the data collected by the cell phone network into two easily understandable metaphors of social dynamics and urban communications flows. We consciously avoided using more invasive analyses, for example using radio wave propagation models to redistribute the data, in favor of an approach that focuses the viewers' attention on the high-level understanding about urban processes that this data can provide.

6. LIMITATIONS

Up to this point we have not able to validate the efficacy of the visualizations as the project is still confidential and cannot be shown outside our research group (we have specific permission for this publication). In this section we describe the major insights and limitations of our approach, which will be addressed in a future user study. Thus far, we have been able to collect informal feedback from the research scientists of the telecom operator, which supports our design and implementation choices. Their positive feedback confirms that the *Obama | One People* visualizations offer a new perspective on the nature and dynamics of a special event such as Inauguration Day. While the main results are not surprising - it is to be expected that call activity would increase markedly on the day of the event – they nevertheless reinforce assumptions about how people may behave during large-scale urban events. As service providers, the telecom operator valued the insight that there was a slow build-up to the actual day of the Inauguration and likewise a slow retreat of the crowd from the city over the course of several days. This may present a future scenario where the provider deploys extra telecom capacity for a special event a few days before the event and leaves it up and running for longer than expected.

Moreover, while most of the operator's feedback praised the simplicity of the interface and the visual system, some would have liked to see more analytical tools included in the visualization so that users could themselves examine the data. In the future, therefore, we intend to create an interface that allows the experts to study more in detail the data while maintaining a simple interface for basic users. On the technical side, we limited our visualizations to cell phone activity recognizing that there are other forms of digital footprints. Works that used vehicle traffic data, for example, have been discussed in the section on Related Works. While it is not clear which datum or combination of data is the best proxy for estimating social activity, our visualizations could be immediately used with traffic data. Again, however, the focus of our project is not on quantitative precision but rather on the qualitative narrative.

Finally the architecture implemented is quite simple. While this allows designers to easily adapt to changes in format and resolution of the data, it does not allow the gathering, storage, and analysis of data in real time. This is a major drawback that is due to the slow process of data collection on the network side by the telecom operator. In the future, however, as information will flow more freely, a more advanced system architecture that fully supports real time data streams will be necessary. In that scenario, the simple geospatial procedures on the data that we perform will not clog the system.

7. DISCUSSION

Obama | One People is part of a long term vision centered on the idea that diffused social consciousness regarding urban dynamics can improve the efficiency of cities by enabling local authorities, service providers, businesses, and citizens to make better informed decision in their urban landscape. This vision was presented in *WikiCity* [16] (see Figure 7) that considered another public event, the Notte Bianca in Rome, Italy, an all-night festival that hosts artistic performances at various locations throughout the city. In that occasion, we developed a public interface that featured a satellite image of Rome with four types of information overlayed on top of it: real-time cell phone activity, the real-time location of public transport buses, starting and ongoing event tags at their corresponding location, and live news feeds from journalists at key locations. While the scope of this paper is not to present *WikiCity*, we believe it is important to discuss its underlying concept to contextualize *Obama | One People*.

Through *WikiCity* we envision the participatory provisioning of urban information by local authorities, service providers, businesses, and citizens, and the enabling of semantic processes for the development of an evolving hierarchy of analysis tools and information visualizations. These mechanisms, coupled with ubiquitous interfaces, are expected to enact the active use of digital technologies for real time location-based decision making in the city. In a similar fashion, they are intended to support the active collection of public feedback on the condition of the city and its services. The mapping of urban information is not limited to providing a real time representation of the city. Instead it becomes an instrument for citizens and local authorities to base their actions and decisions in a better informed manner. In this way the real time information changes the city context as well as is changed by that altered context accordingly. The potential in this scenario is to address a wide variety of problems that interest the multifaceted aspects of managing the city as a complex system. The results of *WikiCity* were mixed. If on one side it proved the technical feasibility of our vision, on the other it failed in creating a user base and the visualization was not adopted for subsequent major public events. While there are many possible reasons behind this, we believe that one of the major issues was that our interface tried to convey too much information to a public that was almost completely unaware of the significance of that

information. We see *Obama | One People* as an intermediate step in dramatically illustrating and popularizing the idea of the city as a living system that responds collectively to the actions and decisions of individuals.

8. CONCLUSION

This paper discussed a visualization project that considered how crowds behave during large-scale public events in urban areas. *Obama | One People* took as its case the Inauguration of President Barack Obama and overlaid telecommunications data over the geography of Washington D.C. The two resulting visualizations – The City and The World – showed from a local and an international perspective that the Inauguration was a multi-day event and that it drew people from all over the US and the world. The potential of visualizations such as *Obama | One People* are great for those who manage and act within urban space. They are a first step in revealing collective patterns of social dynamics, and data such as telephone call activity can offer a insights into how people inhabit the city in different times and locations, and how is the urban environment can be stressed in the case of public events or sudden emergencies.

Having the results of these analyses in real-time, urban planners would be able to promptly detect and correct phenomena that reduce the liveability and sustainability of the city: instead of planning urban interventions and waiting months to evaluate their impact, they could switch to a more reactive, real-time management of the city. Moreover, these kinds of visualizations, if accessed through an appropriate interface, can also be of value to urban dwellers themselves. The ultimate goal of this work is to build urban interfaces where people can deposit and extract information on the functions of the city in real time and thus work together in building more efficient, intelligent and sustainable cities.

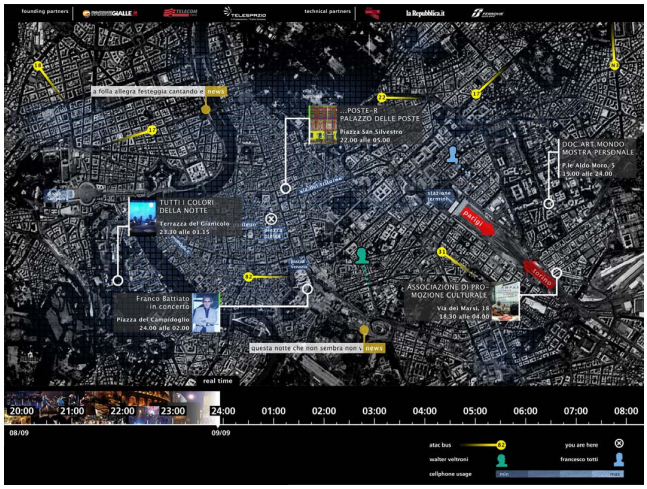

Fig. 7. *WikiCity* [16] was publicly displayed during a major event in Rome, Italy and presented real-time cell phone activity, the real-time location of public transport buses, starting and ongoing event tags at their corresponding location, and live news feeds from journalists at key locations.

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