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APPLICATION OF GPS DATA IN GEOGRAPHIC INFORMATION SYSTEMS

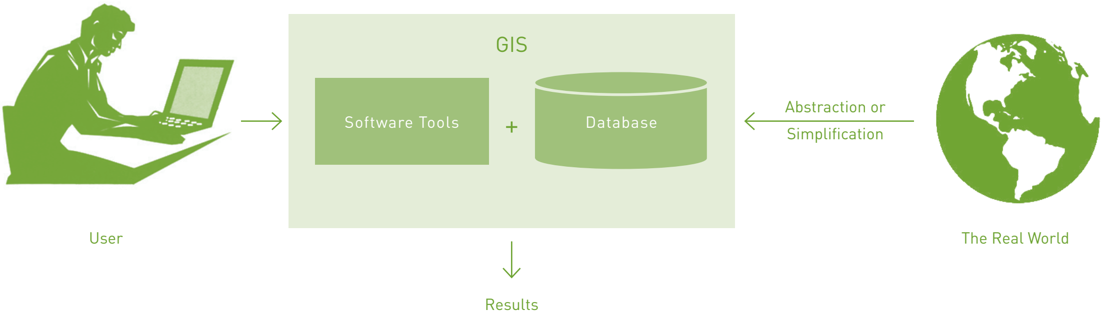
INTRODUCTION

Urban planners and designers depend on spatial-oriented information and knowledge to comprehend a situation and to find design opportunities and solutions for spatial problems. Geographic location, spatial patterns and the distribution of features or events across an urban landscape inform many people of the decisions that planners either make or help others to make. As we will see in this chapter, a Geographic Information System (GIS) provides urban planners with a platform on which they can deal with these complex spatial environments and represent, analyse and model them. It also generates new insights through advanced spatial analysis and helps to increase efficiency and flexibility in the planning process. Parallel to GIS, handheld Global Positioning Systems (GPS) are becoming increasingly available, opening the way for various applications in spatial research. The linking up of GPS and GIS in particular has proved to be a powerful instrument for urban analysis. This chapter is an introduction to the use of GPS tracking data in GIS for the descriptive and comparative analysis of pedestrian movement behaviour and the exploration of space-time activity patterns. The first part of the chapter addresses some key concepts of GIS into urban planning and design. It will address a number of fundamental GIS tools for delineation and the analysis of spatial patterns and relationships. The second part elaborates on the analysis of spatial patterns using GIS in combination with GPS. GPS tracking data will be explored by mapping *movement* and *density* in order to comprehend and monitor pedestrian behaviour in city centres, with Rouen as a case-study.

GIS IN URBAN PLANNING AND DESIGN

Geographic Information System (GIS) has received very wide acclaim as important and powerful tool for spatial research, design and planning (e.g. Stillwell et al., 1999; Longley & Batty, 2003). GIS offers planners and designers a platform on which they can represent, analyse and model complex spatial environments. It can also provide new insights through advanced spatial analysis and help to increase efficiency and flexibility in the process. There are many definitions of GIS, and it is difficult to find a single definition that encompasses the multiplicity of GIS use. It is perhaps easiest to think of GIS as an integrated system of components; information about the real world that has been abstracted and simplified into a digital database of spatial and non-spatial features which, in conjunction with specialised software and hardware, and coupled with the expert judgment of the urban planner, gives insight into the spatial environment and produces solutions to spatial problems (see **illustration 4.1**) (Maantay & Ziegler, 2006). In this perspective, it is very important to realise that computers and software cannot make sense of the data without the user's expertise.

Illustration 4.1 The components of GIS (source: Maantay & Ziegler, 2006)



Mapping and spatial analysis

Maps are a very important component in GIS and are used as both the raw materials and final products in research and design projects. Maps are intended to convey information, as well as abstractions, simplifications and representations of reality. Map-makers organise information on maps in order to view knowledge in a new way or to increase knowledge (cf. chapter 12). As a result, maps suggest explanations, and while explanations reassure us, they also prompt us to ask more questions and to consider other possibilities. To ask for a map is to say, "Tell me a story" (Turchi, 2004). While mapping is an important component of GIS, GIS is more; it combines mapping with information technology, and thereby transfers the control of the mapping process from the cartographer to the planner or designer. In this sense, GIS offers urban planners a platform on which they can deal with complex spatial environments and represent, analyse and model them. Mapping and spatial analysis are intimately linked, as different scholarly studies have pointed out (e.g. Cross, 2006; Steenbergen & Aerts, 2002). However, it is a common idea to think of spatial analysis as something different from mapping, and substantially more sophisticated. "GIS is just a mapping machine" is a statement frequently heard, implying that if sophisticated GIS software is used only to display data in a visual form, it is somehow being underutilised. In fact, the earliest GIS – the Canada Geographic Information System – had no display capacities at all in its original design, and could only produce numerical output in table form (Goodchild, 1999). The Spatial Metro project illustrates, among other studies, that within GIS, mapping and spatial research are very much interwoven (also see chapter 7).

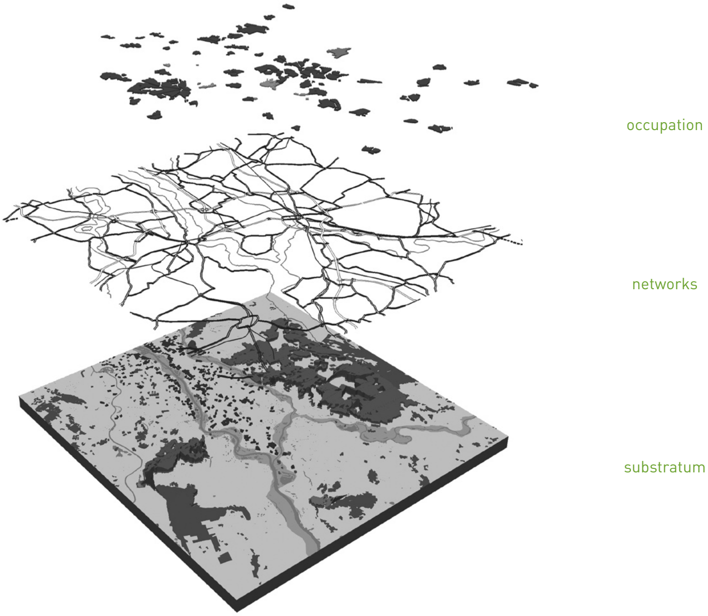
Layering and attribute database queries

For planners and designers, GIS is a way to combine, analyse, and visualise the various kinds of (spatial) information that describe a geographic area. This implies that the application of GIS meets specific needs, but always involves typical tasks within GIS technology such as *creating maps, reconciling map scales and projections, layering*, *handling non-spatial attribute database queries*, *linking the map to other images*, *connecting GIS and CAD,* and *three-dimensional GIS applications* (Maantay & Ziegler, 2006).

Layering is a fundamental feature of GIS. In the late 1960s, Ian McHarg, a visionary landscape architect and a key person in GIS development, introduced a layering system – the 'layer cake' model – for environmental planners in his seminal work *Design with Nature* (1969). He used tracing paper overlays to reveal the cumulative effect of various environmental conditions on an area. This approach is nowadays a widely used technique among designers and planners, and a useful tool to explore how different elements interact with one other within the same geographic area. Layering within GIS offers the opportunity to interact with different levels or elements of urban geography such as land use, topography, geology, demographics, transportation, etc. (see **illustration 4.2**). In the case of the Spatial Metro project for example, we can interact with the layers of pedestrian behaviour, urban layout and attractors to explore spatial correlations. The layers can be overlaid on each other in any combination and can be analysed using logic operators such as *within*, *containment*, or *intersection*. With these topological operators, we are able to run queries on geographic features from different layers that meet certain criteria in terms of *adjacent to*, *connected to*, *contained by*, or *containing*.

GIS data is composed of both spatial and non-spatial information. Non-spatial data is commonly referred to as attribute data and is a database table. The database table is the basic building

Illustration 4.2
'Layer cake' model
(source: Van Uum & Nijhuis, 2007)



block of all attribute *DataBase Management Systems* (DBMS) such as Microsoft Access or SQL Server. An attribute database can be queried through *non-spatial attribute database queries* using logical operators (in Standard Query Language). These queries are useful for measurements and statistics and allow quantifying specific patterns and relationships. The GIS can perform standard database management tasks such as redefining, reclassifying, and altering attribute data. In addition, a linkage to external DMBS is possible to perform data analysis in terms of selection (query), measurement and statistics. Through ODBC connections or middleware such as the ESRI Spatial Database Engine (SDE), the GIS provides direct access to external DBMS. The database tables can also be incorporated into a *relational database* that is capable of combining, managing and updating information that is stored in several tables. In fact, the GIS itself is a DBMS because it links the attribute database to the spatial database that produces maps, and can manage data stored in more than one database table (Mitchell, 2005; Maantay & Ziegler, 2006).

Advanced spatial analysis

At the heart of GIS is spatial analysis. Without spatial analysis capabilities, GIS would be a computerised mapping and spatial database storage utility. Jack Dangermond, landscape architect and the founder of ESRI [1] stated that "The real heart of GIS is the analytical part, where you explore on a scientific level the spatial relationships, patterns and processes of geographic, cultural, biological and physical phenomena". This implies a wide range of possible applications in urban planning and design, since spatial relationships and patterns are key concepts for understanding urban structure and configuration (Lynch, 1960; Hillier, 1996; Alexander, 2002).

Spatial analysis is a process for looking at geographic patterns in spatial data and relationships between features. The actual methods of analysis can be simple – making a map, for instance, or more complexly, involving models that mimic the real world by combining many data layers. The range of geo-spatial analysis methods that are available through GIS consists of the principles of data exploration and spatial statistics, physical surface and field analysis, and network and location analysis. These contain the basic concepts: mapping *where things are*, mapping *most* and *least*, mapping *density*, finding what's *inside* or *nearby*, mapping *change* and *movement*, and mapping *visibility* (Mitchell, 1999; Smith et al., 2007). These analysis concepts and tasks are useful in their own right but can often serve as building blocks for more advanced spatial analyses. By adding analytic capability, in terms of modelling and simulation – e.g. the integration of cellular automata-based, agent-based models and other expert-systems – GIS can be used for advanced spatial analysis (Batty, 2007; Longley & Batty, 2003; Batty et al., 1999). Possible applications of GIS include virtual cities, agent-based pedestrian modelling, the identification and measurement of urban sprawl (Longley and Batty, 2003), the exploration of architectural composition (see **illustration 4.3**) (Nijhuis, 2007) and web-based decision support systems for community planning (Brail & Klosterman, 2001).

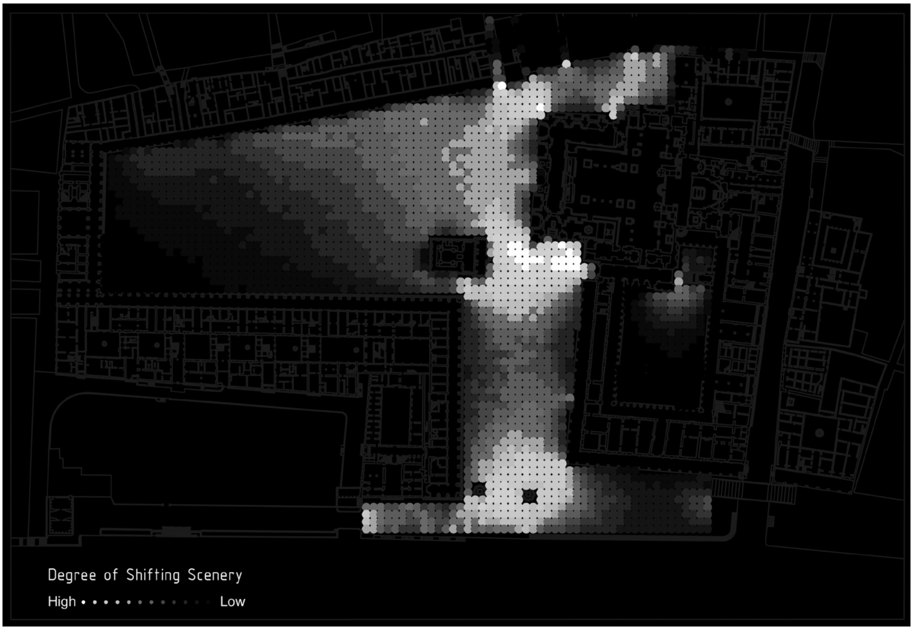


Illustration 4.3 Exploration of the architectonic composition of Piazza San Marco, Venice, Italy (source: Nijhuis, 2007)

The focus in the rest of this chapter will be on the analysis and visualisation of tracking data derived from global position systems (GPS) within the context of urban planning and design. Within the framework of the Spatial Metro project by Spek (2008; chapter 7), this chapter will elaborate on the concepts of analysing *Movement* and *Density* within GIS to comprehend and monitor pedestrian behaviour in city centres.

PATTERNS IN SPACE AND TIME

In the field of spatial and urban research, two different fields of research using GPS can be distinguished, namely travel surveys and activity patterns (Spek, 2006). The first field is related to travel diary research – research in the field of travel choice behaviour, mostly on a regional or metropolitan scale. The second field covers the analysis of activity patterns on different scales. Here, the relationship between activity and space-time is crucial. The focus of GPS research in the Spatial Metro project (Spek, 2008) is the monitoring of patterns and intensities of pedestrian movement on the scale of the city centre, and is therefore part of the second field of research. This research depends on large amounts of GPS data derived from extensive field surveys. To visualise the tracking data, we can use standard GPS visualisation software or specially designed applications as in the projects *Amsterdam RealTime* (Ross, 2006), *GPS drawing* (see **illustration 4.4**) (Pryor and Wood, 2002) or *The Urban Tapestries* (Moed, 2006). However, for scientifically-based research in terms of analysing spatial patterns, intensities and relationships, this software is usually not sufficient or lacks flexibility. Instead, off-the-shelf GIS software [2] is a great deal more suitable. The linking up of GIS and GPS within the context

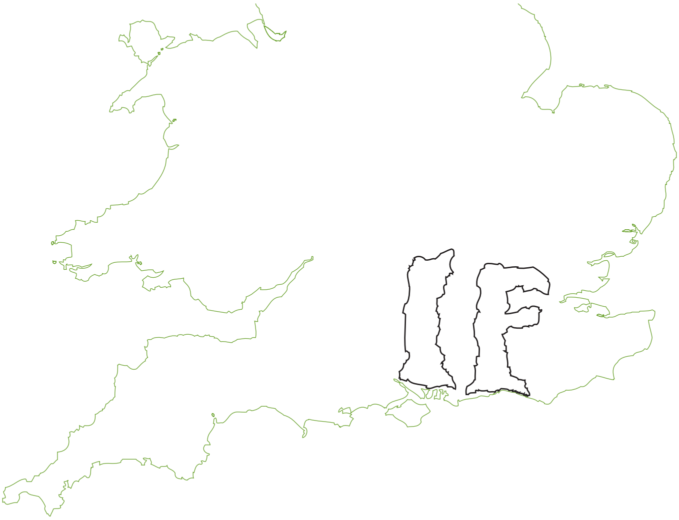


Illustration 4.4 GPS Drawing: The worlds largest "IF" (source: www.gpsdrawing.com)

of urban design is not only for the purpose of the visualisation of tracking data, but also to analyse the data and derive spatial patterns and correlations from it. Parallel to GPS, technology for determining the geographic location of cell phones is becoming increasingly available. This opens the way to a wide range of applications, collectively referred to as Location-Based Services (LBS) and in combination with GIS, these will also become a powerful tool for urban analysis (e.g. Ratti et al., 2006; cf. chapter 8). However, the topic of this chapter is the application of GPS data in GIS for the purpose of urban planning and design. GPS data derived from Spatial Metro field surveys in the city centre of Rouen (France) are used to illustrate the application of the analysis concepts of *movement* and *density*.

MAPPING CHANGE AND MOVEMENT

By mapping where and how people move over a period of time, insights can be gained into the movement behaviour of pedestrians in the city. There are three different methods of analysing change or movement within GIS which are applicable to GPS data: 1) *time series*, 2) *measuring change* and 3) *tracking map*. A *time series* (1) is effective for showing the change of patterns of movement during a certain time span or mapping change in the magnitude or the type of the pedestrians. It is possible for example to map the change of location of individuals or groups throughout a day or the presence of more or less visitors at a specific location. To *measure and map change* (2) the difference in value between two dates or times is calculated and displayed as an amount, a percentage, or the rate of change and is very useful for comparative study. The *tracking map* (3) shows the position of a person or persons at various times. It is useful for showing the incremental movement of pedestrians. It can be visualised as individual points (each feature at each date or time [3] or as a line connecting the points. This 'time-line' represents the path of movement. There is also a possibility of visualising tracking maps dynamically (simulation) or real-time [4]. For example, the tracking data of a pedestrian in the city of Rouen is visualised as a tracking map and projected onto the city map (see **illustration 4.5**). This path of movement, among others, is tagged [5] with individual characteristics such as purpose, duration, direction, etc. and can be displayed by adding a legend (use of different colours of symbols) or opening the database. By performing non-spatial attribute database queries, we can explore the (spatial) statistics and measurements of specified groups or individuals and allow the investigation of their spatial patterns and relationships. By displaying the start and end point for each line, the direction of movement and the travel-mode (walking, cycling, driving a car, etc.), we increase our insight into way-finding, the nature of pedestrian movement and activity patterns of individuals or groups. Via the GIS, we can apply a predefined symbology or multi-level symbology with regard to large amounts of tracking data, increasing the efficiency of the process of data management.

Illustration 4.5

Tracking map of a tourist

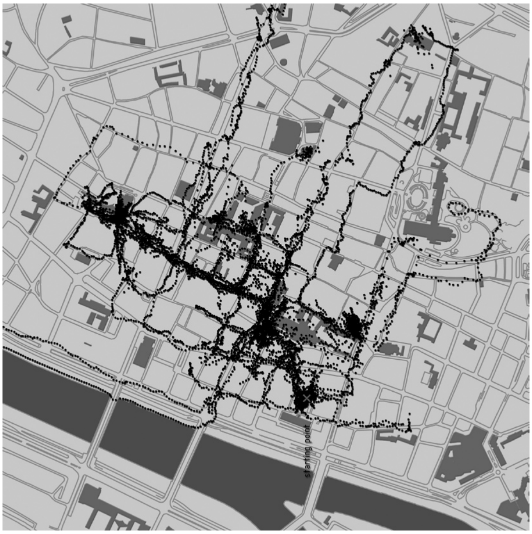


Illustration 4.6

Tracking map of a group of tourists

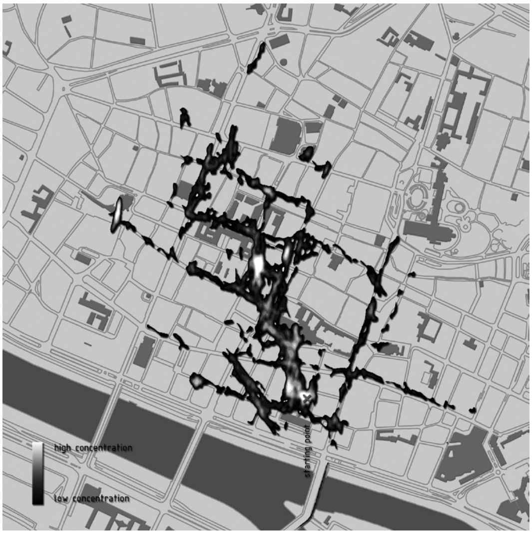


Illustration 4.7

Time-space pattern of commuters

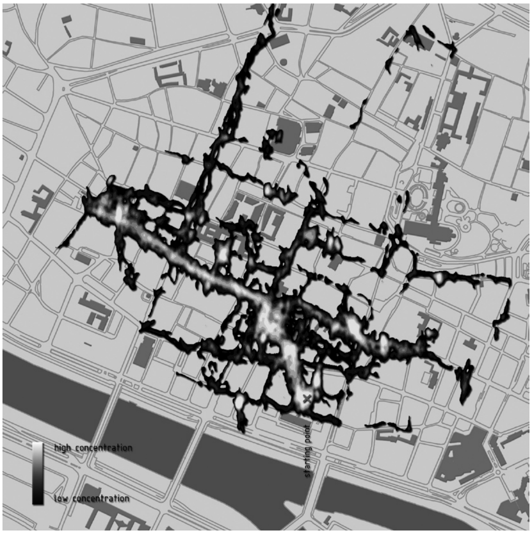


Illustration 4.8

Time-space pattern of tourists

To understand the processes of way-finding and the legibility of the city in relation to activity patterns, it is necessary to monitor patterns of movement of significant groups of pedestrians, not of individuals (e.g. Lynch, 1960; Hillier et al., 1993). With respect to this GPS data, two significant groups of pedestrians were merged (summarised), and generally categorised by familiarity, origin, purpose and duration (see chapter 7). This merged data is also represented as a tracking map, allowing patterns of movement to appear (see illustration 4.6).

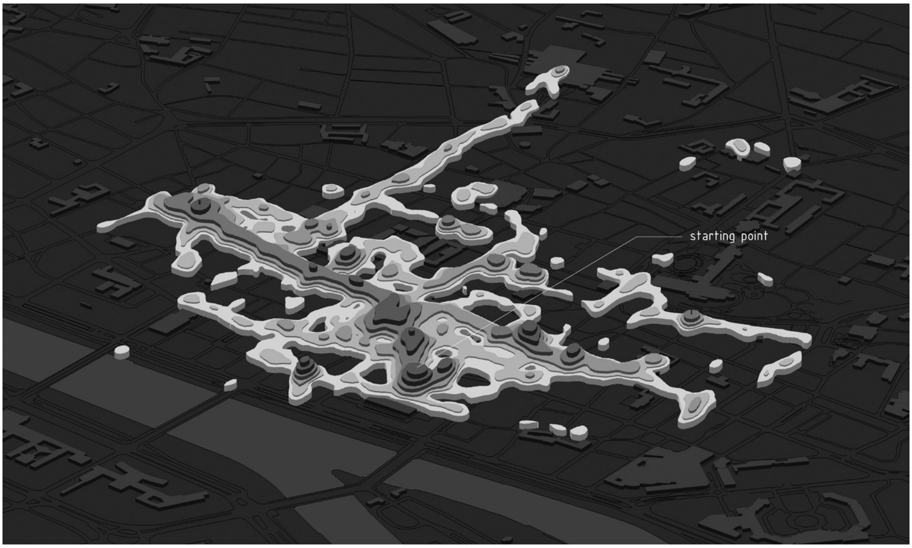
MAPPING DENSITY

By simply mapping the locations of features on areas with large amounts of tracking data, it is often difficult to see which areas have a higher concentration or intensity than others (see **illustration 4.6**). In other words, it is hard to derive patterns in this way at very fine levels of granularity, which is a key objective of the research. For this reason, density maps of the projected tracking data are created within GIS. Density shows the location of the highest concentration of features, and is particularly useful for looking at patterns rather than the location of individual features and for mapping areas of different sizes. It measures the number of features using a uniform real unit (such as a hectare or square mile), allowing distribution and magnitude to be easily distinguished.

In **illustrations 4.7** and **4.8**, tracking data is mapped using a density surface. A density surface is created in GIS as a raster layer. Each cell in the layer acquires a density value (such as number of pedestrians per hectares [6]) based on the total number of features within the specified radius of the cell divided by the area. This creates a running average of features per area, giving a smoothed, continuous surface (McCoy & Johnston, 2002; Mitchell, 1999). Several parameters will affect the way in which the GIS calculates the density surface, and thus what the patterns will look like. These include cell size, search radius, calculation method, and units. The cell size determines how coarse or fine the patterns will appear; the smaller the cell size, the smoother the surface. Generally, the larger the search radius, the more generalised the patterns in the density surface will be. The density surface is calculated by using a (weighted) kernel calculation, which gives more importance to features closer to the centre of the cell. The result is a more equal distribution of values.

In the density surface for commuters, we see a north-south oriented time-space pattern appearing (see **illustration 4.7**). Starting point is the parking area at Place de la Haute (Rue Saint-Denis), where handheld GPS devices were provided. From there, the commuters walked via the Rue de l'Epicerie along the Cathedral Notre-Dame to probable working destinations such as the Palais des Congres, or further northward via the Rue du Bec to the Palais de Justice or the Espaces Du Palais along the Rue St. Lô. High densities of commuters were also apparent at the Rue Jeanne d'Arc. In order to validate these conclusions, it is important to compare the results with the corresponding questionnaires commuters completed. A number of additional conclusions can be found in Spek (2008). However, for these commuters, the car park and their place of work were the most important sites. As seen on the map, commuters can be easily recognized by their patterns of movement, which are typically fast and short. A quite different pattern appeared for tourists with a more widespread distribution. For this group, a more or less northwest-southeast oriented movement pattern can be distinguished (see **illustration 4.8**). This pattern visualises the distribution and number of tourists and correlates with the most beautiful scenery and main attractions of the city. From the starting point at Place de la Haute, the tourists walked via the Place de la Calende to the Notre Dame. From there, most of them took the Rue du Gros-Horloge and Le Cros Horloge to Place du Vieux with the Jeanne d'Arc memorial as their end point. Moving back to the cathedral, slightly north toward the Rue du Gros, high concentrations of tourists are also evident near the Palais des Congres and the Galerie de l'Espace du Palais. From the cathedral to the east, the highest densities are to be found at the Rue Saint-Romain and Rue de Martainville, with the old cityscape and the Church of St. Maclou.

Illustration 4.9
Three-dimensional view of space-time patterns of tourists



To derive patterns from a calculation, the density-surface is usually displayed in a two-dimensional (2-D) view using graduated colours with a random or custom classification [7]. However, a three-dimensional (3-D) perspective can improve the readability of the map and increase the possibility of drawing conclusions from it. The height of the feature indicates the size of the location or area (see **illustration 4.9**). Patterns of density derived from GPS data can provide insight into the use of space and time. For line features, density shows patterns in space or the intensity of use. This addresses the question of the number of people using the path. For point-features, density represents patterns of time, or intensity of 'non-movement' (duration). This addresses the question of how long people stay.

CONCLUSION

The Spatial Metro project proves that the linking up of GPS and GIS is a powerful instrument for analysing pedestrian movement behaviour and exploring space-time activity patterns. Among other things, the concepts of mapping *movement* and *density* are addressed as fundamental GIS tools used for the delineation and analysis of spatial data in order to explore spatial patterns and relationships. By applying these concepts in the *pedestrian movement behaviour analysis,* we can show patterns of lines which represent patterns of *movement* in space. Density surfaces show patterns of *intensity* and *duration* in space and time. Beside these methods of analysis, overlay techniques and operations constitute one of the most useful functions of GIS. This overlay operation allows new information to be derived that does not exist in any 'single layer'. It can provide insights into spatial relationships, e.g. spatial correlations of large numbers of pedestrians and specific locations or attractions. Also, *non-spatial attribute database queries* are useful for (spatial) measurements and statistics, and allow quantifying specific patterns and relationships. Through this kind of analysis, we can comprehend and monitor pedestrian behaviour in city centres. In addition, design opportunities and solutions for spatial problems in the urban environment can be revealed by descriptive and comparative analyses of geographic locations, spatial patterns, and the distribution of features or events across an urban landscape.

Like other professional software, GIS software is very helpful, but not generally easy to use. Software developers are making great efforts to improve the user interface of GIS software, but still have a long way to go. There is a great deal of prejudice with regard to GIS. In order to convince (future) planners and designers that GIS is indeed a powerful tool for representation, analysis and modelling, it is necessary to persuade them by showing them examples of the broad range of possible applications, thereby pointing out the added value. GIS must also be an integral part of education in planning and design. Experience has shown that an intuitive, practical approach based on the philosophy of "learning by doing" is most effective in this sense, and has to be strongly interwoven with an assignment in planning or design.

Due to the introductory nature of this chapter, the emphasis has been placed on the just view applications of GIS in urban research, and various other methods and techniques still have to be explored and developed. It is clear however that GIS is a helpful instrument for urban planning and design and offers a platform on which these complex spatial environments can be dealt with and represented, analysed and modelled. Professional vocabulary can thereby be expanded and new approaches and instruments added to the toolbox to create sustainable and appreciated urban space. GIS moreover generates new insights through advanced spatial analysis and helps to increase efficiency and flexibility in the planning process.

ACKNOWLEDGEMENTS

I would like to acknowledge Stefan van der Spek for his valuable comments and remarks on this topic. The GPS tracking data was used by courtesy of the *Urbanism on Track* research group of Delft University of Technology. The digitised plan of the city of Rouen was used by courtesy of the Municipality of Rouen. This study was supported by the research programme *Landscape Research Methods* at the Chair of Landscape Architecture and the *U-LAB: Urbanism Laboratory for Cities and Regions* of Delft University of Technology.

NOTES

1 Worlds leading off-the-shelf GIS-software developer.

2 The used GIS-software is ESRI ARC-INFO 9.2 with the Data Interoperability extension.

3 With or without a specific time-interval. In this research we use tracking data with a time-interval of 5 seconds, so it is possible to calculate on speed, etc (the farther apart the locations, the more rapid the movement).

4 For application in ArcGIS the Tracking analyst extension is needed.

5 Some information is added automatically by the GPS (e.g. time), other information derived from the questionnaires and is added manually in the database (e.g. purpose, mode of transportation).

6 For lines, the density is based on the length per unit area. For example, the total meters of logging lines of movement per hectare.

7 Common classification schemes are: Natural breaks, Quantile, Equal interval and Standard deviation.

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