CHAPTER THREE
Wayfinding, Spatial Information and Interactions

As discussed in Chapter 2, the development of new information and communication technologies has had profound effects on many aspects of our post-modern society. From the perspective of the research being presented here, technologies such as the World Wide Web (WWW) and mobile phones have mediated the ways in which spatial information is being delivered to the individual. This in turn is likely to impact upon the ways in which people are able to access spatial information in real-time and whilst on the move. Thus, services such as LBS for wayfinding, delivered to location-aware mobile devices with a more individual focus, are now a real possibility. These developments are pertinent to the study of people's spatial abilities, and the ways in which they acquire and develop spatial knowledge. In addition the interaction between people and the environment during wayfinding now needs to be understood in conjunction with this further technological dimension.

This Chapter presents the literature review on human wayfinding and its constituent aspects, spatial acuity, spatial knowledge, methods of measuring spatial ability and spatial knowledge acquisition, and human-environment interaction. The research in these areas comes from different research disciplines, principally psychology and geography. However, rather than take a strictly disciplinary approach to the review, the discussion is organised thematically. In the penultimate Section, a GIScience perspective is presented.

3.1 Human wayfinding

Wayfinding is one of the basic spatial activities which people frequently experience when they interact with environments. The term 'wayfinding' can be regarded as the process in which paths/routes are identified, determined and followed between an origin and a destination (Bovy and Stern, 1990; Golledge, 1999). Wayfinding is differentiated from navigation as being different types of activities, although these two words have been used indistinguishably in some papers. Navigation is formally defined as to "manage or direct the course of (a ship, aircraft etc.)" (Fowler and Fowler, 1995), whilst it can colloquially mean to walk or make one's way deliberately through some place and is often referred to as "the science of locating position and plotting a course for ships and aircraft" (Golledge, 1999). Wayfinding is described as purposive and motivated movement towards a specific and distant destination that cannot be seen directly by the traveller (Heft, 1983; Garling *et al.*, 1984;

Blades 1991; Golledge, 1992). In this thesis, the term 'wayfinding' is used for the process just described. Downs and Stea (1973) define four stages in wayfinding activity, which are:

- orientation to determine self-location and estimated target-location;
- initial route choice in selecting routes from origin to target-location;
- route monitoring, that is, checking the route taken by estimates of self-location and target-location as well as reassessing / confirming the route choice;
- recognition of the target.

Golledge (1999) has subsequently suggested what necessitates successful wayfinding tasks:

- identifying origin and destination;
- determining turn angles;
- identifying segment lengths and directions of movement;
- recognising routes and distant landmarks; and
- embedding the routes taken into a larger reference frame.

There are three general types of wayfinding tasks which can be categorised according to their functional goals (Allen, 1999a). The commute type of wayfinding concerns travel between a known origin and a known destination along familiar routes, such as a commuter's daily travel to work. This type of wayfinding activity usually has low uncertainty and involves a high-level of routinised behaviour. The exploratory type of wayfinding considers the activity of exploring a surrounding environment starting from a familiar origin and returning to a known destination (often the place of origin). In such wayfinding activities, people reconnoitre with the aim of discovering new places, routes and areas. There is a certain level of uncertainty involved in both the relation between current position to familiar places and the usefulness of the information received. Task-based wayfinding, which also refers to quest type of wayfinding, involves travelling to a novel destination from either a known origin or an unfamiliar place. During this type of wayfinding task, there is a higher level of uncertainty. There is likely to be a variation in the traveller's confidence in relating current position to final destination over the course of the task. Compared with exploratory type wayfinding, task-based wayfinding activities require higher levels of ability to comprehend all the information received. This last type of activity is often assisted by the provision of spatial information either in a symbolic form such as maps or in a description such as route instructions.

Wayfinding is interactive behaviour between people and their environments. The attributes of both people and their environments influence how and how well wayfinding is achieved (Allen, 1999b). Such interaction between people and environment is described by Tuan (1977) in a situation of getting lost, in the dark, during wayfinding:

> "Space is still organised in conformity with the sides of my body. There are the regions to my front and back, to my right and left, but they are not geared to external reference points and hence are quite useless. Front and back regions suddenly feel arbitrary, since I have no better reason to go forward than go back. Let a flickering light appear behind a distant clump of trees. I remain lost in the sense that I still do not know where I am in the forest but space has dramatically regained its structure. The flickering light has established a goal. As I move towards that goal, front and back, right and left, have resumed their meaning..."

Furthermore, wayfinding is viewed as entailing spatial problem solving processes for finding one's way to a destination, and consists of the three interdependent processes of decision making, decision execution and information processing (Arthur and Passini, 1992). During wayfinding activities, travellers are in a sequential process of decision making in which the purpose is to match internal with external information as it is obtained (Stern and Portugali, 1999). During wayfinding activities, the environment is a dynamic source of information used by travellers in their decision-making processes. Lynch (1960), in his seminal work, suggests that "there is a consistent use and organization of definite sensory cues from the external environment" during wayfinding. He emphasises the way that humans structure mental images of the city about landmarks, nodes, paths, edges, and districts. It is important to understand and know the external environment during wayfinding activities. However, there is a clear consensus that differences exist between the environments that people perceive subjectively and the objective reality, and the way people acquire, develop and use cognitive information for their wayfinding activities (Golledge, 1999). Cognitive information or cognitive maps are regarded as the internal representation of the structure, entities and relations of space (Hart and Moore, 1973), and are viewed as devices for simplifying and conceptualising the complexities of human-environment interactions (Walmsley *et al.*, 1990; Golledge and Stimson 1997).

Since wayfinding is purposive behaviour involving people and environment, another important aspect of wayfinding is the individual's spatial ability for carrying out such activities. Individual differences in spatial ability will have an effect on spatial knowledge acquisition during wayfinding and hence the success of wayfinding activities. Furthermore, human wayfinding is often assisted by external aids such as maps, some forms of instructions and devices. As discussed in Chapter 2, mobile devices have provided a new way to deliver spatial information which can be used for assisting wayfinding. Spatial information can be accessed, in multiple communication modes, with more individual emphasis. The following Sections will discuss these aspects in detail, focusing on spatial ability, spatial knowledge acquisition, human-environment interactions and spatial information which are particularly related to this research.

3.2 Spatial acuity

People move about and interact in space and places in daily life. Spatial information comes from direct sensory experience such as the senses of touch, balance, hearing and our own sense of movement as well as indirect conceptual experiences such as interpersonal and mass communication (Banz, 1975; Gold 1980; Berthoz *et al*., 1995). Spatial ability develops as one grows up and increasingly sophisticated spatial knowledge can be developed in the later stages of human development. The meaning which people attach to space and place is complex given the variety of human spatial abilities, environments and social-cultural backgrounds (Tuan, 1977). According to The Concise Oxford Dictionary (Fowler and Fowler, 1995), there are nine definitions of *space* as a noun and three more as a transitive verb. Space and place can be viewed as a semantic sequence as illustrated in Figure 3.1.

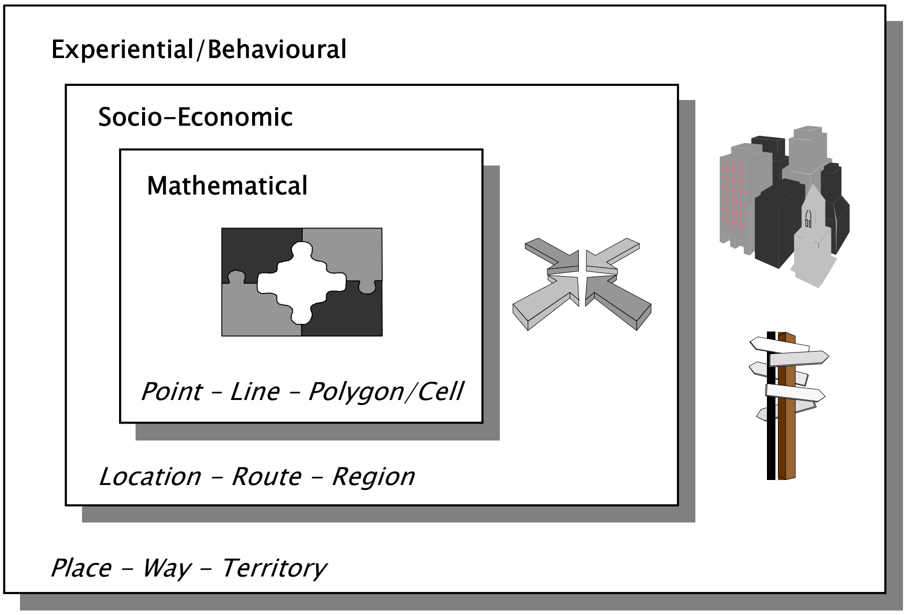

Figure 3.1 Semantic sequence of space and place (Brimicombe, 1999).

Space, when considered at its most objective, is a mathematical, physical space of co-ordinate geometry. The primitive elements, as used in GIS, are *point*, *line* and *polygon* or *cell*; and their spatial relations are a matter of topology. At a socio-economic level, the neutrality of objects in mathematical space is replaced by attributes of superiority or inferiority for some purpose (Brimicombe, 1999). Thus a location can be considered to have both site and situation resulting from the spatial relations that emerge between consumers, producers, labour and raw materials. At this level the primitive elements are translated into *locations*, *routes* and *regions*. Social and business interactions and transactions necessarily occur in some location or are communicated between locations. Finally, in the experiential/behavioural domain, the spatial primitives are further translated into *place*, *way* and *territory* through an infusion of human meaning. Here space and place are defined and mediated through human activity and the construction of meaning. The phrase 'environment' as used in this thesis encompasses this range of meanings of space and place. The term 'spatial acuity' as used here encompasses the whole gamut of spatial ability and people's innate sense of space and place.

3.2.1 Sense of space and place

Tuan's (1977) seminal work on space and place refers to space as abstract, openness, freedom, allowing movement in comparison with place as its identity, stability and familiarity. Space can be turned to place when people feel familiar with the space and endow it with value. Place can been viewed as a type of object. Human beings recognise and become familiar with particular objects, and attach feeling to them, such as the ways in which people learn about their neighbourhood through identifying street corners and particular landmarks within it. People develop strong psychological and emotional links to place (Relph, 1976). The bond between people and place has been termed 'topophilia' (Tuan, 1974). Space and place are schematised with particular and enduring things. "Space… allows movement, place is pause, each pause in movement makes it possible for location to be transformed into place" (Tuan, 1977). Movements are often directed toward, or repulsed by, object and places. Therefore, "space can be variously experienced as relative location of objects or places, as the distances and expanses that separate or link places and as the area defined by a network of places" (Tuan, 1977). Casey (2001) has restated this concept: "self, body and landscape address different dimensions of place in contrast to space".

Space can be viewed as three different types in the context of spatial cognition, including space of the body, space around the body and space of navigation, though all three appear to be used seamlessly (Tversky *et al.*, 1999). Tversky *et al.* (1999) point out that these three spaces are conceptually different and serve different functions as people interact with them. Thus, space of the body concerns the motions and feeling of our bodies, which are essential to our basic life and survival. Space around the body is one's immediate surroundings organised into a mental framework based on body axes. Space of navigation refers to environments schematised to nodes and links (representing landmarks and routes) and their spatial relations, though frequently from a specific perspective (Lynch, 1960; Kuiper, 1978). When the space of navigation is conceptualised as a two-dimensional map, the schematisation results in loss of detail thus permitting efficient memory storage, but the loss of detail also results in distortion.

The sense of space and place differs with the cultural background and living environments of people. Human groups vary widely in spatial skill and knowledge. Culture, within which human beings develop, strongly influences people's behaviour and values. This is suggested through research and empirical evidence. Studies show that the contrast in physical environments and the different social structures give people different senses of space and place, spatial awareness and knowledge (Berry, 1966; Gladwin, 1970; Lewis 1972; Hazen, 1983). However, there are also shared traits in human beings that transcend cultural particularities and may therefore reflect the general human condition. Some studies have pointed out the universal aspects of spatial cognition (Appelle, 1972; Shepard and Hurwitz, 1984; Wallace, 1989). Some argue that cultural commonalities are more significant in spatial cognition than the cultural differences, and many apparent differences are more likely caused by other factors (such as training, expertise and social classes) within cultures other than cultural differences (Montello, 1995). The evidence for substantial culture differences in spatial cognition are then suggested as showing the differences primarily between traditional and technologically developed culture rather than the differences that exist between cultures. Intuitively, we believe that the cultural differences exist and emerge. Current studies do not seem to prove how significant they are. Both the cultural commonalities and differences in the sense of space and place are widely recognised, however there remains the question of how substantial the influence of cultural difference is upon spatial knowledge acquisition.

Information environment and the 'invisible landscape' were considered to be important from as early as the 1960s and 1970s (e.g. Stea, 1967; Gould 1975). With rapid developments in computing, the Internet, World Wide Web and mobile wireless telecommunication technologies over the last two decades, a new kind of space is infusing into social, cultural and economic life. This new kind of space, referred to as cyberspace, has been discussed in the literature (e.g. Castells, 1989, 1996; Batty, 1990, 1993; Graham, 1998; Kitchin, 1998; Dodge and Kitchin, 2000). Cyberspace may evolve to become equally important as physical space and traditional notions of geographical space. The trend is towards cities becoming informational places, mediated through electronic networks (Castells, 1989; Batty, 1990, 1993). Three possible futures for the inter-relationship between geographical space and cyberspace are discussed by Graham, (1998):

- *Technological determinism*: this assumes that new telecommunications technologies will directly cause social and spatial changes in which distance effectively dies as a constraint on social, economic and cultural life. This would result in areal uniformity and urban dissolution into a global village. This theory has perhaps grossly over-estimated the extent to which aspatial networks might substitute for place-based or face-to-face interactions.

- *Co-evolution of geographical and electronic spaces*: this suggests that we will continue to have physical and localised existences. Computer networks are a predominantly metropolitan phenomenon developing out of the old cities allowing the social reconstruction of city spaces. Thus materially constructed urban spaces co-evolve with telecommunication networks and nodes. Space is becoming recast by the interaction of capital and technology.
- *Actor-network constructs of space*: there is not one single, unified cyberspace, but is a fragmented, divided multiplicity of heterogeneous infra-structures and actor-networks. Space is no longer an objective, invariant external container for place with space being continually reconstituted by the actors on the network. The experience of place can thus be both real and virtual - it becomes impossible to define space and place separately from technological networks.

The increasingly widespread usage of NICTs and the integration of NICTs into people's daily lives increase the types of interactions among individuals, technologies and environments (space and place). Such rapid development of NICTs is allowing new combinations of people, technologies and places which may lead to a dramatic change in the spatial organisation of activities within cities (Moss and Townsend, 2000). The characteristics of some activities in people's lives are being changed with the advent and diffusion of such technologies. Moss and Townsend (2000) identify the need to study the effects of new telecommunications and information technologies on commuting, home, work and public spaces. The 'CoolTown' project being carried out in HP Labs (U.S.A.) and 'Mobile Bristol' (U.K.), are aimed at establishing effective relationships between our physical world and an informational virtual world. The linkages created between them could perform "roles in augmenting their counterparts across the physical-virtual divide" (HP, 2001) to produce a mixed-reality. In this way, technology is changing traditional concepts of space and place.

3.2.2 Spatial ability

Individual differences in performing wayfinding tasks are generally considered to be related to people's spatial abilities. Spatial ability carries a variety of connotations from different perspectives and disciplines (Allen, 1999b). From a psychometric perspective, the studies carried out on people's spatial abilities focus on the ability to perceive, remember and mentally transform figure stimuli (McGee, 1979; Lohman, 1988). Visualisation, speeded rotation (spatial relations between objects) and spatial orientation are the three most widely used spatial factors, which mostly involve mentally manipulating shapes, solving mazes, and finding hidden figures. Some of these are described in the following paragraph. Spatial ability has also been studied from an information-processing perspective. This approach is driven by task analysis in general, that is, attempts are made to characterise cognitive processes in terms of a set of constituent parts. Thus the types of analyses include visualisation and mental rotation, as incorporated into psychometric tests, visual-spatial memory, mental imagery, and spatial perspective-taking and orientation (Allen, 1999b). Research in spatial ability from a developmental perspective covers a wide range of aspects, similar to the areas from the information processing perspective, with emphasis upon the development/improvement from early to late childhood. Another perspective for studying spatial ability is from neuropsychology which mainly concerns the correlation between cognitive or behavioural dysfunctions and specific neurological damage.

Three main dimensions of spatial ability have been suggested from a psychological perspective: spatial visualisation, spatial orientation and spatial relations (Self *et al.*, 1992; Golledge and Stimson, 1997). Spatial visualisation concerns the ability to mentally rotate, invert and manipulate visually presented 2D and/or 3D objects. It is widely applied to many studies and is regarded as an important factor in comprehending geometric structures. Psychometric paper-and-pencil tests have been used in most spatial visualisation studies. Some have employed this dimension to examine the differences in spatial ability between male and female (Masters and Sanders, 1993; Stumpf, 1993), whilst others have argued that a single such dimension cannot be used to account for over-all spatial ability (e.g. Self and Golledge, 1994).

Spatial orientation, as another dimension of spatial ability, relates to the ability to imagine the configurations of objects as they would appear from different perspectives. This ability involves distance and angle estimation and orientation-related pointing accuracy, which is viewed as being important in map reading and wayfinding. The third, spatial relations, dimension of spatial ability is less clearly defined and sometimes is not included in the dimension of spatial ability from a psychometric standpoint. It includes a wide range of elements, from abilities to recognise spatial pattern, layout, and connectivity, through to wayfinding ability in the real-world with regard to landmark cognition, shortcutting and orientation. There are limited studies and tests on these aspects from a psychology perspective.

Spatial ability can also be studied and identified according to its relation to a common function (Rosch and Mervis, 1975). Allen (1999b) divides different types of spatial ability into three groups: a stationary individual with manipulable objects; a stationary or mobile individual with moving objects; and a mobile individual with large stationary objects. In the first situation, the focus is upon the ability to recognise objects based upon their constituent features, and concerns the interactions between individuals as observers and objects which can be rotated, disassembled and manipulated visually and mentally. This type is very similar to the spatial visualisation dimension of spatial ability. The second type concerns the dynamic spatial skills required to estimate objects' velocities or trajectories, and concerns the spatial relations between individuals (stationary or moving) and moving objects. The third type of spatial ability concerns mobile individuals interacting with a surrounding environment consisting of large objects. This last type of spatial ability is more directly related to wayfinding activities. Differences between individuals in assimilating knowledge about a spatial layout may arise from differences in identifying and remembering environmental objects long enough to establish their spatial relations, together with the variable capability to create the spatial relations between objects and reference points. Furthermore, individual differences can also reflect knowledge and skills in communication of spatial information such as by cartographic, symbolic or linguistic means.

As discussed above, individuals differ in identifying environmental objects and learning spatial relation and layout. Thus, the contents of individual internal representations of external environments, often referred to as cognitive maps, would be different. Such differences would also exist in the process of cognitive mapping. Cognitive mapping is defined as a process consisting of a range of psychological transformations through which individuals acquire, store, recall and decode information relating to locations and attributes of spatial environments (Downs and Stea, 1973). Types of spatial knowledge and the ways in which they are acquired (see §3.3) might also reflect individual differences. On the other hand, the data acquired rather than the cognitive mapping processes may differentiate spatial learning between individuals (Allen, 1999b). Thus the way in which individuals understand the spatial information of the environment such as distance and direction might vary according to their processing speed, working memory capability and experiences.

Although psychometric testing has been used in many studies to measure spatial ability, a number of studies point out that the spatial abilities identified through such tests exhibit only a weak positive association with the performance of spatial tasks in geographic-scale spaces, such as real-world environments (Lorenz & Neisser, 1986; Bryant, 1991; Allen *et al.*, 1996;). Other studies that address variation in spatial ability are more focused on relating large-scale environment task performance such as map and route learning, to real-world wayfinding activities (Malinowski and Gillespie, 2001; Kato and Takeuchi, 2003). Spatial abilities in geographic-scale spaces involve spatial tasks such as wayfinding to unfamiliar destinations and learning the layout of a new environment. How well people recognise objects and scenes from a learnt environment, estimate route distance, retrace routes, identify pointing direction, and comprehend the layout of the environment have all been used to measure spatial ability (Evans, 1980; Gärling and Golledge, 1987; Spencer *et al.*, 1989). Another promising approach for predicting people's spatial ability in geographic-scale space has entailed use of self-reporting questionnaires. A number of studies have reported high correlations between such self-reported measures and environmental spatial task performance (Montello and Pick, 1993; Prestopnik and Roskos-Ewoldson, 2000; Sholl *et al.*, 2000). Other issues that have been included into this type of self-reported questionnaire have concerned general abilities such as judging distances, finding one's way and shortcuts, and map reading. Similar correlations between these self-reported measures and spatial task performance in geographic-scale environments are also found in several studies (Byant, 1982; Lorenz & Neisser, 1986; Hegarty *et al.*, 2002).

3.3 Spatial knowledge

Study of the nature of spatial knowledge and how spatial knowledge is acquired, developed and used gives insight and understanding into how people behave and navigate while they interact with the environment. It also provides insight into individual and group commonalities and differences in spatial ability. Furthermore, it provides better understanding of the use of spatial information for assisting people in performing spatial tasks.

3.3.1 A typology of spatial knowledge

Knowledge can be distinguished as two types: *codified* and *tacit*. "Knowledge is codifiable if it can be written down and transferred relatively easily to others. Tacit knowledge is often slow to acquire and much more difficult to transfer" (Longley *et al.*, 2001). Knowledge of space and place is both codifiable and tacit.

Spatial knowledge allows individuals to "create large and complex schemata that exceed by far what an individual can encompass through direct experience……That knowledge is transferable to another person through explicit instruction in words, with diagrams, and in general by showing how complex motion consists of parts that can be analysed or imitated" (Tuan, 1977). People's spatial knowledge structures are generally viewed as providing the basis for interpreting places in the environment. Spatial knowledge structures are a subset of an individual's knowledge of the environment. A knowledge structure, from the perspective of information processing, is also viewed as a set of symbolic structures representing certain aspects of an individual and the individual's environment (Golledge, 1987).

Spatial knowledge has been classified into different types in various research over the decades, including ego-centric and domi-centric knowledge (Trowbridge, 1913), strip map and comprehensive map knowledge (Tolman, 1943), and topological / projective / Euclidean knowledge (Piaget and Inhelder, 1956). The concepts of route and survey knowledge, and of landmark/route/configurational knowledge can been seen in the research of Shemyakin (1962) and Seigel and White (1975). Kuipers (1978, 1983a, 1983b) suggests sensorimotor, topological and metrical knowledge. Thorndyke and Hayes-Roth (1982) use procedural and survey knowledge. Stern and Leiser (1988) identify three levels of spatial knowledge in landmark, route and survey knowledge. Golledge and Stimson (1987; 1997) contend that spatial knowledge comprises three basic components including declarative component, relational/configurational component and procedural knowledge.

Although different types of spatial knowledge have been defined, they are each in turn generally deemed to fall within one of the following categories:

- *Declarative knowledge*: this type of knowledge refers to those objects and/or places with meaning or significance attached to them (Golledge *et al.* 1987). It is also referred to as landmark knowledge, frames of reference (Minsky, 1975; Kuipers, 1978) or cue knowledge.
- *Procedural knowledge*: this concerns understanding of the process of how to travel or find one's way from one locality to another, and can also be defined as route knowledge. Route knowledge typically refers to knowledge about movements and mostly consists of procedural descriptions, some landmarks and path elements.
- *Configurational knowledge*: This generally refers to the integrated knowledge of the layout of a space and the interrelationship of the elements within it, and people's ability to traverse in complex configurations of paths and nodes within some external frame of reference. This knowledge is considered to comprise not only visual and geometric, relational, perceptive and descriptive information, but also spatial relations. Survey knowledge, relational knowledge and metric knowledge are generally deemed to be in this category. Configurational or relational knowledge, in particular, refers to knowledge about spatial relationships between objects or places, and allows people to develop other knowledge structures including hierarchical networks and 'chunking' of knowledge (Golledge *et al.* 1997). Configurational knowledge has been defined as comprising of several characteristics as follows (Golledge *et al.*, 1995):
    - sets of identifiable 'occurrences' of spatial phenomena, such as landmark knowledge and routes linking them;
    - knowledge of the spatial distribution of such 'occurrences';

- the spatial processes that facilitate the integration and understanding of phenomena;
- spatial contiguity and association;
- linkage and connectivity; and
- geographical regions and spatial hierarchies.

Knowledge relating to 'areal' information, denoted as map-like knowledge, has been defined separately from configurational / survey knowledge in some of the literature (Aitken and Prosser, 1990). Configurational knowledge refers to the concept of 'sense of direction' (Kozlowski and Bryant, 1977), while areal knowledge focuses more upon familiarity with places and routes in a neighbourhood. The exact distinction between configurational / survey knowledge and areal / map-like knowledge seems unclear in most of the literature. There does not yet appear to be a clear theoretical basis for separating configurational and areal knowledge, or for relating areal knowledge to the processing of landmark, route and configurational information. However, Aitken and Prosser (1990) argue that areal knowledge provides people with different understanding about the environment from the configurational knowledge. This will be discussed in the next Section.

3.3.2 Spatial knowledge acquisition

People acquire and develop their spatial knowledge through various experiences and processes, which may include recognising and understanding the characteristics of objects, localities, the inter-relationship between elements in environments, and so on.

Shemyakin's Theory (Shemyakin, 1962) suggests that spatial knowledge can be acquired by a process of starting with landmark knowledge, progressing to route knowledge and finally to survey (configurational) knowledge. As knowledge accumulates, so its accuracy in terms of angularity, direction and proximity improves. According to Piaget and Inhelder's development theories (Piaget and Inhelder, 1967), spatial knowledge development progresses over the four phrases of a human life: the sensorimotor period covering infancy, the pre-operational period covering pre-school age, the concrete operational period covering middle childhood and the formal operational period covering the age from adolescence onwards. An individual proceeds from an egocentric pre-representational space, to topological, projective and finally to a Euclidean metric relational structure through these development phrases. Stern and Leiser (1988) further contend that spatial knowledge progresses from landmark knowledge to route knowledge and then to survey (configurational) knowledge through accumulated direct navigation experience and/or map learning at different stages.

Siegel and White (1975) suggest that the process of spatial knowledge acquisition comprises recognising landmarks, finding routes connecting the salient landmarks, and then developing a complex and general configurational survey representation. Thus spatial knowledge acquisition begins with landmarks and develops into route knowledge by the process of joining up the landmarks. This route knowledge progresses from being topological to metric. Groups of landmarks and routes are then organised into clusters based on the metric relationships within them. The topological relationships remained between clusters. In the final stage, a co-ordinating frame of reference develops and thus results in survey (configurational) knowledge. Kuiper (1978) also contends that knowledge of an external environment is hierarchically organised with landmarks, routes and configurations into a coherent structure organised around the relative location of landmarks. The anchorpoint theory of Golledge (1978) is similar, with a hierarchical ordering of locations, paths and areas. He suggests that some locations become primary nodes or anchorpoints from which a skeletal structure develops as spatial knowledge develops outwards from these nodes. Through this spread effect, survey (configurational) knowledge develops.

Over the years, a considerable body of literature (e.g. Kaplan and Kaplan 1982; Thorndyke and Hayes-Roth 1982; Smith *et al.*, 1982; Golledge et al. 1985; Stern and Leiser, 1988) has demonstrated that there is a progression from declarative to procedural and from procedural to configurational knowledge. Using an alternative terminology, there is a progression from landmark to route and from route to survey knowledge. This progression leads to an increasingly complex cognitive representation. Moreover, configurational knowledge of spatial pattern and of spatial relations depends upon integrating landmark and route knowledge into configurational knowledge within some frame of reference. Some studies suggest that route knowledge is acquired by 'chunking' information spatially by splitting routes into segments (Pellegrino *et. al.*, 1987; Gibson *et al.*, 1989). However, Aitken and Prosser's (1990) study suggests that the acquisition of survey (configurational) knowledge is not always sufficient for areal knowledge, as areal knowledge includes propositions and facts in addition to the knowledge necessary to traverse an area. Aitken and Prosser provide evidence that areal knowledge gives individuals better understanding both on cardinal directionality and some non-cardinal features. They argue that knowledge of a complex network may not be enough to provide an areal knowledge structure, and that as a consequence there may be no direct sequential relationship between linear- and areal-based knowledge. They conclude that theories of spatial knowledge acquisition and the relationship between linear knowledge and areal knowledge are still in need of more research despite some weighty studies that have developed some understanding of the transition between landmark and linear knowledge.

Furthermore, Montello (1989) suggests that metric knowledge, such as survey (configurational) knowledge, is acquired and accumulated from the beginning of exposure to the environment. He also contends that non-metric knowledge, such as landmark and route knowledge, is not necessarily a precursor to configurational knowledge and may exist concurrently with metric knowledge. Thus, the non-metric and relatively pure topological knowledge is described as being used in linguistic systems for storing and communicating spatial knowledge about places. Acquiring spatial knowledge in large-scale environments is, therefore, regarded as the quantitative accumulation and consequent refinement of metric information instead of a qualitative change from non-metric to metric knowledge. However, there is some doubt as to the degree to which spatial knowledge is itself qualitative or quantitative (Egenhofer, 1991; Frank, 1992; Mark, 1993).

In the above theories of spatial knowledge acquisition, one has to further consider whether such knowledge is obtained via direct experience or is acquired indirectly. 'Direct' experience is usually taken to refer to that gained through activities in a real environment, while 'indirect' and 'conceptual' experience relates to that gained through assimilating simplified and symbolised representations rather than from exposure to real environments. Direct experience can also refer to active learning modes, in which people view or experience an environment via perceptual focusing, head and body movement (Presson and Hazelrigg, 1984). Indirect experience can be referred to as a passive learning mode, mostly involving only one mode at a time such as vision without direct contact with the environment. From the perspective of spatial knowledge acquisition, direct experiences include route-based learning in a spatial environment and indirect experiences include map study and verbal instructions. Internet or mobile device approaches (such as www.streetmap.co.uk and www.mapquest.com) can be deemed as indirect experiences. Spatial knowledge can also be acquired through VR environments that are structured so as to simulate real environments (see Chapter 4). The indirect experiences referred to in most of the spatial knowledge acquisition literature are experiences of acquiring survey knowledge such as through map reading. Some authors have pointed out that the spatial knowledge acquired in this way is usually assumed to be the most advanced level of spatial knowledge (Shemyakin, 1962; Hart and Moore, 1973).

A number of studies (Thorndyke and Hayes-Roth, 1982; Moeser, 1988; Lloyds, 1989; Giraudo and Pailhous, 1994; Taylor and Tversky, 1996) provide evidence that spatial knowledge acquired through direct experiences provides a better understanding of route distance estimates and route knowledge, while that acquired through indirect experiences (e.g. map learning) facilitate better Euclidean distance and object judgements. In performing object location tasks, people with direct wayfinding experience have to transform route knowledge into survey (configurational) knowledge and complete the task with less accuracy and longer time than those with conceptual map-reading experience. Also, the ability for object location has shown little improvement after repeating the task for those with direct experience. Moreover, for those acquiring spatial knowledge through a map, their verbal descriptions of the environment can be from either a route or survey perspective. On the other hand, those acquiring spatial knowledge through direct wayfinding experience in an environment are more likely to provide route-oriented descriptions. The study by Golledge, Dougherty and Bell (1995) further suggests that people's knowledge acquired via map learning is better than that via direct route learning in understanding spatial relations and suggests that people who are new to an environment will acquire more spatial knowledge if they learn from maps. It is commonly accepted that people acquire better survey (configurational) knowledge through indirect / conceptual experience, particularly through map study, and acquire better route knowledge through direct experience of wayfinding in real environments. However, while Thorndyke and Hayes-Roth (1982) show evidence that reasonably accurate survey knowledge of an environment can be achieved after a long time of repeated direct experiences, Moeser (1988) finds no evidence for accurate survey (configurational) knowledge acquired through direct experience. This raises the question as to whether direct experience invariably leads to survey (configurational) knowledge or whether this outcome depends upon the complexity of the environment.

Another difference existing between the spatial knowledge derived from direct experience and that of indirect experiences concerns orientation specificity effects. Orientation specificity means that the knowledge concerning spatial objects and their layout is strongly associated with a specific orientation. For example, some people who use maps for wayfinding in an environment are likely to associate 'up' on the map with proceeding forward (Shepard and Hurwitz, 1984). Orientation-free, therefore, means that there is no particular orientation attached to people's understanding of their surrounding environment. A number of studies have shown that orientation specificity for map acquired knowledge is a persistent phenomenon (Evans and Pezdek, 1980, Presson and Hazelrigg, 1984; MacEachren, 1992). Evans and Pezdek (1980) also suggest that there is little orientation specificity in the spatial knowledge derived from direct experience.

Pazzaglia and Beni (2001), from a different angle, tested individuals and were able to differentiate between spatial knowledge acquired as isolated landmarks and knowledge acquired from landmarks within route connectivity. They refer to the former as landmark-centred representations, which contain landmarks but lack the routes connecting them. Individuals with landmark-centred and survey-centred representations have different strategies for acquiring and processing spatial information, with survey-centred individuals leading to a spatial-holistic strategy. Their findings also show that landmark-centred individuals made fewer errors than survey-centred individuals in verbal description conditions.

VR experience, as a means of environmental exposure, has some considerable shared common characteristics with direct experience, despite subtle differences. A number of studies provide evidence of connections between direct experience and VR environment experience. For example, spatial knowledge acquired through direct and VR experiences are both shown to be orientation-free when compared with map learning experience (Tlauka and Wilson, 1996). Studies also point out that people who acquire spatial knowledge in virtual reality often have similar capabilities to those who acquire it via direct experience: however, while they can demonstrate extensive and accurate route knowledge, they have less well developed survey knowledge (Witmer *et al.*, 1996; Wilson, 1997; Ruddle *et al.*, 1997). Other studies show evidence that survey knowledge may be acquired more quickly using VR environments. It needs to be noted that the differences amongst various VR systems are likely to provide different levels of realism and active involvement with the environment. This will be discussed in detail in Chapter 4.

Figure 3.2 illustrates the prevailing consensus on the different types of spatial knowledge and their associated characteristics, as summarised from the literature.

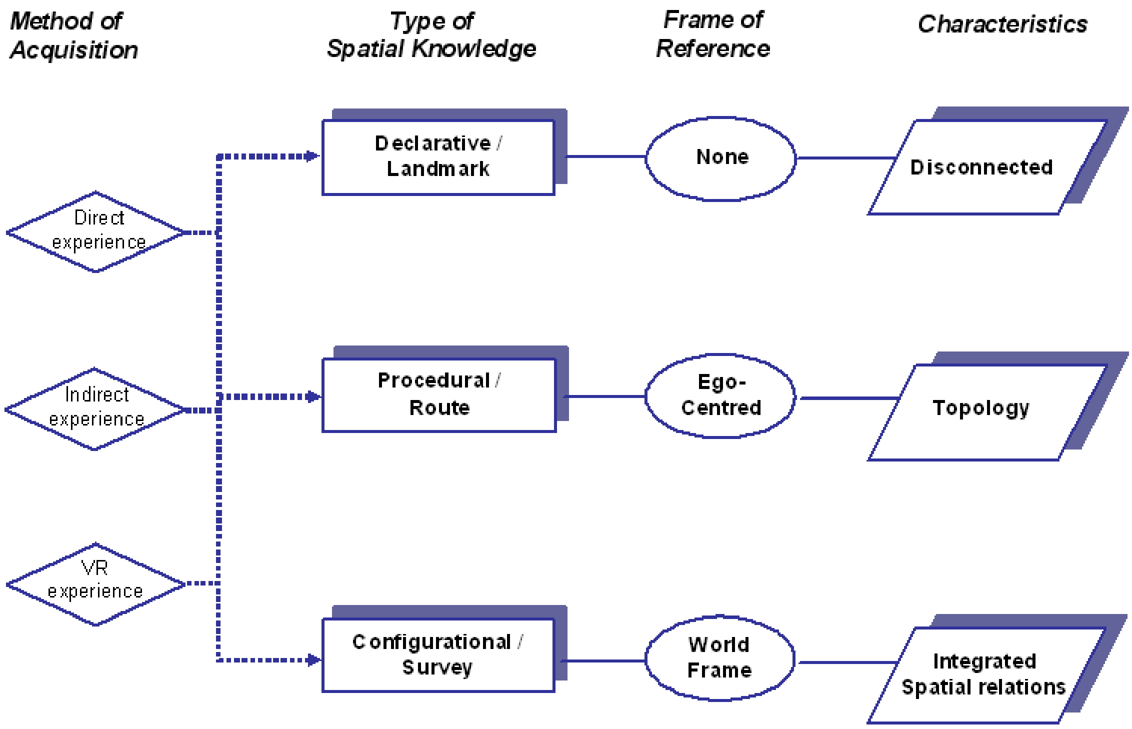

Figure 3.2 An overview of the nature of spatial knowledge, its reference frames and salient characteristics.

3.4 Methods for examining people's spatial ability and spatial knowledge acquisition

A range of tests are widely used in the literature for examining and measuring people's spatial ability and spatial knowledge acquisition (Shepard and Metzler, 1971; Gould, 1975; Thorndyke and Hayes-Roth, 1982; Lloyd, 1989; Silverman and Eals, 1992; Golledge *et al.*, 1995; Montello et al., 1999; Rossano *et al.*, 1999). In this Section, some of the commonly used methods are discussed.

The spatial ability of individuals is often measured from a psychometric perspective (see §3.2.2). Various psychometric tests can be used to indicate an individual's mental ability at handling spatial objects, including mental rotation in three dimensions, orientation, two-dimensional or flat rotation, embedded figures and figural reasoning. One of the examples is the Minnesota Paper Form Board (Likert and Quasha, 1941) which tests participants' decisions as to which of five 2D line-drawings of shapes can be made out of a set of fragmented parts. There are also the Hidden Patterns and Card Rotations developed by French *et al.* (1963), Shepard and Metzler's (1971) Mental Rotation task and the Vandenberg Mental Rotation Test that uses three-dimensional objects (Vandenberg and Kuse 1978).

These tests measure both 'visualisation' and 'orientation' dimensions, static and dynamic spatial ability, two-dimensional and three-dimensional spaces. Previous experience might however influence performance.

A different approach entails the use of questionnaires to provide indications of individual spatial ability, particular with respect to ability in performing spatial tasks in geographic-scale spaces, as discussed in §3.2.2. Questionnaires, often in self-reported styles, can be applied to reveal people's sense of direction, spatial aptitude, spatial preferences and spatial anxieties (Kozlowski and Bryant, 1977; Lorenz & Neisser, 1986; Hegarty *et al.*, 2002). They can also indicate some level of understanding of the individual's spatial thinking (e.g. tend to have landmark or route oriented thinking) and spatial ability (Pazzaglia and Beni, 2001). In addition, questionnaires can be designed to measure people's knowledge about local, national and international places and locations which they know from direct experience or indirect sources such as maps. People's backgrounds, previous knowledge of areas and familiarity in usage of any technologies can be also revealed.

People's knowledge of directions and distances between locations are often measured to indicate how well and accurately people acquire spatial knowledge of an environment. Distance estimation between locations can be achieved through various methods, such as psychophysical ratio scaling, psychophysical interval and ordinal scaling, mapping, reproduction and route choice such as choosing shortest route tasks (Montello, 1991). Direction estimations can be carried out by estimating the direction between two locations in the environment, or by pointing to the direction of one location from another. People are either required to imagine both their location and facing direction in the simulated direction test, or to give directions from within the environment itself in the actual direction test. Distance and direction estimation methods have been used in many forms; however, the validity and reliability of these measurements still needs to be researched (Kitchin and Blades, 2002).

There are various methods for assessing integrated understanding of an environment and the interrelationships between the elements within it. One of these is configuration tests which require participants to arrange objects or locations in the correct spatial relations according to the environment they represent. For instance, people can be required to place a location in relation to others along a route (Thorndyke and Hayes-Roth, 1982). As another example, people are asked to place building objects on a campus plan according to their understanding of the actual arrangement in the real-world (Rossano *et al.*, 1999).

Map sketching is another commonly used method to measure to what degree and what type of spatial knowledge is acquired by people (e.g. Milgram and Jodolet, 1976). It requires participants to sketch routes or maps on paper showing landmark locations, estimated distances, directions, interrelationships and other details after themselves directly undertaking activities in a given environment or gaining indirect conceptual experience of an environment. The content of such measurements can include route reproduction, cue location, distance estimation, orientation and directional tests. The outcome of this method could be influenced by individuals' skill and applied effort in sketching maps.

Completing a wayfinding task in a given environment is another method used in research for assessing people's spatial ability and spatial knowledge gained through experience of the environment. Various tasks are assigned to participants to carry out in real environments, such as walking about and completing tasks in buildings, on campuses and in other environments (e.g. Thorndyke and Hayes-Roth, 1982; Malinowski and Gillespie, 2001). The environment for performing tasks can also be a VR environment, that is, a reality simulated by computer systems. Participants are asked to perform required tasks in these simulated environments (Ruddle *et al.*, 1997; Sandstrom *et al.*, 1998; Steck and Mallot, 2000). Wayfinding performance can be measured by the tasks accomplished (e.g. finding destinations), the time needed and (virtual) distance travelled. The methods discussed in previous paragraphs are also used in conjunction with the wayfinding task performance.

Finally, in order to assess the spatial knowledge gained from map learning, participants may be required to study a map of a given environment and then draw a sketch map including its landmark locations, distances and so on. They may also be asked to provide a verbal description of the route as if they were instructing someone how to follow that route by giving them the most useful information, after having had direct experience of that environment.

3.5 Human-environment interactions

As discussed in the previous Sections, the acquisition of spatial knowledge and performance of spatial tasks such as wayfinding involve interactions between people and their environments.

> "It is commonly agreed in behavioural geography that the acquisition of environmental information, and the use of that information in some form of decision-making process, serves as a prelude to overt or 'acted out' behaviour. In many cases, however, the processing and evaluation of environmental information does not influence overt behaviour and human activities directly. Rather these processes operate to change how

> the mind construes the environment, very much in the way proposed in the transactional-constructivist approach to environmental awareness. Thus it is the changed mental construction of the environment that most immediately influences overt behaviour." (Walmsley and Lewis, 1984)

Within the literature there has been considerable research to conceptualize these processes of interaction with the environment and the role of cognitive maps in determining spatial behaviour (Kitchin and Blades, 2002). A wide range of conceptual models have been developed over the years. These have been extensively reviewed by Kitchin (1996) and Kitchin and Blades (2002). This Section does not aim to cover all of these models, but to demonstrate the general concepts embodied in these different conceptual models.

The model established by Kirk (1963) is widely recognised to have introduced the behavioural environment of the decision-maker as separate from the objective environment of the physical world (Figure 3.3). In his model the decision-maker is embedded in a world of physical fact and a world of economic and social facts. The behavioural environment is the basis for rational human behaviour. The behavioural environment is the "psycho-physical field in which phenomenal facts are arranged into patterns or structures and acquire values in cultural contexts" (Kirk, 1963). However, this model has been criticised by its failure to accommodate individual idiosyncrasies.

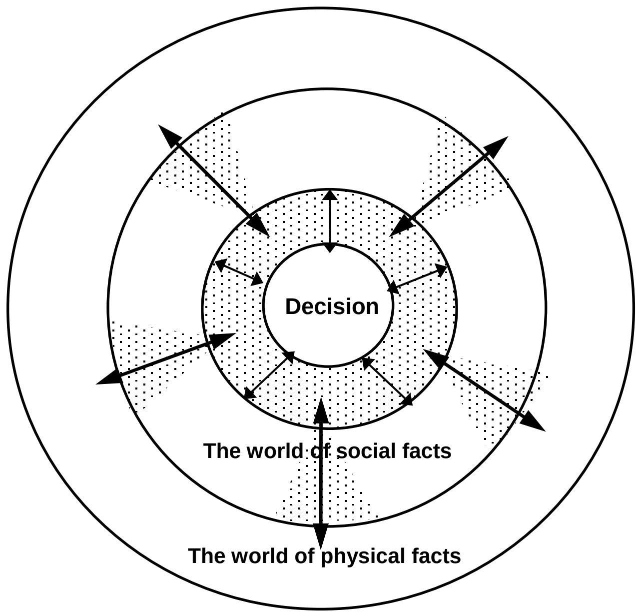

Figure 3.3 Model of behavioural environment of the decision-maker (Source: Kirk, 1963).

Another conceptual model is Downs' (1970) environmental perception and behaviour schema, in which the dynamic process between individuals and environments is emphasised through receiving information and decision-making (Figure 3.4). In this schema individuals derive information about an environment through perception and evaluate this information through their own value system and then arrive at a cognitive image. The cognitive map knowledge is, therefore, continually updated by the flow of new information in order to inform decision-making. The decision might lead to a search for new information from the real-world and start the whole process again until sufficient information has been acquired. Overt behaviour then follows the decision. Although individuals play an important role in this schema, they are still largely regarded as passive receivers and processors of information in the model. Based on Downs' model, Lloyd (1976) and Pacione (1978) add further elements into their models with more emphasis on selecting and processing information by individuals.

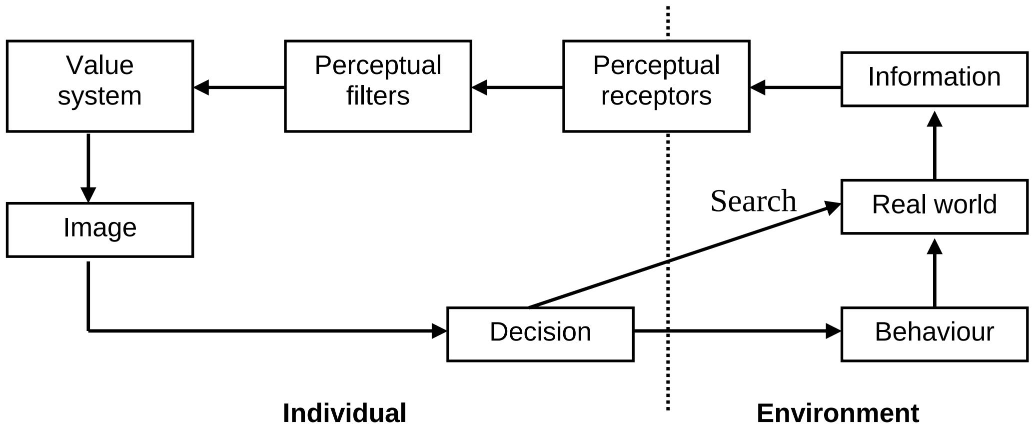

Figure 3.4 Environmental perception and behaviour schema (Source: Downs, 1970).

A more developed model is proposed by Pocock (1973). This model consists of three parts, showing how a perceiver interacts with an environment and processes information to create a cognitive map of that environment (Figure 3.5). The environment includes current context, actual environment and previous information. Individuals' psychological, physiological, and cultural backgrounds interact with their current states in order to determine how they get information from the environment and how it contributes to the development of an environmental image. In this model, individuals are not just regarded as passive receivers but have a more active role in selecting and processing information. Their responses, in this model, also have a feedback on both the environment and the perceiver. Another more complex conceptual framework, developed by Gold (1980) and refined by Golledge and Stimson (1987, 1997), suggests that the individual is part of the objective environment as well as a behavioural environment. Decisions are then made by individuals based on the information received from the behavioural environment.

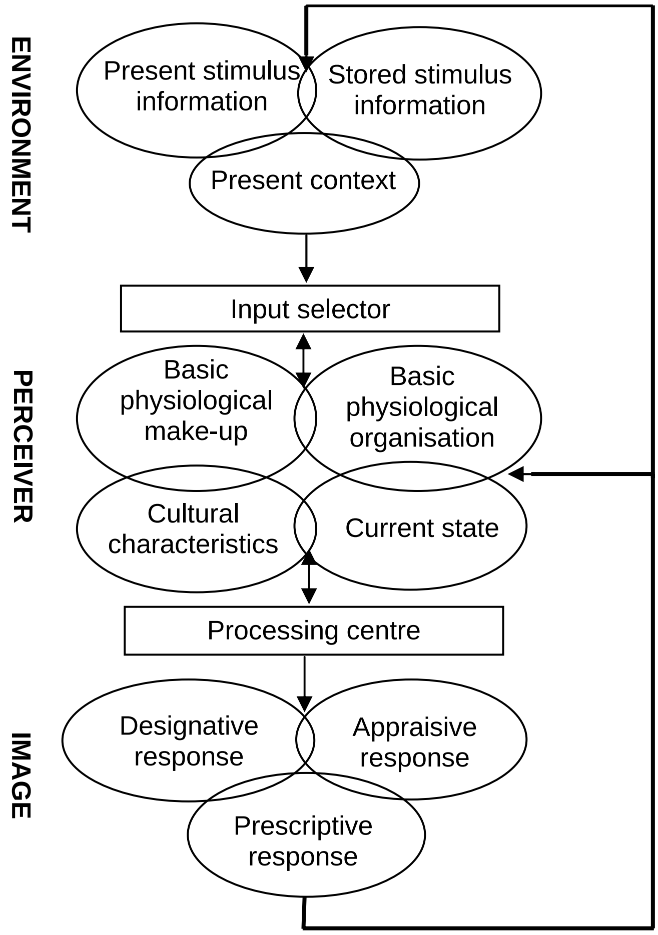

Figure 3.5 Pocock's (1973) model for interactions between environment and individuals.

Different from the sequential models above, Neisser (1976) proposes a schema with an active information-seeking structure (Figure 3.6). In this schema all elements are synchronous rather than temporally successive. Individuals actively and selectively search the environment to gain information. In other words, individuals select the relevant information discriminately and actively for their needs. Furthermore, one schema can be embedded within another, and several of them can be active simultaneously in a cyclic interaction with the environment.

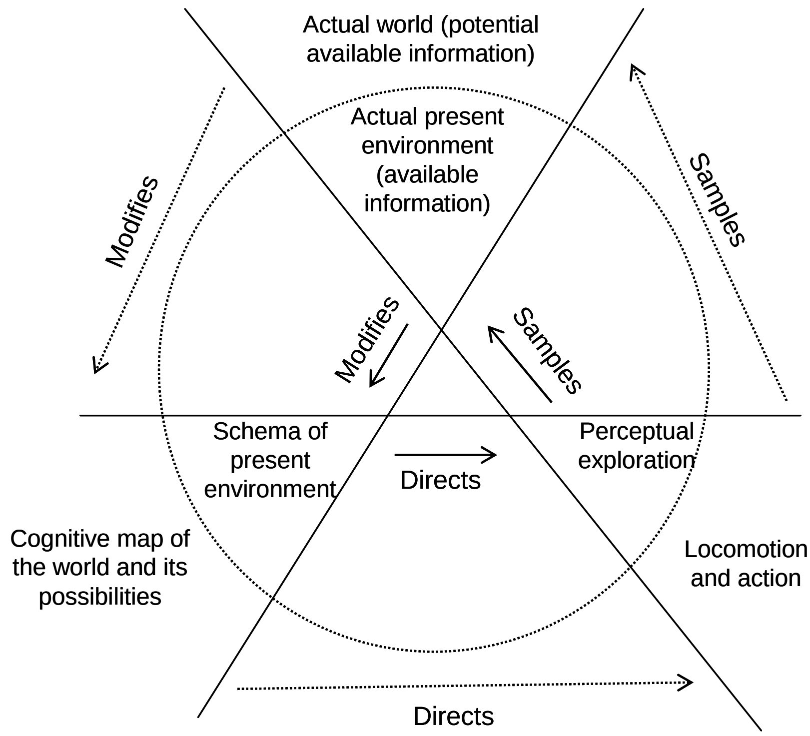

Figure 3.6 A schema for individuals interacting with the environment (Source: Neisser, 1976).

An integrated conceptual schema is proposed by Kitchin (1996), which comprises three sections as illustrated in Figure 3.7. The first section, the 'real-world' section, is the environment acting as primary environmental interaction sources and secondary social interaction sources. Individuals interact with this environment which influences the development of the cognitive map and individuals' spatial decisions. The 'working memory' section represents the effect of personality and character upon the process of conscious and unconscious thinking, and includes senses filters and such factors as beliefs, needs, emotions, values, personality, preferences and desires, all of which will influence any decisions made. The third section, 'long term memory', illustrates how our knowledge is stored and accessed in the memory, which contains an events store and an information store. All sections in the model are embedded rather than successive, and the whole system is dynamic.

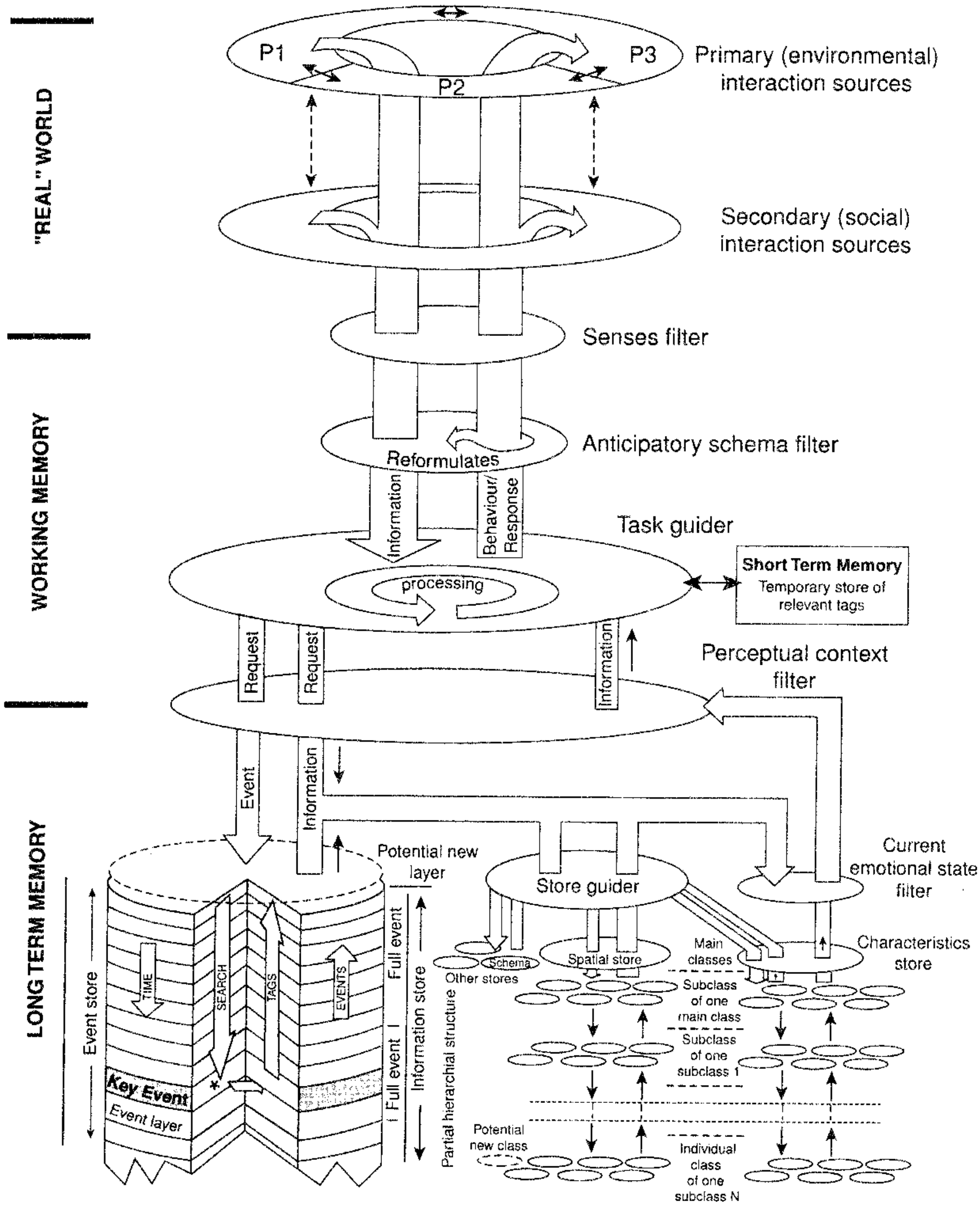

Figure 3.7 A conceptual schema by Kitchin (1996).

As pointed out by Kitchin and Blades (2002), many such conceptual models "have not always generated much empirical research". Many of these models also have a strong emphasis on "people's thought, knowledge and decisions which influenced that behaviour, rather than by studying the behaviour itself" (Golledge and Rushton, 1984).

3.6 GIScience and spatial information

Geographic Information Science (GIScience) is pertinent to the discussion in this Chapter from two perspectives. Firstly, the individual is increasingly at the heart of GIScience and therefore an understanding of individual cognitive processes in understanding spatial concepts and reasoning with geographical data is important (Longley *et al*. 2005). Secondly, as discussed in §2.3.4, mobile technologies are transforming the ways in which geographical information (GI) can be accessed and used in real-time whilst on the move and hence it is becoming more intimately connected with environmental contexts and individual decision-making. In applications such as LBS, this looks set to have implications for human-environment interactions during wayfinding.

Goodchild (1990, 1992) argued that the systematic study of geographical information constituted a scientific domain. He set forward two main criteria for the recognition of this science: that there were a legitimate set of scientific questions and that spatial data were unique. Thus the spatial key {x, y}, the presence of spatial dependence (Tobler's First Law of Geography) and the durability of the spatial data primitives of point, line, polygon and cell/pixel (Burrough, 2000) creates a well-defined class of information in its own right. In this view, geographical information systems (GIS) provide tools for geographical information science. Whereas Information Science studies the fundamental issues arising from the creation, handling, storage, and use of information, so GIScience studies fundamental questions for the creation, handling, storage, and use of geographical information (Longley *et al*. 2005). Mark (2003) also lists key research themes of GIScience as including data structures, algorithms, data quality, spatial analysis, visualisation, ontology, spatial reasoning, and cognition including human-computer interaction.

Mark (1999) has expressed a cognitive view of GIScience. It is assumed in any computational (digital) system, that the data (entities) and processes (algorithms) have some correspondence with and meaning in the real world. 'Representation' and the fidelity of representation are key factors in usability. Representations of geographical things rely to a greater or lesser extent on our cognitive perspective of the real world and are therefore an important issue in GIScience. Some aspects of the geographical world can be determined objectively through measurement; while others rely more heavily on perception, reasoning and memory. Thus an object, such as place of worship, can take many forms (church, mosque, synagogue) which each need to provide cues that make them recognisable as places of worship. Once recognised and so classed their location and extent can be determined objectively using GPS, aerial imagery and/or land surveying. The reverse process from digital representation must also be possible for the digitisation of places of worship to have any use. The ontology of geographical space determines what things are deemed to exist and also necessitates the use of language. Language is a specialised form of behaviour and can be a means of communicating thought. Thus we can differentiate basic geographical entities such as 'point', 'line', 'polygon' and 'cell' using linguistic terms for which there are very specific meanings. The classification of things according to accepted ontologies is a fundamental cognitive process. We tend to view geographical objects as categories of things (road, hill, town). This can also be extended to spatial relations between geographical objects such as 'north of ', 'near' or 'within'.

> "Nothing can be more abstract than, more unreal than what we actually see. We know that all that we can see of the objective world, as human beings, never really exists as we understand it. Matter exists, of course, but has no intrinsic meaning of its own, such as the meanings that we attach to it. Only we can know that a cup is a cup, that a tree is a tree." (Giorgio Morandi, artist, 1890-1964)

Goodchild (2003) considers that digital information has the advantage that it can be changed into other forms through transformations. GIS make it easy to carry out such transformations for spatial information. He further proposes that rather than measuring 'quantity' of information in terms of, say, bytes, it would be better to base such a measure using semantics, in other words, to focus on the meaning of the information (semantics) rather than its form (syntax) or file size. Such a measure also needs to distinguish between information which adds knowledge to a user as separate from that which only duplicates existing knowledge. Frank (2003) extends this discussion to consider 'pragmatic' information content in the context of wayfinding. In doing so he suggests "a formal approach to relate data to the practical situation in which it becomes information". He defines the pragmatic information content as being a measure of the amount of information useful for decision-making. In his schema, information is received by an individual and is used for decision-making as expressed in the individual's overt action. However, from the discussion of §2.3.4 and §3.5 we need to extend this schema to include the nature of the initial request for information by the user, say, using a mobile device, and how the server-side GIS might interpret the request and respond in relation to the data sets that are available. What information is requested and the actual decision/overt action taken are likely to depend on the nature of the problem/task facing the individual on the move, the nature of the surrounding environment and the immediate context of the situation (e.g. day/night, sunny/raining). Hence, the introduction of mobile devices and the access to spatial information in real-time and whilst on the move, poses fundamental questions for GIScience.

3.7 Conclusion

This Chapter has reviewed the research literature on spatial acuity, spatial knowledge acquisition, human-environment interaction and cognitive aspects of GIScience. These are all closely interconnected when considering wayfinding activities in the presence of mobile information devices. However, there is a lack of research into the interactions and spatial information transactions between individual, environment and their mobile device. This research focuses on developing an understanding of these interactions and spatial information transactions. The methodology is developed in Chapter 5, but before doing so it is necessary to consider the validity of using virtual reality as a test environment to study such interactions and transactions. This forms the subject matter of Chapter 4.