The Cartographic Journal *Vol. 51 No. 2 pp. 152–165 Cartography and Narratives - Special Issue May 2014*

REFEREED PAPER

Towards (Re)Constructing Narratives from Georeferenced Photographs through Visual Analytics

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We present a study that explores methodological steps towards (re)constructing collective narratives from the photo-taking behaviour of two groups (foreign tourists and inhabitants of Switzerland) by analysing spatial and temporal patterns in user-contributed, georeferenced photographs of Zurich, Switzerland. We reason that the photographers typically capture a scene or a moment because they want to remember or share it, thus these scenes or moments are meaningful to them. Various scholars suggest that the human experience (i.e. this meaningfulness) is what separates a place *from the mathematical descriptions of* space. *While this notion is well known in larger geographic literature, it is under-explored in cartographic research. We respond to this research gap and reconstruct static and dynamic patterns of photo-taking and -sharing behaviour to assist in capturing the implicit* meaning *in the studied locations. These locations may be meaningful to only a certain group of people in certain moments; therefore, studying group differences in spatial and temporal photo-taking patterns will help building a collective and comparative story about the studied* place. *In our study, we focus on experiences of foreign versus domestic visitors, and in the process, we examine the potential (and feasibility) of georeferenced photographs for extracting such collective narratives using qualitative and quantitative visual analytical methods.*

Keywords: narrative, user-generated content, UGC, VGI, Flickr, place, trajectory, trajectory network, tourism

INTRODUCTION

The term 'narrative' has been described as 'any cultural artefact that tells a story' (Bal, 2009, p. 3), or an expression of 'experiencing and thinking about the world, its structures, and its processes' (White, 2010, p. 274). All formal definitions in essence indicate that a narrative is mainly about related events that occur in a certain temporal order (Walker, 2004). In their most traditional sense, narratives occur in verbal form and can successfully 'paint a picture' in reader's or listener's mind. Narratives can also successfully integrate explicit visual aids (Ryan, 2003); for example, film is possibly one of the most immersive forms of telling a story. Another type of everyday visual narrative occurs as we share photographs. We share our experiences as we show photographs on paper, on a camera or computer, a projection screen or an online photo repository. As a contemporary means of sharing, online repositories are getting ever more popular and richer in content with the rise of social media and smartphones. Therefore, the content of such photo repositories offer an exciting opportunity to capture the traces ('digital footprints') people leave behind as they explore a place, and potentially allow us to (re)construct a collective narrative about that place.

Place and narrative

Geography is the science about the world, its structures, and its processes and thus fits squarely with White's (2010) definition of narrative (an expression of 'experiencing and thinking about the world, its structures, and its processes'). Therefore, and because every story happens in some *place*, we contend that geography always bears a direct or indirect link to narratives and narrative artefacts. This link has been previously explored in the literature to some degree. For example, Kwan and Ding (2008) discuss the concept of *geo-narrative* to extend Geographic Information Systems (GISs) for narrative analysis. Arguably the most popular form of conveying a narrative using quantitative data is through visualisations; and these have become more and more popular (e.g. in journalism) with the terms 'data journalism'

DOI: 10.1179/1743277414Y.0000000079

and 'narrative visualisation' appearing frequently, even forming genres (Segel and Heer, 2010). However, sometimes these visualisations are used without sufficient reflection. From a critical perspective, Pearce (2008) discusses how narratives can be best integrated in cartographic depictions to represent space as shaped by human experience.

In the context of including the human experience in the representation, an important concept in geography and indeed one of the foci of geographic storytelling is the notion of *place*. Unlike *position* or *location* (which can be expressed in abstract and precise reference systems), *place* denotes a 'shared frame of reference, corresponding to a collective conception of regions' (Hollenstein and Purves, 2010, p. 23)[1]. Thus, places typically expose fuzzy properties in their spatial as well as thematic dimensions. The discourse about how *place* differs from a merely geometric expression of location (position, space) relates well with how post-modernist geographers argue that maps are not the only way to represent geography (e.g. Soja, 2003). Therefore, the idea that humans produce narratives by moving through places (and that modern technology allows recording fragments of these experiences) should be explored further (Warf and Arias, 2009; Caquard, 2011). This study offers such an exploration, by analysing people's movements through places – which are implicitly contained in a user-generated collection of georeferenced photos.

User-generated content

With the development and popularisation of the Web 2.0, we are experiencing a new era where content is partly produced by users or '*(prod)users*' (Bruns, 2007). This is labelled as User-Generated Content (UGC) and, in geography, often as Volunteered Geographic Information (VGI) (Goodchild, 2007). Other terms such as *neogeography*, *user-contributed*, *community-contributed*, *crowd-sourced* and *crowd-harvested* also occur (e.g. Bradley and Clarke, 2011). Throughout this paper, we use *UGC* as an umbrella term as it appears to be commonly used and expresses the concept in an all-encompassing manner. UGC through social media, blogs, wikis, photo and video sharing sites, social trip planners and 'social' production of maps (e.g. OpenStreetMap) have 'changed the game'. This change took us away from a state where geographic information was exclusively produced and distributed (and thus, controlled) by official authorities to a new age in which alternatives are possible (Goodchild, 2008). Content-creation by users (as opposed to *top-down* depictions of space) enables us to study how people experience and make sense of things *bottom-up*, therefore, allowing us to study *place* (Agnew, 2005, cited in Sui and Goodchild, 2011). UGC has a number of other advantages too, e.g. one can aggregate a large number of individual experiences/ expressions and obtain quick updates. However, it also has considerable challenges such as severe lack of structure, potential quality issues (e.g. uncertainty, noise, vandalism), demographic biases (digital divide, over/under-representation of certain groups) and privacy questions.

Despite these shortcomings, UGC has created opportunities and excitement in the Geographic Information Science (GIScience) community, and was embraced quickly as demonstrated by an influx of research papers covering a wide range of topics such as: developing better disaster response strategies (e.g. Goodchild and Glennon, 2010; Li and Goodchild, 2010; Zook *et al.*, 2010; MacEachren *et al.*, 2011), gathering perspectives of citizens (e.g. Ricker *et al.*, 2012), studying the spread of diseases (e.g. Doan *et al.*, 2012) and many more tasks that are geared towards discovering spatio-temporal patterns in this kind of data (e.g. Jaffe *et al.*, 2006; Andrienko *et al.*, 2009; Kisilevich *et al.*, 2010; Çöltekin *et al.*, 2011; Naaman, 2011).

Necessarily, a fair amount of reflection on data quality, methods, ethics and ownership of the information also emerges in current publications (e.g. Haklay, 2010; Crampton *et al.*, 2013; Dodge and Kitchin, 2013). Additionally, various authors, such as Sui and Goodchild (2011), further caution the GIScience community to be careful not to be 'trapped' by a data-driven agenda but to develop theories as well[2]. Specifically, they point to three directions where they encourage additional efforts: development of network-based ontologies, formalizing place in GIS and multimedia representation (Sui and Goodchild, 2011, p. 1744). What we report in this paper coincides with and contributes to the efforts of two of the listed directions: formalizing the notion of place in GIS and devising a supporting network-based approach. We use time- and speed-filters as well as clustered aggregates in order to elucidate movement patterns and paths between sights as documented by photo-sharing activity and we use data from Flickr photo collections (http://www.flickr.com) to explore how two distinct groups of people explore the city of Zurich (foreigners versus inhabitants of Switzerland).

Flickr and tourism studies

Several other researchers used Flickr (or similar) data to study various aspects of *place*. For example, taking a vernacular geography approach, Jones *et al.* (2008) explored the modelling of vague places and Hollenstein and Purves (2010) reported on the *extent* of places (e.g. city cores). Our specific focus is to study methodological steps to reconstruct potential narratives hidden in static and dynamic spatio-temporal patterns of the residents of Switzerland (domestic visitors) versus foreign visitors who share photographs of Zurich. Extracting tourist behaviour from Flickr has been a popular topic in recent years as roughly 60% of the Flickr user profiles seem to include the country of the photographer (Girardin *et al.*, 2009). Various researchers have used Flickr data to quantify 'urban attractiveness' or 'hotspots' based on digital footprints of the visitors in various locations (Girardin *et al.*, 2008a; Ferrari *et al.*, 2011; Gavricet *et al.*, 2011). In a similar context, Popescu and Grefenstette (2009) reported a metadata filter to automatically extract geo-tagged images and estimate visit duration times to answer questions of temporal nature. In an applied example (not published as a research paper), Fischer (2010) mapped Flickr photograph positions of domestic and foreign photographers, which he distinguished based on photo-taking activity over time (cf. chapter 2.2). The methodology behind Fischer's work is not fully documented (or at least not published). A similar piece (MapBox, 2013) employing tweets by domestic visitors and foreign tourists instead of Flickr photos has drawn some criticism for certain aspects of data portrayal (Field, 2013).

van Canneyt *et al.* (2011) have analysed Flickr data to study tourist behaviour to eventually create a tourism recommendation system. Taking the individual tourist's perspective, Tussyadiah and Zach (2012) examine how the availability of geo-technology and location based information affects tourists' behaviour. Approaching the subject from a planning aspect, Edwards *et al.* (2010) state that, for tourism managers, understanding tourists' behaviour and how they engage with the urban space has multiple implications such as controlling overcrowding of certain sites, maximizing exposure to under-discovered sights or services, minimizing adverse effects to sensitive historical sites and informing transportation policies.

While many of these studies are concerned with behaviour analysis and what it might mean for tourism management or for the tourist, a number of other researchers focus on the methods and what can be done with the data at hand. For example, Zeng *et al.* (2012) offer a method to discover 'rational paths' for tourists, Jankowski *et al.* (2010) use a geovisual analytics approach to explore 'landmark preferences' based on movement patterns and Andrienko *et al.* (2010) propose a set of visual analytics methods to discover and reconstruct 'place histories' from people's activity traces obtained from photo collections.

Contributions

In this study, we explore the digital movement patterns of visitors (domestic and foreign) to Zurich with the intention to explore methodological steps towards (re)constructing a narrative about the city from their movements and their foci. More specifically, we are interested in *the number of photographers*, *how many pictures they took (and shared)*, *when* (we study various temporal patterns) and *where* people took (and shared) these pictures (and *where not*) as well as *how they move* throughout the city. To tackle the question on how photographers move, we focus on pedestrian movements, as we view walking as a distinct mode of experiencing a place, especially given that we study photo-taking behaviour. In all questions, we distinguish foreign visitors from domestic visitors. We examine differences and similarities of the coverage and the movements of these two groups in space and, by proxy, the narratives they can convey about Zurich using their geocoded photographs. We also analyse temporal groupings and elucidate potential seasonal variation in photo-taking activity and, again thus, the source material for the construction of narratives. We discuss how UGC can be treated in analyses similar to ours and we propose new approaches and refinements to existing approaches.

THE STUDY

Study area and data

We view Flickr with its 6 billion hosted images (Wood *et al.*, 2013) as a vast source of material with great (and currently under-explored) potential to build narratives about places; with *visual*, *textual*, *temporal* and *spatial* components. For this study, we focus on spatial and temporal components and a particular city that we know well (Zurich, Switzerland). Local knowledge provides a means to 'ground-truth' (i.e. validate) our findings, though it is not a requirement for the use of our approach in other cities. To conduct the study, we acquired data about 81,194 geocoded Flickr photos in a 20×20 km area around Zurich. We started with IDs of Flickr photos, taken between 2005 and 2011, that were previously obtained by our collaborators (see the section on 'Photos–photographers balance and countries of origin'). We then employed various Python scripts to acquire the respective metadata via the Flickr API and to clean and pre-process the data for analysis.

Classification of foreign and domestic visitors

For distinguishing domestic visitors from foreign visitors, we employed a semi-automated methodology to classify the *user location* attribute of Flickr user profiles. For the sake of simplicity, we call the two resulting groups 'domestic' and 'foreign'. The first step was to extract the countries of residence from the string stored in the *user location* attribute. Automatic extraction worked well for many users, except for users in the USA who typically state their city and abbreviated state name rather than the country name (e.g. 'Boston, MA'). We corrected for this and some further idiosyncrasies and irregularities semi-automatically and, in very few cases, manually[3]. In a second step, the country information was used to flag users as domestic (Switzerland) or foreign (others). In some cases where country information was not retrievable, the distinction of domestic versus foreign could still be made (e.g. for 'Scandinavia').

We are aware that a part of the group of domestic visitors may live relatively far from Zurich, but they are likely residents of Switzerland. Further, we acknowledge that calling users 'domestic' and 'foreign' is somewhat imprecise also in other ways due to the unstructured nature of UGC with its partial absence of enforced guidelines on how to provide profile information. Further, the user profile data that may also be outdated in some cases. Nonetheless, we opted for this classification since a recent study compared the country information on Flickr with immigration information collected at national borders and was able to demonstrate that the user-provided information was representative (Wood *et al.*, 2013). Other researchers have based their analyses on a similar approach (Girardin *et al.*, 2007; Girardin *et al.*, 2008b). We favoured our approach specifically over time-based approaches that build on the idea that if somebody visits a given area only during a narrow timeframe in a longer period (e.g. 2 weeks in 3 years), they must be visitors. While the *potential* resolution of time-based approaches seems attractive, they also have substantial shortcomings: For example, domestic people that take or share photos infrequently can be misallocated to the group of foreigners. Also, the approach necessarily depends on a set of subjectively chosen thresholds. As an additional downside, time-based approaches rely on a multiple of the data volume and thus processing time,

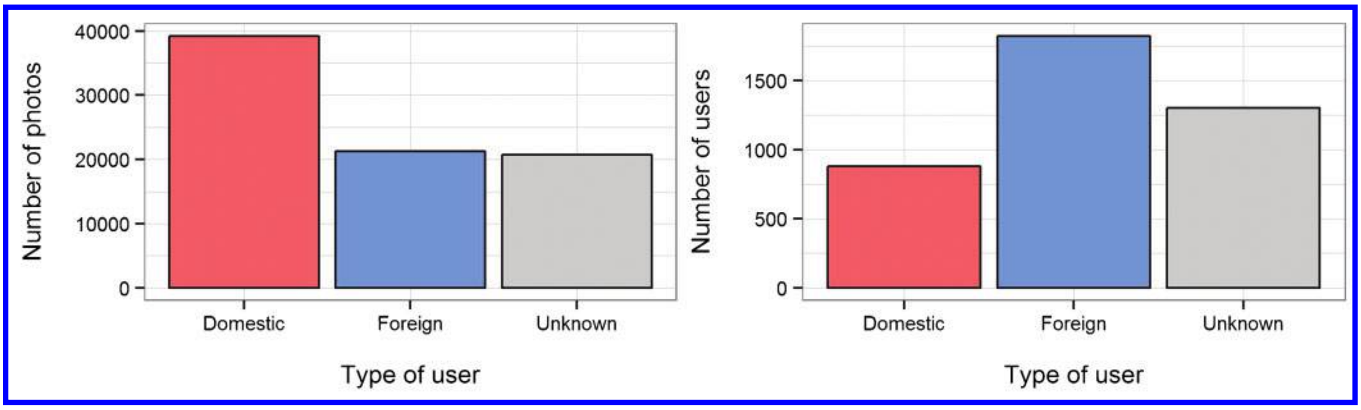

Figure 1. Proportion of pictures by photographers of different residency (left) and proportion of photographers of different residency (right)

since *all* photos (or at least, large samples) of *all* users need to be analysed which may be prohibitive for some studies. Finally, time-based approaches appear to have been used more for predicting the geo-location when it is not explicitly disclosed (e.g. da Rugna *et al.*, 2012).

Photos–photographers balance and countries of origin

Our data amounted to metadata of 81,194 pictures uploaded by 4002 distinct users. According to the user ocation analysis, the largest amount of photos (39,219, almost 50%) has been taken by domestic photographers. The other half of the photos are by foreigners (21,226 photos) or by people with unknown residency (20,749 photos) (Figure 1). The number of photographers shows a partly reversed pattern: there are slightly more than double foreign photographers in the sample than domestic ones. The latter are thus a lot more 'productive' (most likely facilitated by their sustained presence in the region).

Figure 2 displays (on $\log_{10}$-scale) the most prevalent countries of residence, computed at the photo- and user-level. It is evident that the Swiss (CHE) and users with *unknown location* (represented by a question mark in Figure 2) make up large proportions. Considerable amounts of photos and users originate from North America (USA and Canada), neighbouring countries (Germany, Italy, France and Austria), Great Britain, Australia, Spain and the Netherlands. These distributions both feature a 'long tail', i.e. many different countries but very few users/photos per country. At the user level, Switzerland is second; however, it is leading in terms of number of photographs.

Spatial accuracy

We checked the geocoding accuracy as defined by Flickr using numerical codes [1, 16], where 1 is 'World', 3 is 'Country', 6 is 'Region', 11 is 'City' and 16 is 'Street'. These 'accuracy codes' reflect the zoom level that was used when (if) a user geocoded photographs by dragging them onto a map. However, market penetration of devices with GPS and other location technology is increasing. When photographing with such devices, presumably, the highest accuracy code is applied to geocoded photographs. Clearly, Flickr accuracy codes are only rough guidelines. Additionally, a high accuracy code (zoom-level) does not manifest a sufficient condition for accurate geocoding nor is a less than highest accuracy code a sufficient condition for inaccurate geocoding. A medium accuracy code can still yield good accuracy, if the geocoding is done carefully. It is merely safe to say, with respect to production processes following Flickr's guidelines, that an accuracy code above *some* threshold is a *necessary* condition for accurate geocoding.

With these caveats, we have found the mean geocoding accuracy to be high at 14.58. The distribution is highly skewed (Figure 3). After examining the zoom levels and associated map displays, we have adopted a threshold accuracy code of 11 and higher, thus filtering out a bit more than 8% of the initial set of pictures.

Spatiotemporal coverage

For analysing the spatial distribution of photos and photo-taking activity (i.e. presence of photographers as attested to by geocoded photographs), we disregard the group of people of unknown origin and their photos. We started by gridding the photo locations at 62.5 and 250 m resolutions[4]. For both resolutions, we computed the percentage of the total of both *photographs* and *photographers* per grid cell. The resulting maps (Figure 4) allow inferences about evenness and contrast in the spatial distribution of photographs and photographers.

Figure 4 clearly shows a different spatial behaviour in the two groups. Foreigners are strongly focused on a relatively small area (downtown Zurich) and appear to take a significant number of pictures at the airport (1). Domestic photographers share photographs of other spaces as well: for example, the suburb of Oerlikon/Seebach (2) and Affoltern (3) with two small attractive lakes and to a lesser degree the lake Greifensee (4). These areas (especially the lakes) are virtually not photographed by foreigners (those included in this analysis). When foreigners venture out of the downtown area, they cover for example Ueetliberg (5). This hill overlooking the city is an attractive spot for domestic visitors, too. Our data tells us, however, that the domestic visitors also walk along the ridge of Ueetliberg to the south of the study area (6). Similarly, their reach seems farther and their photo coverage denser on both sides of the

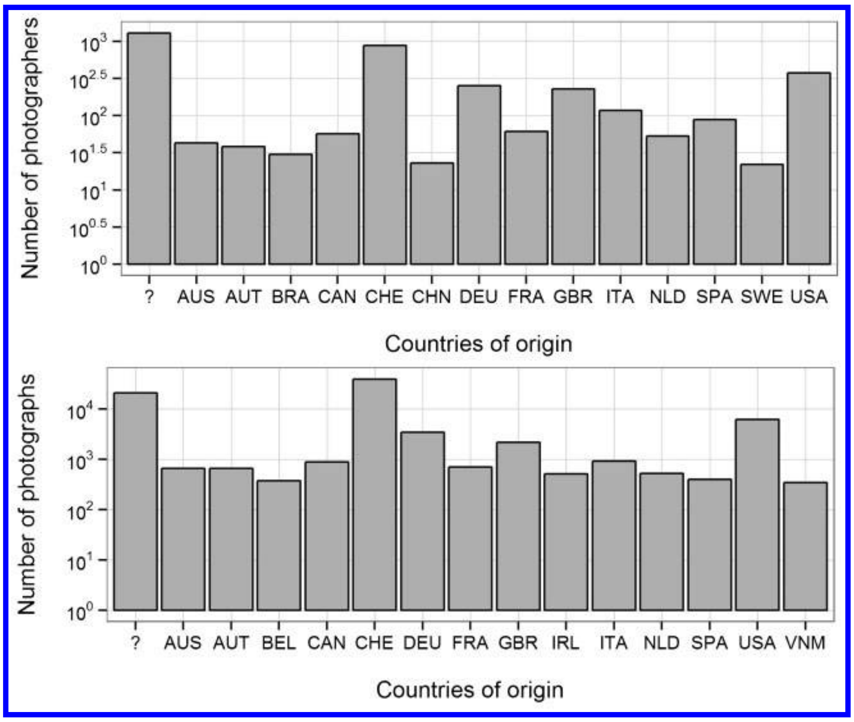

Figure 2. Fifteen most prevalent countries of residence (ISO-A3 codes) at the photographer-level (top) and photo-level (bottom). AUS: Australia; AUT: Austria; CHE: Switzerland; DEU: Germany; NLD: Netherlands; VNM: Vietnam

Zurichsee, the main lake of the city (7) and around the downstream river valley (Limmat) (8).

Figure 5 explores spatial differences between the two groups in a smaller region. Small deviations between the relative coverage by the two groups are filtered out. The suburban Oerlikon/Seebach area (1), western parts of the city (2, 3) and the Zurich zoo (4) clearly stand out (more densely photographed by domestic photographers). The suggestion that domestic people cover the lakesides (6) more evenly with photographs than foreigners is also confirmed. In (5), we can see the core-area of attraction for foreign photographers, a narrow region in the heart of Zurich downtown which we will shortly describe in more detail.

Similarly, we can explore spatio-temporal patterns. Figure 6 shows the distribution of photos by the two groups throughout the year. While domestic visitors have peak photo-taking activity in April–June, the activity of foreigners peaks in August and May. We also computed the difference in relative coverage by group in winter (months 10–12 and 1–3) versus summer (months 4–9) (Figure 7). Some interesting similarities and differences emerge: e.g. while the relatively few foreigners who visit the zoo (1) do so primarily in summer, the pattern is mixed for domestic photographers (2). Both groups seem to seek proximity to water in the summer months; however, judging from the photographs they shared, foreigners primarily stay at the lake and relatively close to city centre (3), while the domestic photographers move farther out (4) and visit other locations more frequently along the river, e.g. (5). Domestic visitors also appear to spend time in parks more

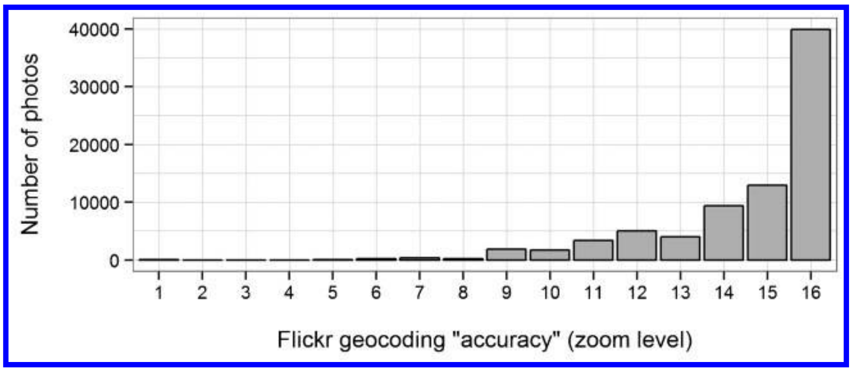

Figure 3. Proportion of pictures with different geocoding accuracy codes

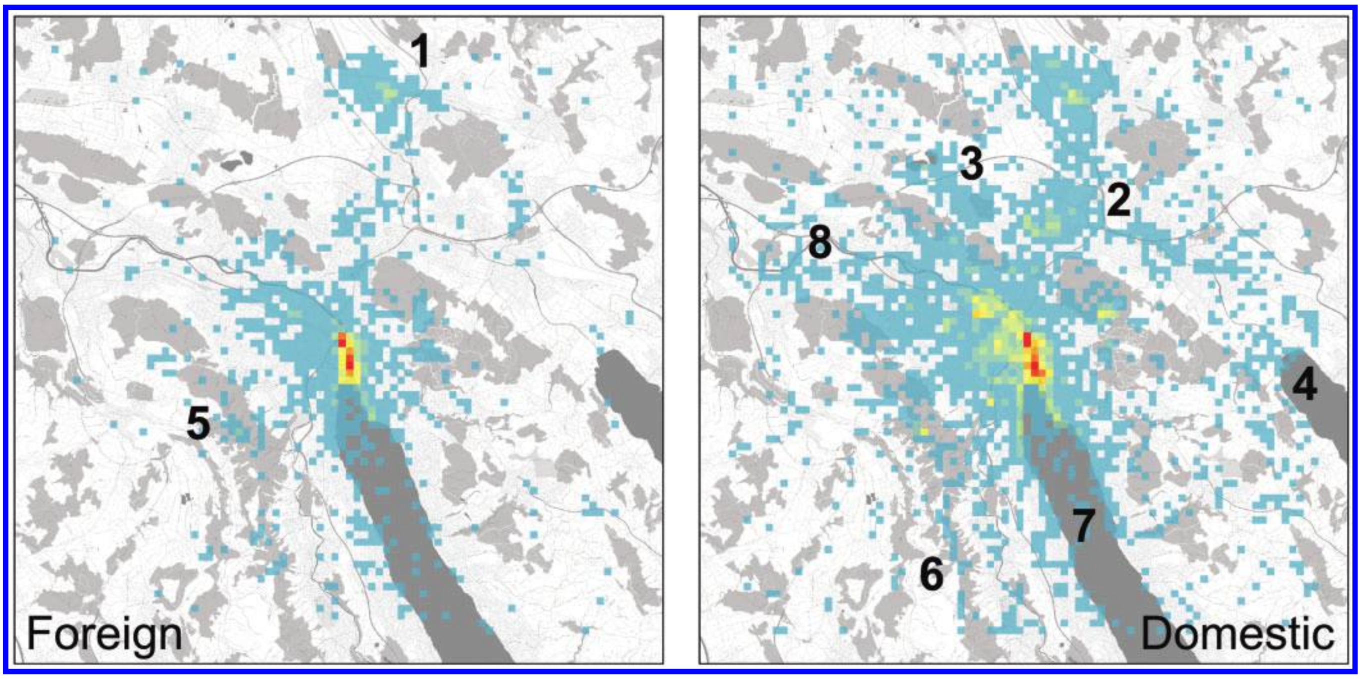

Figure 4. Relative spatial distribution of photographers in the group of foreign (left) and domestic visitors (right). Both figures use identical colour scale from blue (low density) to red (high density). The numbers show neighbourhoods (explained in the text), dark grey areas denote lakes, grey areas represent forest

often (6) in summer, which seems to be potentially unknown (or undesirable) to, foreigners. Further, both groups cover the region around the main train station and main shopping street (7, 8) more in the winter months.

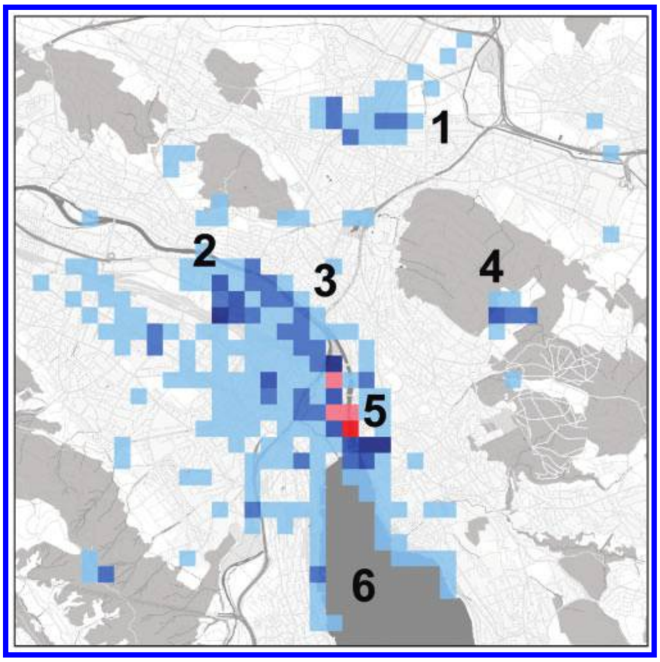

Figure 5. Difference of relative spatial distribution of photographers in an excerpt of the study area centred on the city. Blue: proportionally more domestic visitors, red: proportionally more foreign visitors

TRAJECTORY NETWORKS

While spatio-temporal patterns of e.g. 'hotspots' are interesting in that they constitute the basis for constructing narratives about a place, they convey a relatively static view of the subject. The Flickr data constitutes so-called 'episodic movement data', meaning that interpolation between recorded positions is possible only if the temporal gap is very short (Andrienko *et al.*, 2012). To further inform the findings from temporally aggregated coverage, ways to uncover how people move through the city as they record fragments of visual narratives about the place are explored.

Every photo in the dataset defines a spatio-temporal event: a geocoded Flickr photo puts a distinct user in a certain position at a certain time (with some unknown level of accuracy). When several of these events are present for a user, the user's trajectory can be reconstructed by connecting the time-ordered event locations in space. We call the smallest unit of a trajectory (the path between two photo locations) a *trajectory segment*. Overlaying all the trajectory segments of different users (and potentially identical users at different times) allows the construction of a *trajectory network*.

Trajectory reconstruction from VGI has been explored by other researchers (e.g. Joh *et al.*, 2002; Kisilevich *et al.*, 2010; Andrienko *et al.*, 2011; Vrotsou *et al.*, 2011). However, these approaches usually rely on a moving-window in time to construct trajectories. For example, Andrienko *et al.* (2009) used a window of three days to separate sequences of VGI footprints into individual trajectories. With generous time thresholds (or with no time thresholds at all when the time period is short), we

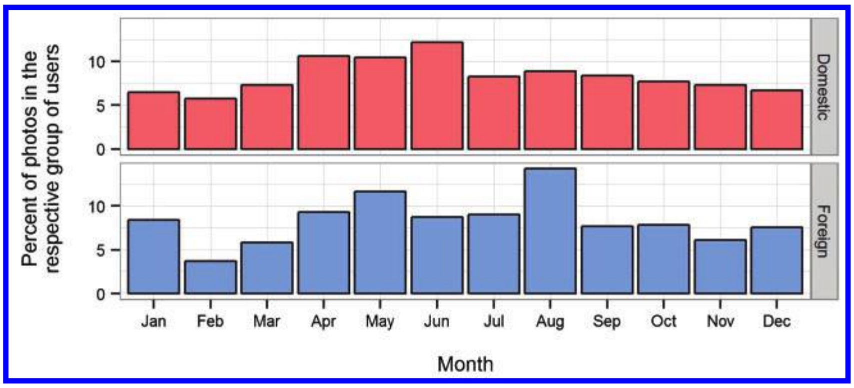

Figure 6. Monthly distribution of photos per group of users

contend that these networks constitute a different kind of network: while there will be substantial overlap with a trajectory network in the way we define them, those networks rather equate to *networks of interests*, since they reflect which points-of-interest (POIs) have been visited by the same individuals *at some point in time* (within the generous time threshold if one is applied). Drawing a network edge between two POIs in such a network does then not necessarily reflect the movement of people somewhere along this edge, but rather a connection in topic space: people who have found it worthwhile to visit location A at one end of the network edge have found it worthwhile to also visit location B at the other end. Importantly, however, the actual path of how they travelled between the two locations may not be near the network edge but may be entirely different, e.g. if they left from their hotel in the morning to visit location A and did the same sometime later with location B. While such a *network of interests* is certainly worth investigating (and may yield findings that are applicable e.g. in a tourist guide), in this study, we are interested in a network that approximates the true trajectories of visitors exploring a city as they *walk*. We are specifically interested in pedestrian trajectories for two reasons: first, walking allows a more intimate interaction with *place* than other, more 'detached' modes of transport using a vehicle. On foot, one can stop any time and take a picture in any direction. Second, measurement of people and vehicle flows is routinely done for other modes of transport but the flow of visitors on foot at a city-scale is much less explored (as it is considerably harder without access to privileged information such as mobile phone records). UGC that would help quantify such flows is potentially very interesting to tourism managers as well as traffic and urban planners (Wood *et al.*, 2013).

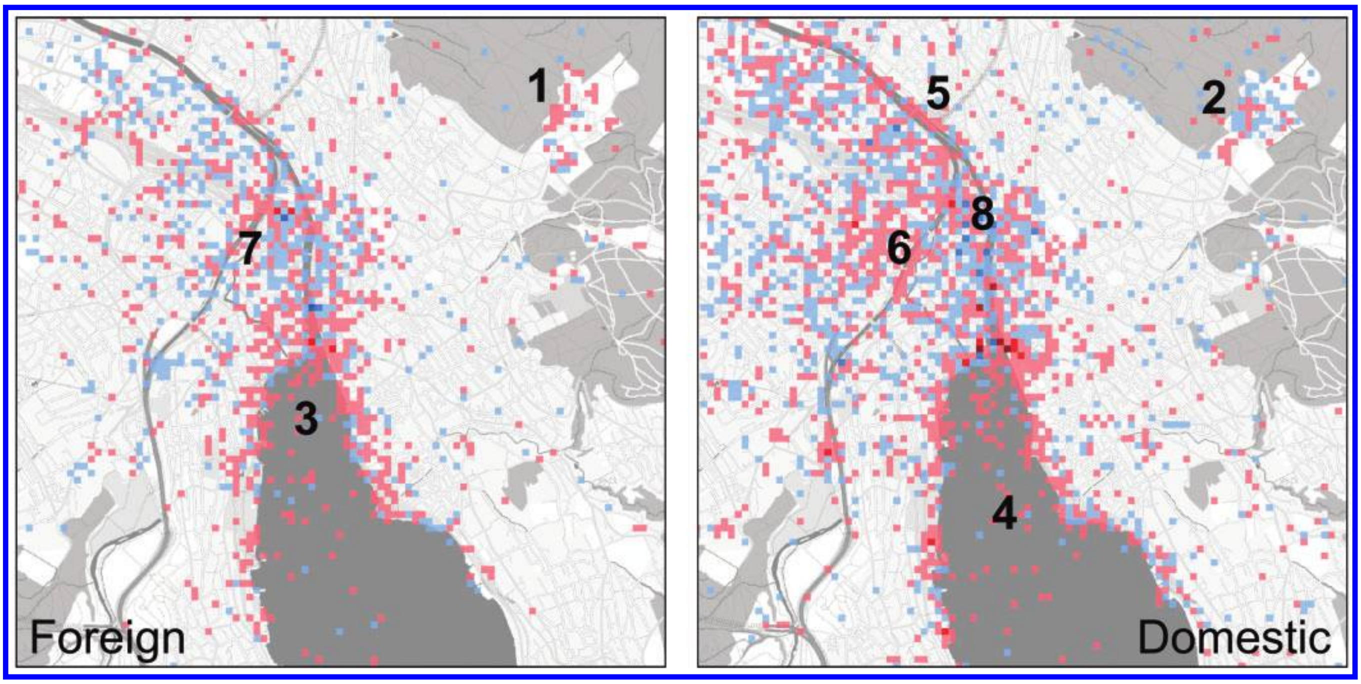

Figure 7. Differences in relative coverage by foreigners and domestic visitors in winter versus summer. Blue: winter, red: summer

Figure 8. Unfiltered trajectory network (left), time-filtered with 30 minutes (centre), time- and speed-filtered with 5 km/h (right)

To construct pedestrian trajectories, the photo locations are spatially clustered in two areas where most movement occurs, a wider suburban area and a narrower area centred on downtown Zurich. For clustering, a *k-medoids* approach was applied (Kaufman and Rousseeuw, 1990; Maechler *et al*., 2013) for each area with[5] $k=100$. *k-medoids* is a partition clustering method similar to the more widely known *k-means*. *k-medoids* differs from the latter as it assumes only existing data points as cluster centres rather than the cluster means (centroids); i.e. the method will not pick locations without photographs as cluster centres (locations that do not occur in the original dataset). The cluster centres will constitute the network nodes.

Next, in accordance with above distinction of trajectory networks versus networks of interests, thresholding techniques are applied. First, we apply a time threshold: a pair of time-ordered photo locations, p_i and p_{i+1}, by the same user is considered a candidate pair for construction of a trajectory segment if the time between their occurrences is short enough:

$$t(p_{i+1}) - t(p_i) < t_{crit}$$

After this step, the dataset will still contain other modes of transport than walking. There are various approaches to detecting mode of transport from movement data (e.g. Draijer *et al*., 2000; Stopher *et al*., 2008). However, the data at hand contain many trajectories that are relatively sparse (i.e. overall low number of nodes or dense bursts of photographs followed by spatially and temporally relatively large stretches without photographs). Moreover, some trajectories manifest mixed modality movements, where somebody e.g. travelled on train, on foot and on tram, potentially in quick succession. In such conditions, application of transport mode detection methods is less than promising. Thus, in a second step, an upper speed-filter is applied:

$$v(p_i, p_{i+1}) < v_{crit}$$

For speed calculation, the offset of two photographs in space is computed using the original coordinates of the photographs rather than the coordinates of the cluster centres they have been assigned to.

Finally, trajectory segments that manifest self-loops are disregarded, i.e. where people take more than one photograph in locations that are assigned to the same cluster. The majority of potential trajectory segments (37,150 out of 50,214, ~74%) fall in this category. This is a clear indication that the typical movement pattern of photographers is indeed one where stretches of movement are interspersed with bursts of photo-taking activity. Examining the effects of different filter thresholds and considering the scale of the study area, we settled for $t_{crit}=30$ minutes and $v_{crit}=5$ km/h. (Figure 8) shows the effect of these filters. Without filters, a classical 'hairball' network forms. The time-filter removes a considerable amount of complexity. Most of the information that is filtered out likely stems from domestic visitors, as they can revisit the study area with arbitrary gaps of time between visits. Application of the speed-filter weeds out some more edges in the trajectory network, mainly on the north-south and east–west axes. Also, the area in the eastern half of the depicted region is covered by considerably less edges after the second filtering step. This area features some attractions (viewpoints, hilltops, zoo) and is markedly elevated with respect to downtown. The removal of edges in this region is a clear indication that many people access the region with means that are faster than walking, most likely by tram or by car.

As a result of these processing steps, a set S of trajectory segments ($n=2791$) of any user u (foreign or domestic) between any two cluster centres A and B is retained. Any occurrence of such a trajectory segment of one user is assigned a weight of 1:

$$S = \{\text{trajectory segments } s(A, B) \text{ with weight } 1 \mid t_{crit} \text{ and } v_{crit} \text{ are met}, A \neq B\}$$

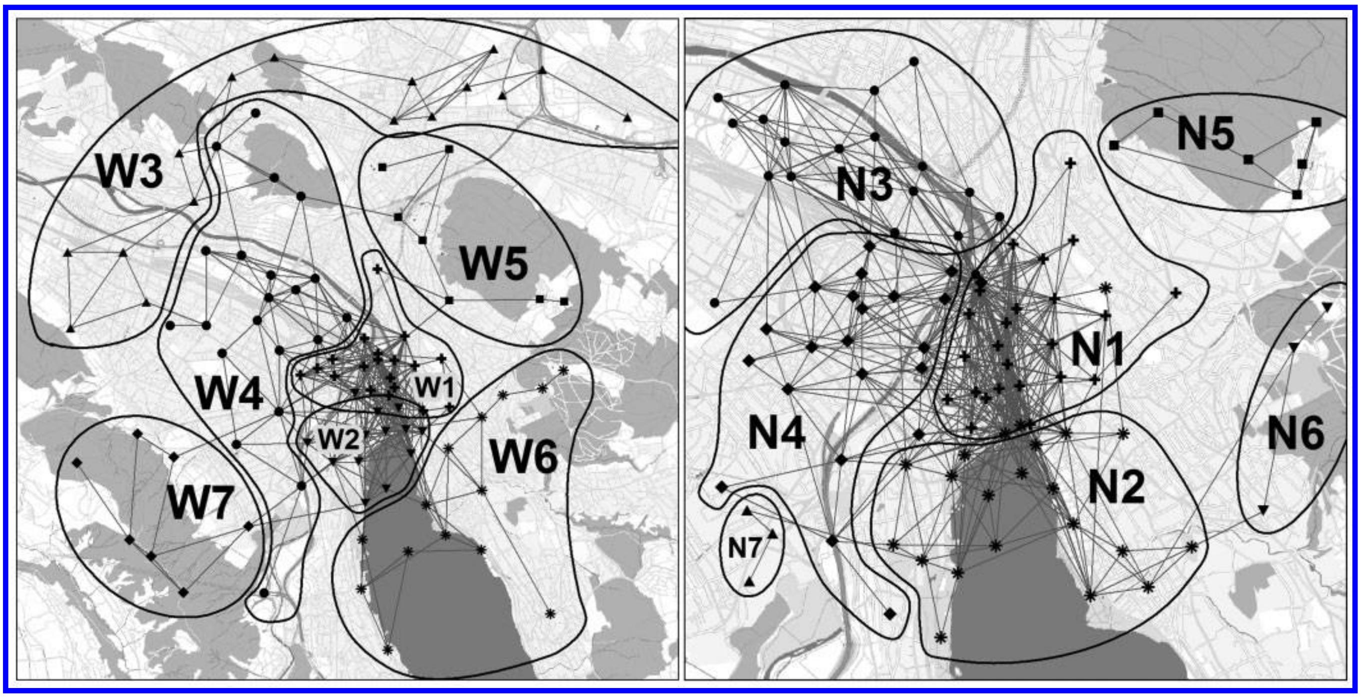

Figure 9. Cluster centres (dot symbols) and communities in the wider (left) and narrower area of interest, computed using all photographs. The communities of the wider area of interest are: (W1) downtown and universities, (W2) lake basin, (W3) northern suburbs, (W4) Hoenggerberg and West, (W5) Oerlikon and Zuerichberg (W6) Dolder and lake, (W7) Ueetliberg. In the narrower area of interest, the communities encompass: (N1) downtown and universities, (N2) lake shore, (N3) formerly mostly industrial, now trendy neighbourhoods (Kreis 4/5 and Albisrieden), (N4) Wiedikon, (N5) Zuerichberg and zoo, (N6) Dolder, (N7) Friesenberg

An undirected network graph G over all such trajectory segments is then constructed by summing up the individual segments. In the summation, both directions are summed up, from A to B and from B to A. The edges of G then obtain weights w between any points A and B thus:

$$w(A, B) = \sum{}_s s(A, B) + \sum{}_s s(B, A)$$

We chose to investigate the undirected network graph, because it presents a good compromise between complexity and information content. Certainly, depending on the setting or the application, direction can play a role for narrative construction and this analysis thus foregoes some information content in lumping together the directions. One may e.g. find that in Paris, many visitors may choose to stroll from Trocadéro to the Eiffel tower and only few the other way. We may explore opportunities of the direction information in follow-up research, with tools that allow the visual analysis of a necessarily much more complex network.

A community detection algorithm based on modularity classes (Newman, 2006) was run on this network that encompassed trajectories by both domestic and foreign visitors (Figure 9). Virtually all found node communities are connected by network edges to at least two other communities – the exceptions being W3 (only connected to W4), N5 (disconnected) and N6 as well as N7 (both only connected to N2). However, the segregation into communities still shows which regions tend to be grouped by the movements of people between them (and are thus more likely to feature in the same photo collections) and to which other clusters they are linked only by weaker ties. At both scales, there is a community boundary between the downtown area around main train station (N1/W1) and the lake basin area (N2/W2 and parts of W6). The hills surrounding the city (marked mostly by the darker grey of the forested areas in the figures) and their hillsides usually constitute their own network community. This pertains mostly to N5, N6, N7, W7 and a bit less to W5, and W6[6].

At this point, the trajectory network was split into the parts constituted by the activities of foreign and of do mestic photographers, respectively. Besides edge weights, *betweenness centrality* (weighted by edge weights and normalised by network size) and *eigenvector centrality* metrics were computed in these group-specific networks. Betweenness centrality (Freeman, 1977) is high for nodes that lie on the shortest path between many node pairs in the network, i.e. that act as a gateway. Eigenvector centrality assigns those nodes high centrality that have many connections to nodes that are themselves considered central nodes in the network (Ruhnau, 2000); the recursive concept is related to Google's PageRank algorithm for assessing the comparative relevance of websites. Thus, while betweenness centrality can be seen as a proxy for a gateway function of locations in the network, eigenvector centrality can be interpreted as signifying important locations.

Figure 10 shows the group-specific trajectory networks in the narrower area of interest with edges scaled according to their weight and nodes according to their betweenness centrality. It is apparent that the main train station (0) is an

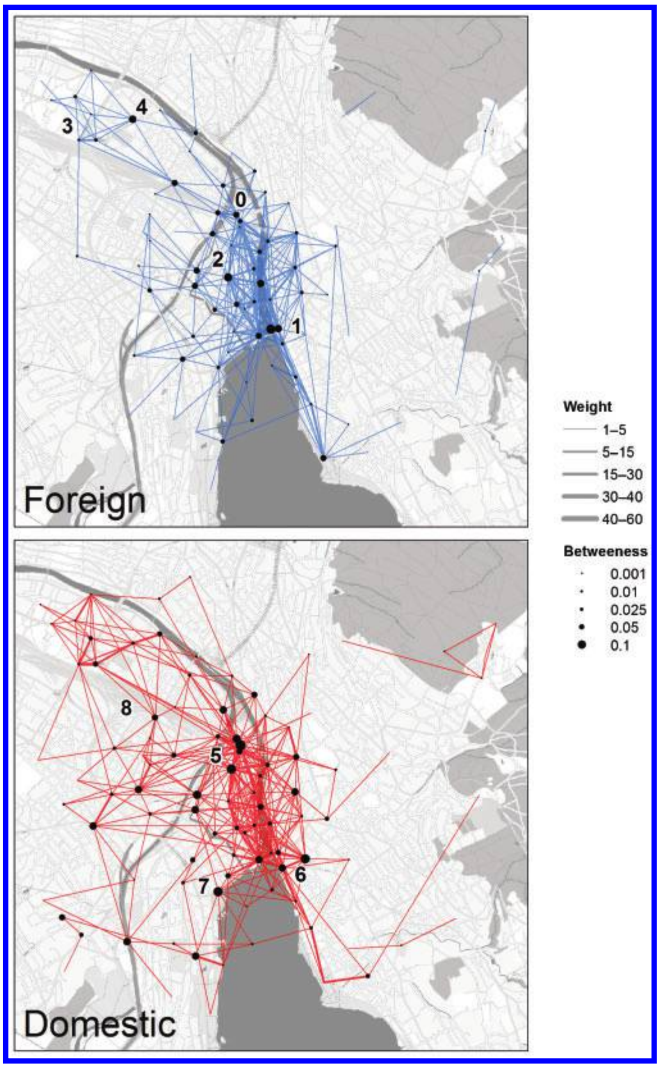

Figure 10. Trajectory network of foreign (top) and domestic photographers (bottom). Edges are scaled proportional to their weight. The nodes are scaled according to betweenness centrality

important node in both networks. Per its betweenness centrality the station assumes a stronger gateway function for domestic photographers than for foreigners. Most of the movement of foreigners appears to occur along the river Limmat between (0) and (1). The bridge at the lake end (1) serves as an important gateway. Another important network node for foreigners is situated near the centre of Bahnhofstrasse (2) where much movement occurs to and from the east; likely, this node together with a node of high betweenness near the river Limmat connects the region around main station and the one at the lake shore for foreigners.

The situation as attested to by the photo-taking activity is a bit different for domestic users: While both the main train station and the lake basin (6) are relatively important nodes also for them, the main gateway node between the two appears to be closer to the main train station, at (5). Also, on the western side of the lake basin, an additional node is a prominent gateway (7), little used by foreigners. A big difference is again apparent in the west of the city: While both groups take photos in the region (though to a different degree, cf. section 2.5), one can observe from the edges as well as from the high betweenness of one node at (4), that the foreigners who visit the region around Hardbruecke (3) travel there mostly north of the tracks (or via train/tram in which case their traces are likely filtered out). Domestic visitors, in contrast, use several routes to reach the region around Hardbruecke; they much more approach the region also from the south – this is manifest in the presence of edges and intermediate betweenness values for all the nodes connecting to the Hardbruecke region.

Figure 11 depicts a zoomed-in version of Figure 10 visualizing a different node metric, the Eigenvector centrality which highlights prominent nodes in the network. The main train station at (0) is marked as part of numerous trajectories of foreigners. Note, however, the emergence of another strong difference between foreign and domestic users: Foreigners tend to travel north-south and vice versa mainly along the river Limmat, via Central (1), (2) and (4) to (5). (4) with its many sights (bridges, Grossmuenster, Rathaus, Fraumuenster) can be described as the photography hotspot, or rather, triangle (this links back to (5) in Figure 5 that was picked out as being visited by especially many foreigners). As briefly mentioned before, foreigners deviate significantly from the path along the river in what seems almost like a side-step motion at (3), mid-Bahnhofstrasse, in an area that offers more sights which they seem to be wanting to include in their photo-taking activity. Further, a significant proportion of trajectories is again manifest on the bridge next to the lake.

The behaviour of domestic people strongly differs in the north–south movement: A significant amount of domestic photographers' trajectories is manifest all along Bahnhofstrasse (6–9), the main shopping street of Zurich and, supposedly, also a tourist hotspot. For domestic photographers, this route acts as a significant by-pass of the route along the Limmat, which is also popular with them. They create especially many trajectories between mid-Bahnhofstrasse and famous Paradeplatz (8). A final significant difference between foreigners and domestic visitors is the substantial number of trajectories the latter have that visit the area around train station Stadelhofen (10), one of the city's most important public transport hubs. Only few trajectories of foreigners ever follow that direction of movement.

CONCLUSIONS

In this article, as a step towards (re)constructing human narratives about cities, we connect the notion of narrative to a quantitative and qualitative visual analytical examination of data that was generated by individuals taking, geocoding and sharing photographs. When many people take pictures of a particular place, it implies something meaningful about that place (and potentially, time): maybe it is monumental, beautiful or unusual. If no one seems to take (or share) pictures in a neighbourhood, that may also tell us something: maybe this particular place is not visually rewarding? Maybe it is just too ordinary to take a picture and share, or

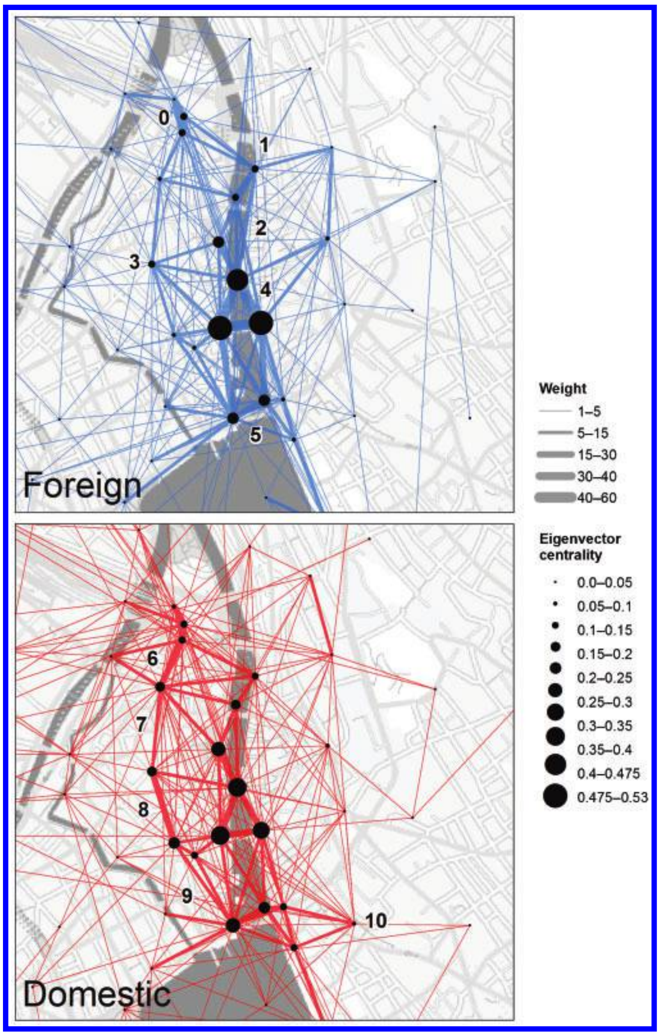

Figure 11. Trajectory network of foreigners (top) and domestic visitors (bottom). Edges are scaled proportional to their weight. The nodes are scaled according to their eigenvector centrality

maybe the place is simply *undiscovered*? Geocoded photos allow us to play with the idea that we can, indeed, observe aspects of people's spatial behaviour without intruding into their experiences and without violating their privacy. As we place their digital footprints on a map and analyse aggregated spatio-temporal patterns, we are able to take the first steps to (re)construct a plausible narrative about the *place*, as it is enriched by human experience, instead of merely mapping the (geometric) space.

The spatial patterns revealed in this study suggest that domestic and foreign visitors have a significant amount of overlap: both groups visit and photograph the downtown region very much, the lakesides (6 in Figure 5), a nearby hill called Ueetliberg (5 in Figure 4) and the airport. However, striking differences also emerge: for example, domestic visitors photograph certain areas (e.g. northern suburban areas, west of Zurich (1–3 in Figure 5), countryside) more than foreigners and more evenly throughout the year (e.g. the zoo). This suggests that certain regions do not feature in photo-collections of foreigners, and by extension, these regions may not be included in the narratives that foreigners construct about the city. Some of the areas are likely considered less attractive for a variety of reasons, and are thus probably not prominently featured in many tourist guides. An interesting region in this respect is the west of Zurich which has been a traditionally industrial and a less affluent neighbourhood; however, it has experienced a revival as the newly trendy quarter for mostly young people. Our analysis indicates that this area is largely unvisited by foreigners as of 2011. In our network-based trajectory analysis of flows of photographers, we find additionally that the famous Bahnhofstrasse in Zurich (6–9 in Figure 11) is photographed considerably more by domestic people and thus likely features more prominently in domestic narratives than in those of foreigners.

Even though the data are only a sample (not all visitors take pictures, not all pictures are uploaded, not all uploaded pictures are geocoded), we contend that it is reasonably indicative. However, it must be stated that working with UGC is not trivial. Facing various methodological questions and challenges, we also explored improvements over (and refinements to) existing approaches. Specifically, various raster- and network-based analyses were proposed, partly integrating spatial and temporal dimensions. The network-based analysis could show that introducing both a time- and a speed-filter in trajectory generation can make the resulting networks suitable for studies of visitors' movements (in particular for pedestrian movements).

With this study, we presented an exploratory visual analytics approach that lies at the interplay between the quantitative geographic data and information and how these may connect to narrative. As we present steps towards (re)constructing collective narratives based on the way domestic and foreign visitors take photographs of Zurich and choose to share them, we hope to have contributed to the cartographic story-telling from a modern 'user-generated' perspective. Besides serving as a stepping stone towards narrative (re)construction, analysing UGC offers potentially valuable information for disciplines such as tourism studies, urban studies, city planning, traffic analysis and geography in general (in our analyses, we have gained several insights which are relevant to these disciplines, e.g. overall seasonal differences in spatial behaviour or specific findings such as train tracks (with over- and under-passes) acting more strongly as a barrier for foreigners than for domestic people). Comparing these insights deduced from data with professional experience and expertise is accordingly an interesting opportunity for a follow-up study. Thus, future directions we consider at this point are to combine our analysis with a point-of-interest database, further analyse the photo-content (e.g. via tag analysis as well as a 'geo-photo browser' tool which is currently under development), to identify private and/or public events and the participation by domestic versus foreign visitors in these events, and more fine-grained spatio-temporal sequence analysis (e.g. similarly to Coltekin *et al.* 2010), as well as an expert testing of the approach by tourism planners and other urban researchers.

BIOGRAPHICAL NOTES

Ralph K. Straumann researches geographies of the Internet and user-generated content with the Oxford Internet Institute at the University of Oxford, UK, and works as a GIS analyst and consultant at Ernst Basler+ Partners in Zurich, Switzerland. He has earned his graduate qualification and his PhD in Geography from the University of Zurich with foci in Geographic Information Science, Remote Sensing and Cartography. He works and publishes on GIScience, user-generated content, social media and social networks, (geo)visual analytics and digital terrain modelling. He maintains a blog and an online presence at http://www.ralphstraumann.ch.

NOTES

[1] This distinction has been also made in philosophy – however, reader should note that even though the argument is similar, de Certeau (1984) uses the term *space* for what is addressed as *place* in geography. While this may be somewhat confusing, it is important to note that it is only a terminological difference, and not a conceptual one.

[2] Asimilar debate is currently active beyond the GIScience community, where a provocative piece in popular media claimed that there are possibly much more insight hidden in 'big data' than any scientists could really 'theorize' (http://www.wired.com/science/discoveries/magazine/16-07/pb_theory, last accessed 10 November 2013; also see Boyd and Crawford, 2011)

[3] Irregularities included use of non-English language, toponym subordinate or superordinate to the country level, colloquialisms, coordinates, too ambiguous or non-specific indications ('Earth', 'Nowhere and Everywhere').

[4] Resolutions of 1 km, 500 m, 250 m, 125 m and 62.5 m have been tested. 250 m was deemed most suitable for visualizing patterns in the whole study area, while 62.5 m lent itself to depicting distributions in the core region.

[5] Other numbers of clusters have been assessed; $k=100$ clusters yielded a sensible tessellation of the study areas. This seems to be a subjective decision in current practice.

[6] In the remainder we abstain from further analysing the trajectory networks in the wider area of interest for two reasons: first, the differences in the periphery are caused by relatively few photographers in either group and, second, the relative scarcity of trajectories in the periphery does not allow much more than analysing the difference in coverage. This, however, is not a unique affordance of the network analysis approach and, in fact, is better done using the approaches applied in the section on 'Spatiotemporal coverage'.

ACKNOWLEDGEMENTS

We would like to extend our thanks to Dr Georg Fuchs (Geographic Knowledge Discovery Group, Fraunhofer Institute IAIS, Germany) and his colleagues for providing the base dataset.

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