Exploring Human Spatio-Temporal Behaviour Patterns

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ABSTRACT: The complexity of pedestrian spatio-temporal behaviour calls for the combination of several complementary empirical methods in order to comprehensively understand human motion behaviour patterns and underlying motives, habits and intentions. This is essential for the development of mobile spatial information technologies, as the huge amount of potentially available information has to be filtered and customised to individual needs. Therefore, in this contribution a currently ongoing project aiming at the classification of pedestrian walking behaviour and related influence factors is described. We illustrate the multi-methods-approach applied in this study and present experimental results based on a dataset of more than 100 trajectories of pedestrians observed in indoor and outdoor environments as well as results of a survey containing 130 interviews.
The project uses a multi-method triangulation approach in order to obtain comprehensive insight to human spatio-temporal behaviour. Firstly, a brief overview concerning most common methods in pedestrian monitoring is given. Secondly, the current approach is described and each employed method and related preliminary results are presented. Finally, an outlook concerning forthcoming steps is given and the main conclusions at this stage of the study are discussed.

KEYWORDS: Pedestrian Navigation, Spatio-temporal Behaviour, Methodical triangulation, Typology

Introduction

Ubiquitous access to information services in active environments can supply pedestrians with practical information concerning optimal routes and useful facilities in the vicinity. Hence, mobile tools for wayfinding are becoming more and more popular, and Location Based Services (LBS) are increasingly serving a multitude of purposes to different types of users.

Mobile navigation services currently still fail to fulfil pedestrians' expectations, as they are hardly able to respond to individual needs and preferences. Several studies indicate that there are differences among pedestrian walking patterns. Daamen and Hoogendoorn (2003b) for example described several influence factors affecting the walking speed of pedestrians (personal characteristics, characteristics of the trip, properties of the infrastructure and environmental characteristics); Hartmann (1976) discovered significant variances in the spatial behaviour of observed tourists, and Koike et al. (2003) revealed differences by age groups in the walking behaviour and length of stay in shopping malls.

First attempts to develop mobile navigation systems for pedestrians follow the common concepts of on-board navigation systems for vehicles, generally offering the "shortest path" to a desired destination. The shortest path, however, does not always represent the optimal route for an individual's purposes. In fact, studies have revealed that people often

forgo to take the shortest path or the fastest path and prefer the “most beautiful”, “most convenient”, or “safest path” (Thomas, 2003). Studies on environmental preference and route choice behaviour confirm that pedestrians prefer certain routes according to their environmental qualities, such as relative quietness and greenery (Blivice, 1974). Thus, it can be assumed that the choice of a specific route and the actual walking behaviour depends on a variety of influencing factors, for instance the task a user wants to perform, the present environment, and the individual preferences associated with personal attitudes and lifestyles. The development of future ubiquitous navigation systems and LBS will have to take individual preferences and wayfinding styles into consideration, in order to provide efficient, personalised services to fulfil individual requirements.

Generally, it is assumed that behavioural strategies show certain regularities (Helbing et al., 2001). Their investigation can be used to develop a typology of mobility styles based on observable motion patterns and internal preferences. These types can then be applied in ubiquitous navigation systems in order to supply the navigating person with customised information based on individual mobile behaviour and interests and available facilities in the actual surroundings. Moreover, current developments in the field of pedestrian simulation models require profound investigations of pedestrian spatio-temporal behaviour patterns in order to create naturally acting agents.

Following the assumption that individual walking patterns and route decision preferences can be classified by observing the spatio-temporal motion behaviour and investigating internal motives, intentions and habits, currently a study aiming towards the development of lifestyle-based pedestrian mobility styles is conducted. After giving an overview about previous findings concerning the most relevant influence factors on human walking patterns as well as most common methods in pedestrian monitoring, this contribution presents our approach to the development of pedestrian mobility styles. Subsequently, the current approach is described and each employed method and related preliminary results are presented. Finally, an outlook concerning forthcoming steps is given and the main conclusions at this stage of the study are discussed.

Research on Human Spatial Behaviour

Due to the vast amount of critical factors influencing pedestrian walking patterns and route choice behaviour, there have only been limitated efforts to observe and describe group-specific spatial behaviour so far. The research designs of previous studies predominantly concentrate on a small number of specific aspects, for example the spatio-temporal behaviour of certain age cohorts (Ahrend, 2002), the visible pedestrian movements within a specific area such as a particular urban square (Yan and Forsyth, 2005), or the mobile behaviour of people within the context of specific activities, like recreation (Götz et al., 2003), tourism (Hartmann, 1984; Shoval and Isaacson, 2007) or shopping (Koike et al., 2003).

Studies indicate that there are two main categories of behaviour influencing factors: internal factors (personal characteristics of individuals) and external factors (characteristics of the environment). Personal characteristics include for example socio-demographic attributes (gender, age, health, etc.) (Daamen and Hoogendoorn, 2003b) as well as culture, lifestyle, level of education, beliefs, and attitudes (Holden, 2000). External factors refer to characteristics of the trip (familiarity, trip length), properties of the infrastructure (type, attractiveness, shelter), and environmental characteristics (ambient, and weather conditions) (Daamen and Hoogendoorn, 2003b). External factors can also be classified to several dimensions of route qualities: physical (distance, acclivity), psychological (attractiveness, safety), and mental qualities (complexity, landmarks) (Millonig and Schechtner, 2007a).

Concerning the route choice behaviour of pedestrians, Golledge (1995) found “fewest turns” (simplest path) to be one of the most relevant factors influencing route planning strategies. Other factors include e.g. “least time”, “most scenic/aesthetic”, or “different from previous (novelty)”. Apart from all the previously mentioned factors influencing human route choice and route planning behaviour, Joh et al. (2001) point out that uncertainty should also be taken into account. Unexpected events may force individuals to reconsider previously scheduled activities, especially under time pressure.

Given the vast amount of factors affecting the spatial behaviour of individuals, it is not surprising that the spatio-temporal behaviour of pedestrians is still poorly understood. Nevertheless, there have already been several approaches to investigate and describe human spatial behaviour applying different empirical methods.

Common Empirical Methods in Monitoring Pedestrian Behaviour

The complexity of human walking patterns and spatial decision processes have led to the usage of numerous methods in order to monitor, interpret and analyse pedestrian spatial behaviour. Each of the techniques employed possesses its advantages and drawbacks.

Many investigations concerning the collection of data on pedestrian route choice use questionnaire survey techniques. Inquiries represent one of the most important data collection techniques in transportation studies and provide detailed information concerning route decisions and individual habits, motives, and intentions (e.g. Blivice, 1974). Questionnaire surveys are relatively cheap, provide comparatively large samples, and allow the collection and analysis of data within a rather short time. However, as human behaviour is never fully determined by verbalised structures (Nisbett and Wilson, 1977), and people tend to adapt their answers – consciously or subconsciously – to what they expect to be socially desired behaviour (Esser, 1985), the accuracy of the results gathered from questionnaires may suffer.

Another frequently used technique in studies concerning human time-space patterns is the time-space budgets technique. This includes several methods: recall diaries in questionnaire or interview form, face-to-face interviews, and self-administered diaries (Shoval and Isaacson, 2007; Thornton et al., 1997). Recall diaries and interviews can provide detailed information; however, they are strongly dependant on the subject’s memory, whereas self-administered diaries (which are written in real-time) require the subjects’ cooperation to a very large extent.

While trip diaries and inquiries mainly aim at the investigation of motion behaviour from the agent’s perspective, allowing the analysis of motivations and intentions underlying pedestrian activities, other empirical methods focus on the investigation and interpretation of the visible motion behaviour. A common method used in pedestrian behaviour surveys is direct observation, also known as behavioural mapping or “tracking”. Participatory observation involves the observer taking part in the participant’s activities, where the researcher can gain insight to the purposes influencing the subject’s decisions. Nonetheless, this technique faces issues similar to inquiry methods; being aware of the fact that they are under observation, participants may tailor their behaviour to the researcher’s expectations.

Non-participatory, unobtrusive observations avoid the risk of such “observer effects”. They have first been used for studies concerning the movement behaviour of visitors of museums and exhibitions (Hill, 1984). Tracking involves following the subject at a distance and recording her movements by drawing a line corresponding to the subject’s

activities on a map of the investigation area. This method yields information concerning the exact routes and activities of pedestrian in urban environments in time and space, while avoiding the risk of influencing the "natural" behaviour of participants (Hill, 1984; Keul and Kühberger, 1996; Keul and Kühberger, 1997). Yet, this technique is very time-consuming and labour intensive, and findings are limited to the observable activities of pedestrians; motives and intentions cannot be revealed.

Technologically sophisticated methods use video analysis to monitor and interpret pedestrian behaviour. Especially the development of agent-based simulation models requires calibration and validation to confirm the accuracy of simulated human behaviour (Daamen and Hoogendoorn, 2003a; O'Connor et al., 2005). Most studies using video captured data, however, are limited to a very small observation field, although there are approaches observing a larger area by a network of several surveillance cameras (Millonig and Schechtner, 2007b). Yet solely still visible behaviour can be investigated, leaving the subjects' intentions and motives as well as most other personal characteristics in the dark, albeit there are attempts to perform modelling approaches not at the level of visible patterns of motion, but at the level of intentions (Dee and Hogg, 2006).

Other technological methods to gather information on the spatial behaviour of pedestrians use digitally based localisation technologies to track individuals (Shoval and Isaacson, 2007; Spek, 2007; Svetsuk, 2007). These include for example satellite-based technologies (Global Positioning System, GPS), land-based technologies (cell identification), or hybrid solutions. The main advantage of using tracking technologies lies in the possibility to gather data within a very large study area. Yet, collecting localisation data with the help of tracking technologies can be of a rather invasive nature, if the participants have to be equipped with tracking devices, and therefore, again, observer effects may be suspected. On the other hand, the use of data gathered from private mobile phones without knowledge of their owners may pose various ethical questions. Apart from that, localisation techniques still are only able to describe observable motion behaviour.

Being aware of the limitations each method implies, there have been several approaches combining two or more techniques, in order to overcome their drawbacks and maximise their benefits. Examples are the development of activity-based transportation models by collecting data with the help of GPS enhanced self-administered diaries recorded on PDAs (Janssens et al., 2007), the combination of unobtrusive tracking methods and inquiries to analyse urban tourism (Keul and Kühberger, 1996), or the study of tourist behaviour using video and behavioural mapping techniques (Hartmann, 1988).

Within the presented ongoing study, tracking techniques, inquiries, and localisation technologies are combined in order to obtain a comprehensive insight into human spatio-temporal behaviour.

Triangulation Approach

Especially applied problems, like the factors influencing human behaviour are so various and complex that it appears highly recommendable to benefit from the strengths that different methods offer. Nevertheless, it should not be ignored that different kinds of methods may carry different types of error. Therefore, the selection and combination of specific methods used in empirical surveys has to be well-grounded.

For the current project, a combination of qualitative and quantitative methods following the concept of *"across-method"* triangulation (Jakob, 2001) is used. The methods refer to different aspects of human spatial behaviour (e.g. observable patterns and interpretative investigation of motives and habits) and are to complement one another:

- *Unobtrusive Observation:*
  Non-participatory, unobtrusive, structured observation
  This method allows the observation of the "natural", unswayed spatio-temporal behaviour of pedestrians. However, only visible behaviour can be recorded; intentions and motives cannot be unveiled.
- *Non-disguised Observation:*
  Non-participatory, non-disguised, structured observation
  This allows continuous observation over a long period and can be combined with standardised interviews to obtain data from both the structural and the agent-centred perspective. Though, as the participants are aware of the observation, their behaviour may be influenced (consciously or subconsciously) and differ from normal behaviour.
- *Interviews:*
  Standardised and partially standardised interviews
  Motivations underlying the activities can be revealed and self-assessments of individual motion patterns can be surveyed. Nevertheless, as individuals usually are not able to directly observe the cognitive processes concerning their walking patterns, they are oblivious to their spatio-temporal behaviour; responses may therefore be incorrect and constructed ex post.

The study includes two phases of empirical data collection combining observation and inquiry methods. The systematic integration of both qualitative-interpretative and quantitative-statistical methods is expected to result in a reciprocal fortification of the techniques and in a deeper understanding of pedestrian spatial behaviour. The first phase consists in a heuristic approach, aiming at the identification of a provisional pedestrian typology, which will be tested in the second, deductive phase of the study. Results of both empirical phases will then be consolidated and compared in order to delineate a model of pedestrian mobility styles, which will be used as basis for the description of mobility-style based pedestrian profiles to be integrated in pedestrian navigation systems.

Figure 1 illustrates the overall study design comprising different steps leading to the development of a model of pedestrian mobility styles. Currently, the heuristic phase of the study has been completed and the collection of data within the deductive phase is conducted.

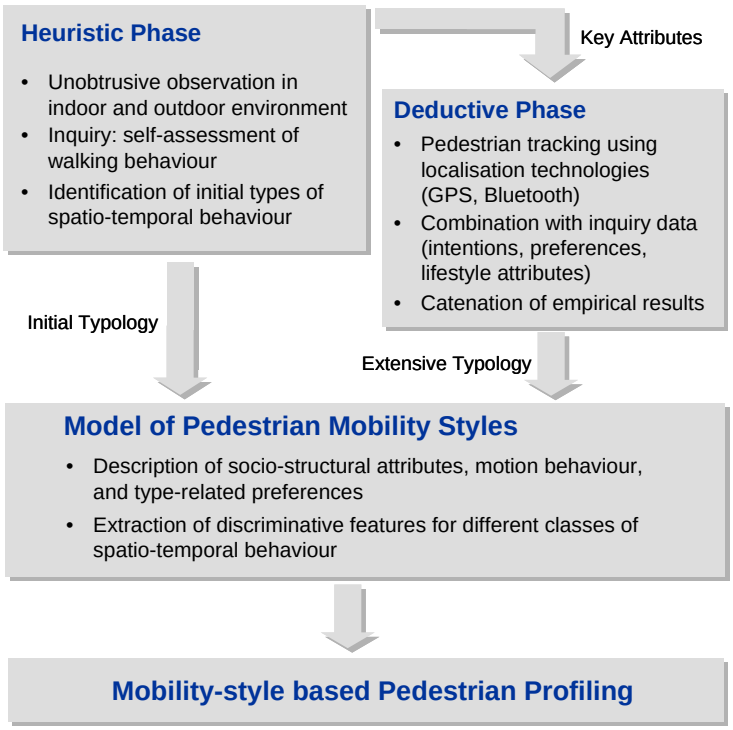

Figure 1: Methodology.

The study started with a phase of empirical research methods to hypothesise and identify basic types of pedestrian route choice behaviour. Research results are based on pedestrian observations in an indoor environment (shopping centre) and outdoor environment (shopping street) under varying circumstances (daytime, weekday, weather conditions). Participants were followed by researchers mapping their routes and annotating main attributes (gender, age, etc.). The method used in this tracking study is a non-participatory, unobtrusive type of observation. For a detailed description of the observation procedure see Millonig and Gartner (2007). In total trajectories of 111 individuals with a balanced gender and age ratio have been collected (57 observations on the shopping street, 54 in the shopping mall). Outdoor observations had an average length of 12 minutes (maximum: 62 minutes), indoor observations lasted approximately 16.5 minutes on average (maximum 57 minutes).

Additionally, standardised interviews have been conducted with another sample of participants to obtain data regarding socio-demographic factors, individual intentions and motives, as well as a self-assessment of the participants concerning their walking patterns. Interviews offer the only chance to gain insight to these determinants influencing human spatial behaviour. The questionnaire consisted of questions concerning socio-demographic attributes (age, gender, education, profession, etc.), goals and time budget for the current activities in the study site, frequency of visits, and questions referring to individual walking habits. Participants were asked to give a self-assessment of their preferences concerning walking behaviour and walking environments (e.g. rather “slow” or “fast”, rather “exploring” or “goal-oriented”, rather “bustling environments” or “calm environments”). In total, 130 individuals have been interviewed in the heuristic phase of the study; 100 interviews have been conducted in the indoor environment, 30 interviews have been given by visitors of the outdoor shopping area, as pedestrians walking the shopping street were conspicuously less willing to give an interview. The majority of the participants were female (61.5%). The sample possessed a balanced age distribution with an average age of around 36 years.

Results

The collected datasets have been analysed according to the velocity computed between each marked point in the observed path, additionally locations and durations of stops within the trajectory have been detected (cf. Figure 2). Subsequently, speed histograms of each trajectory have been compiled, showing the proportional amount of time an individual walked at a velocity within a specific time interval. Based on these results classes of homogeneous behaviour have been identified.

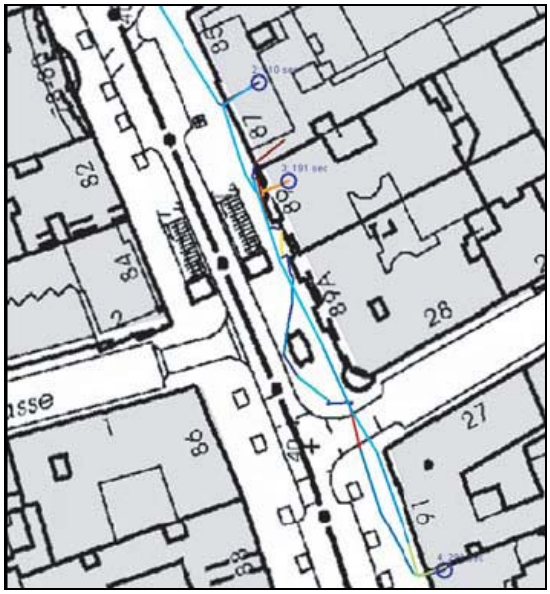

Figure 2: Velocities and stops of a typical trajectory. The velocities measured in the segments are colour–coded, using a "hot-to-cold" colour ramp (red for high velocities, green for middle values, blue for low values). Locations of stops are marked with blue circles and labelled with consecutive numbers and duration in seconds.

In order to gather initial classes of behaviour, the collected datasets have been classified using clustering algorithms (hierarchical clustering and k-means algorithm). For the indoor observations three discriminative clusters have been identified, whereas the analysis of outdoor observations resulted in eight clusters. However, half of the clusters derived from the outdoor analysis consist of only a very small number of people; hence these classes have only limited significance.

The main clusters identified by analysing tracking datasets can be described as follows:

- *"Passionate shoppers"* (both areas): High amount of female participants; low speed; frequent stops of comparatively long duration, predominantly at fashion shops; casual or convenient style.
- *"Convenient shoppers"* (both areas): Balanced gender and age ratio; moderate average speed; fewer and shorter stops; casual (males) or conservative (females) fashion style.
- *"Discerning shoppers"* (only outdoor): Mainly female subjects; balanced age distribution; comparatively high speed; stops almost as frequently as in cluster "convenient shoppers", but very short; either casual and convenient style or elegant and proper style; slight tendency towards specialised and exclusive shops.

- *"Swift shoppers"* (both areas): High amount of male individuals; average age lies by 30-35 years (none older than 60); fast speed; rare and short stops; fashion style mainly casual or trendy; food stores or no main focus.

The self-assessment profile interrogated in the interviews contained 17 pairs of opposed attributes. Responses turned out to appear quite arbitrary: Although some of the items had very similar meanings, only little correlation could be observed. This confirms the assumption that pedestrians have only little knowledge about their own behaviour and seem to guess what they prefer. The reported profiles were classified using hierarchical and k-means clustering algorithms. For each of the observation areas the analysis resulted in 4 clusters. In general, the classes derived from the clustering process do not show very distinct patterns when regarding the reported self-assessment of walking preferences. This is presumably caused by the previously discussed limitations of interview data analysis.

The comparison of indoor and outdoor interview results shows slight resemblances between individual clusters. The classes include the following types based on self-reported subjective behaviour:

- *"Urban, self-conscious shoppers":* Balanced distribution of females and males with slightly more male participants; predominantly aged 30 to 60, large amount of grammar school degrees as highest level of education; self-conscious and flexible but goal oriented.
- *"Modern, curious shoppers":* Large amount of young, highly educated individuals; swift, curious, modern, planning, and self-determined.
- *"Planning, rational shoppers":* More female than male participants; comparable distribution of age groups and levels of education; varying favoured walking speed (fast vs. slow).
- *"Fun-oriented shoppers":* Predominantly female participants, curious and fun-oriented, weak orientation skills.

Most determining factors in the behaviour profiles are related to personal characteristics (e.g. curiosity, anxiety, and self-determination); motion-related characteristics and environmental characteristics appear to be less important in the participants' subjective perceptions.

Discussion

The results derived from the analysis and the interpretation of the preliminary outcomes confirm the assumption that human spatio-temporal behaviour patterns are distinguishable and can be described by defining specific types of pedestrian walking styles. Still, several results cannot yet be explained as observation data and interview data are not combined at this stage of the study.

During the classification process, outside observations produce a greater number of different classes of behaviour than indoor observations. Although there are still many individuals spending a considerable amount of time inside a shop or standing in front of it, more time is spent walking at a greater number of different speed levels than in the indoor observation field. These differences in behaviour also seemed to confirm consequences caused by a greater variety of context influences: As the outside investigation area consists of an urban street, observed individuals might have aimed for other objectives than shopping. A person, who enters a shopping mall (so it is assumed) seldom pursues other goals than shopping, which leads to the identification of a smaller number of discriminative behaviour categories. However, as the analysis of interview

responses suggests, the amount of people visiting a shopping area *without* following shopping purposes is comparable in both investigation sites (appr. 23%). Still, this can only be stated for the interview sample; intentions and motives of the pedestrians observed by tracking techniques are not known.

A comparison of all outdoor and indoor results illustrates that individuals observed in the indoor environment spend significantly more time stopping (in front of or inside a shop or other facility) and walk in general at lower speed than subjects observed in the outside area. Comparing indoor and main outdoor clusters shows strong similarities; the analysis of outdoor observations additionally produced one behaviour cluster which could not be identified in the indoor environment. Without knowledge concerning underlying motivations and intentions it is not possible to give a sound interpretation of these differences. The combination of observations and interviews in the following deductive phase is to overcome these limitations.

The analysis and classification of self-assessment profiles in interviews could not entirely reproduce the clusters derived from tracking datasets. The reported behaviour preferences for each cluster differ only marginally from each other. A comparison of indoor and outdoor results unveils slight resemblances between individual clusters. Still, both differences and similarities are quite small, and hence conclusions are limited. This applies accordingly to comparisons between tracking and interview results; although some of the interview clusters seem to be comparable to tracking clusters, similarities do not possess satisfactory significance.

Outlook

The deductive phase of the study follows the heuristic phase and is conducted to verify the provisional types defined in the first survey. The actual walking and route choice behaviour of people in specific indoor and outdoor situations is observed using technological localisation methods (outdoor: GPS; indoor: Bluetooth) and compared with the formerly identified hypothetic typology.

In this survey we use a non-participatory, non-disguised observation technique. Participants are equipped with devices in order to locate them in the environment. In the indoor environment, we use a tracking process based on Bluetooth (Pels et al., 2005), whereas in the outdoor environment, GPS related methods are used to record individual tracks (Kunczier, 2005). The analysis of the tracking results focuses on routes, velocities and breaks. After the tracking process, detailed standardised interviews are conducted with the participants who have been previously tracked to obtain information about their actual intentions, their attitudes, and lifestyle and socio-structural attributes. The combination of observation techniques with interviews offer two major advantages: Firstly, inaccuracies in observations can be validated with the help of interview responses, and secondly, distortions in the reported self-assessment of motion behaviour can be identified by analysing motion data.

Results of both survey phases are related to each other to identify a specific spatial behavioural style for each provisional category. The catenation of both results is processed to test the hypothetic types defined in the first heuristic phase of the study. At the end of this process a model of pedestrian mobility styles is developed, where each type is described with regard to multiple aspects (basic parameters, behavioural characteristics, preferences, requirements, and main socio-demographic characteristics within the sample).

As the results of the survey are based on data collected of pedestrians acting within a specific context (shopping), it cannot be implied that the identified types of pedestrian

behaviour are comparably valid, when individuals follow different intentions. Therefore, the outcomes will be tested with regard to their validity in other context situations.

Conclusions

The results show that especially the analysis of tracking data results in several distinctive classes of behaviour. Outdoor results bear resemblance to indoor outcomes, although several significant differences have been identified.

First results derived from analysing data collecting during the heuristic phase of the presented study suggest that distinctive patterns of behaviour based on specific underlying, type-related intentions, attitudes and motivations can already be identified when using individual methods separately. However, the results lack important insight if not combined with complementary techniques. The combination of motion observation and interviews in the ongoing deductive phase of the study will lead to further progress in understanding human spatio-temporal behaviour.

Several presuppositions could not be affirmed so far: Individuals seem to be less aware of the factors influencing their route decisions and walking preferences than expected, and context influences can hardly be avoided and barely identified when monitoring human motion behaviour even in assumingly unambiguous context situations (e.g. shopping centres). Still, the preliminary outcomes indicate that human spatio-temporal behaviour can be sufficiently described by identifying mobility types which can be used as a basis for customising spatial information.

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