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Current and Future Trends in Dynamic and Mobile GIS

The terms “dynamic GIS” and “mobile GIS” have been around for some time. For example, back in 1990 Perez-Trejo suggested that a *dynamic GIS* could help analyse the impacts of climatic change on complex ecosystems. According to the author, climatic changes can not be assessed by studying one aspect of the system alone, but a dynamic GIS might contribute to the understanding of the dynamic interactions of physical and ecological subsystems within an integrated framework (Perez-Trejo, 1990). While in 1995 Olsen described the use of an enhanced version of the Highways Works Order Costing System (HiWOCS) by the UK Gloucester City Council's highways department. The system was integrated into a pen-based, *mobile GIS* system for the management of roads, paving, etc. The mobile GIS allowed the accurate location of faults on-site and was linked directly into the council's financial system. Additional elements allowed cyclic inspections providing a link from initial fault detection and works order through to final inspection (Olsen, 1995). However, despite this early start, current research is generating particularly exciting results both in terms of dynamic and mobile GIS as can be seen in the different chapters of this book. This last chapter aims to summarise the main key findings, recent advances and opportunities (Section 15.1) and identify key problems, threats or constraints (Section 15.2). The chapter concludes with suggestions for future research (Section 15.3) and recommendations for future practice (Section 15.4).

15.1 Key Findings, Recent Advances and Opportunities

15.1.1 Dynamic Processes (RB)

That the real world is dynamic is self evident. Consequently, it should be self evident that characterizing and simulating real world processes implies modelling their dynamic nature. To date, GIS have provided useful tools for investigating spatial patterns but have suffered from an inability to explore the dynamic aspects of geographic phenomena. Therefore, new models dealing with these dynamic aspects are needed. This implies a dramatic evolution in GI systems: the mixing of space and time. One has to move from static geographic feature (object) representations inherited from traditional cartography to new space-time representations addressing the very nature of change. The result should be a new generation of GIS tools incorporating multi-dimensional space-time modelling as proposed by Maguire (Chapter 1), and leading to so-called spatio-temporal information systems (STIS).

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Recent advances in the field consider occurrent entities, such as *events* (chapter 4) and *processes* (chapter 5), instead of static objects. Events with associated attributes of change such as rate of change or rate constancy provide key units for the exploration and analysis of mechanisms of change. Furthermore, events provide a basis for the integration of information from heterogeneous spatio-temporal data streams. Such streams are currently quite challenging to integrate, due to the diversity of spatial and temporal regimes which one can expect to encounter. In a process-based simulation, information about a whole process is represented - not only its state at a precise moment of time, which has been the case, to date, for most existing models dealing with dynamic phenomena. This represents a real improvement but is still at an early stage of development.

As we can see, current research and advances in dynamic modelling are based on a redefinition of core entities. However, other aspects should be taken into account when thinking about dynamic processes. The management of spatial constraints through time is one of them (chapter 7). This shows the complexity of handling space and time in a coherent way; a constraint, for example, can be true at time t and false at time t+1.

Considering research and business opportunities is both straightforward and challenging. The research potential is tremendous. The applications' potential almost infinite. However, commercial GIS are currently far removed from functioning as STIS and modeling dynamic processes is still in its research infancy.

15.1.2 Mobility

Mobility is undoubtedly a fundamental aspect of contemporary life. This has been known for some time. For example, as quoted by Mateos and Fisher in Chapter 11, twenty years ago Prato and Trivero suggested that mobility was the primary activity of existence in contemporary societies (Prato and Trivero, 1985, cited in Thrift, 1996). What is particularly relevant to Geographical Information Science is that those movements (e.g. of people) are increasingly leaving "digital trails" that can be tracked, collected in large databases and then analyzed. In the past, wearable tracking devices to collect motion data were mainly used by small populations under study. This was usually for ecology studies – e.g. tracking endangered species like the Amur leopard in Siberia – ref. …). However, nowadays most people (some unknowingly) wear tracking devices in the form of mobile phones. This is one of the reasons why there has been such an increase in the volume of available tracking data (see Chapter 11).

Laube et al., in Chapter 14, consider that Geographical Information Science can contribute to finding out about patterns made by individuals and groups while at the same time coping with the large volume of tracking data. For this reason, the authors argue that the study of *motion* (i.e. exploring the dynamic processes of such digital trails) is an emerging research area in Geographical Information Science. Laube et al. in their chapter actually try to *quantitatively* analyze motion, as opposed to just *visualizing* motion. Laube et al. argue that one effective way to analyze motion quantitatively is through a geographic knowledge discovery technique called "mining motion patterns". Laube et al. find that mining motion patterns exhibits a high potential to cope with the emergent large volumes of tracking data, particularly when compared to visually-oriented analysis techniques such as exploratory spatial data analysis. Mining motion patterns allows the integration of space and time, and therefore the analysis of the dynamic aspects of motion. Laube et al. conclude that integration of knowledge discovery techniques, such as mining motion patterns, with Geographical Information Science is an appropriate means to move beyond the snapshot with respect to motion analysis and provide a powerful means to investigate motion processes captured in tracking data.

A major technological development relevant to motion, and a key tool for a mobile society, is the advent of mobile GIS and other mobile devices such as cellular phones. The next section evaluates key findings, recent advances and opportunities related to mobile devices such as mobile phones and mobile GIS.

15.1.3 Mobile Devices (DF)

Technological advances can be expected to increase the production of individualised trajectory data. Telecommunication services or customer loyalty card systems already automatically produce amounts of data that push the analysts' capabilities beyond their limits. (14)

Mobile or cellular phones form part of the everyday life experiences of a larger part of the adult population in developed countries and its use is growing. They have quickly become ubiquitous devices that go wherever their users go, surpassing their original purpose of an individual communication system to become a 'wearable computing' device. (11)

mobile phone location, together with the individual identification of its user, can provide a new methodology to understand population mobility in contemporary societies. Amongst its benefits this technology presents significant advantages over GPS to track mobility, such as its low setup costs as the existing technology already covers nearly 80% of adult population, its accepted ubiquitous presence in all aspects of everyday life, and its better urban coverage inside and between buildings. (11)

Mobile phone location methodology allows the measurement of the mobility patterns of large groups of people, through the analysis of the 'spatio-temporal signature' of their mobile phones. Therefore Chapter 11 suggests that mobile phone location (or its technological successors) ought to become a new spatial reference system, drawing a parallel with the development of the Postcode to become the 'New Geography' a decade ago. Chapter 11 suggests that this should be called 'New Cellular Geography', that is, a geography of cells through which people can be seen moving. This parallelism is based on the fact that if postcodes enabled the linking of many different datasets about the population to a unique spatial reference from which to undertake cross-sectional geographical analysis, mobile phones (or their technological successors) will soon allow the linking of many different datasets about individuals to their spatiotemporal flows, linking datasets through their different *timespaces*, facilitating the longitudinal analysis of the network society linking a space of 'cellular geographies'. (11)

Mobile GIS is one of the most vital technologies for the future development of disaster management systems because it extends the capability of traditional GIS to a higher level of portability, usability and flexibility. The unique feature of mobile GIS is the ability to incorporate Global Positioning Systems (GPS) and ground-truth measurement within GIS applications. (11)

creation of environmental collaborative monitoring networks can form a framework to promote citizen participation within environmental monitoring, while supporting the use of citizen collected data. (13)

mobile computing applications, together with mobile communications, create new opportunities for environmental monitoring. Mobile communication and computing may be used to link citizens and therefore create new opportunities to support the creation of environmental collaborative monitoring networks. (13)

The need to deliver the required map information on small display screens of devices in particular PDA's, necessitates the application of appropriate map generalization techniques that are specifically tailored for this purpose. (9)

Three-Dimensional non-photorealistic maps are more effective than photorealistic maps when delivered on small screen devices. They are more easily understood by users. More realism does not always lead to a more useful product – photorealism less important than functional realism - Need to focus much more on what users actually need / can best use rather than 'pushing the limits of technology (8)

Non-photorealistic graphics offer the potential to improve displays of 3D spatial information on mobile devices. the inadequacy of just importing photorealistic images has been exhibited (8)

15.2 Problems, threats or constraints

15.2.1 Systems and Technology (DF)

One issue not yet mentioned in this chapter is that, with a number of constraints, conflicts may arise, therefore, a good mechanism has to be developed to check for this. When users can change the constraint definitions of an existing application, then a conflict check should take place. (7)

the development life cycle of mobile devices, such as mobilephones, constrains the research in this application area. (13)

major barriers to the creation of an environmental collaborative monitoring networks are related to the large variety of mobile devices and the costs associated to the communication services. (13)

creation of an environmental collaborative monitoring networks - issues like users' privacy have to be considered. (13)

creation of an environmental collaborative monitoring networks - the need to have an attractive business model (at least for the mobile operator) also needs to be considered. (13)

The specific limitations of devices for mobile GIS – in some respect represents a return to the early days of computer graphics and desktop PCs when resolution & number of display colours were limited. However, not too much attention should be paid to resolution limitations as these are bound to improve, although the need for portability is likely to retain the small size of display, so issues such as navigating around the image, showing large amounts of information, etc. will remain an issue. Thus selection, generalisation and appropriate representation of information will remain critical. (DF)

However, in many instances the way in which the maps are designed for use with contemporary information delivery tools, and especially those that deliver geographical information via small screens is no different to the designs for their paper map cousins. 'Just' applying the 'rules' of paper maps, or maps on large screen computer graphics, cannot ensure a usable mapping product for navigation and wayfinding. A different approach needs to be explored. (8)

15.2.2 Data, Accuracy and Scale (EJ now completed)

The other major source of possible problems, threats or constraints that can be detrimental to the development of location aware devices and mobility studies is associated with data, accuracy and scale issues. First there is the issue of *data availability* that was mentioned by several of the chapters in the book. Reitsma and Albrecht, in Chapter 5, for example suggest that there is a lack of appropriate data for validating process definitions and the results of process-oriented data models. While Laube et al., in Chapter 14, point out that there is a lack of tracking data for large (i.e. more than 200) groups of individuals. Cost - that increases with the number of individuals being tracked, and the spatial and temporal coverage - is a major contributor to this. It is therefore not surprising that many animal tracking studies focus on a small number of individuals (e.g. http://www.spacetoday.org/Satellites/Tracking/Animals/MalaysiaElephant.html). In case of humans, Mateos and Fisher, in Chapter 11, suggest that the need for user consent to disclose their location also can limit the size of the population sample than can be surveyed.

More fundamentally, the underlying data model can also affect the availability and quality of tracking data. How the data model can constrain data collection can be illustrated by the fact that tracks of mobile phones give cell information but do not disclose more accurate x,y coordinate observations. Mateos and Fisher, in Chapter 11, observe that the measurement of mobility patterns of large groups of people through the analysis of the 'spatio-temporal signature' of their mobile phone is limited by the spatio-temporal *accuracy* imposed by the technology. Mateos and Fisher suggest that the current limited spatio-temporal accuracy of mobile phones makes it only suitable to measure inter-urban mobility. Laube et al., in Chapter 14, also suggest that data originating from certain moving object database applications (e.g. taxi cab fleet management systems – see for example ……), feature long static periods and rare updates and therefore might not be appropriate for certain mobility studies. Finally, Laube et al., in Chapter 14, point out that investigating objects that move on a network, for example vehicles moving on a street network, may reveal more about the structure of the traffic network than about the behaviour of the drivers.

The other major issue that may possibly cause some problems or constraints is *scale*. There are two key aspects to be considered here: the appropriateness of scale choice *and* scale effects (i.e. how the choice of scale may affect the results). First, in relation to scale choice there is a fine balance between collecting too much data and not collecting enough. For example, in relation to the spatial scale, O'Neill et al.

(1996, p. 169) recommended that “in reporting landscape pattern, grain should be 2 to 5 times smaller than the spatial features of interest”. In relation to the temporal scale, the “granularity of time” and its importance for incorporating the temporal dimension in a GIS has also been studied (e.g. see Kemp and Kowalczyk, 1994, p. 91). Laube et al., in Chapter 14, p. ??, warned that in order to avoid semantic mismatches, the knowledge discovery process must be performed at an ‘adequate granularity’: “undersampling a lifeline causes information loss, while oversampling may drown out the track's signal and may even feign autocorrelation between successive moves”. For example, in their Porcupine caribou case study Laube et al. suggest that in order to search for seasonal migration patterns an analysis granularity of hours would not be adequate because it might introduce noise caused by daily movement patterns.

Regarding scale effects it is well known that patterns of objects will change according to the spatial and/or temporal scale (e.g. see Fernandes *et al.*, 1999 in the case of ecology; João (2002) in the case of environmental assessment; Meentemeyer and Box, 1987, in the case of landscape studies; Osterkamp, 1995, in the case of water quality; Sposito, 1998 in the case of hydrology; and Stein and Linse, 1993 in the case of archaeology). Gray (1999, p. 330), for example, found that “one’s conclusions about whether land is degraded are influenced by the scope and scale of the analysis. For example, if we examined changes at the local or regional scale using aerial photographs, we would most likely arrive at a different conclusion than if we examined soils at the farm scale. The scale at which studies are undertaken affects the conclusion because processes and parameters important at one scale may not be important or predictive at another scale”. Openshaw (1984) discussed the Modifiable Areal Unit Problem (MAUP) in the case of the spatial scale. Laube et al., in Chapter 14, propose something equivalent but for the temporal scale. Laube et al. suggest that if in their study the temporal units were differently specified, different patterns and relationships would have been observed – i.e. a “modifiable temporal unit problem” or MTUP (c.f. MAUP mentioned above).

It is crucial to have accurate and up-to-date information (see Hummel, in Chapter 10) as no clever algorithm can compensate for poor data. However, it is also important to consider the human and legal aspects that may be another source of possible problems, threats or constraints, and this is discussed in the next section.

15.2.3 Human and Legal Aspects (now completed by JD)

We quite literally broadcast our location while using mobile GIS. This may prompt actions which are life-saving, life-threatening or invade our privacy.Thus we are obliged to question the human and legal implications of dynamic and mobile GIS; such implications have been addressed significantly by Matt Duckham and Lars Kulik in Chapter 3 and are alluded to by Qingquan Li in Chapter 2. Further, Patrick Laube and his co-authors in Chapter 14, comment that “in a globalised world, people, goods, data and ideas move in increasing volumes at increasing speeds over increasing distances, and more and more leave a digital trail behind them”. Data representing such a digital trail can be automatically collected, either overtly or covertly, in databases, implying not only active surveillance and but the possibility of misrepresentation and adverse decision-making through the(mis)matching and analysis of spatially referenced and other data that identifies individuals.

To consider these data and their databases, are the implications (with regard to the expectations that individuals remain unidentified, private) regarded or even understood by policy-makers, systems developers and the public? Bennet and Raab (2003) remind us that Government proposals for the electronic delivery of services and information; the rationalisation of information processes ; and, open government, depend, for their effectiveness and acceptability, on controlling the potential misuse of personal data. Are controls to accessing these data in place, or being adequately thought about at government level? Electronic identity theft and fraud are now publicly discussed (Gowen and Hernadez, 2005) and obviously of concern to the financial sector. But if research for the prevention of financial fraud can be aligned with that for the protection of privacy, then, perhaps, technical solutions will emerge. The benefits of such an alignment can be understood from figures proposed by Ingrian Networks (2005) which claim that each security breach costs a financial firm, on average, $1.65 billion in market capitalization. Without this alignment, there is a good chance that those developing techniques to abuse data privacy will 'win out'.

The current situation has prompted the technical response, outlined in this book's chapter 3, namely obfuscation. Duckham and Kulik propose that an individual's location is protected by broadcasting a set of locations (an obfuscation set), only one of which is the individual's true location. For this, or any technical solution, to be effective not only does the proposed technology have to be thoroughly researched, but also the techniques employed, now, or having future potential, to invade a person's privacy (circumventing location privacy protection and attempting to discover an individual's exact location) must be understood.

Other extant technical solutions include authentication of all access; audit trials of all access; identification of security breaches and suspicious attempted access; data masking; encryption hardware; and, above all internal security. It is claimed that 50% of all security breaches arise internally (Ingrian Networks, 2005) initiated.

We need to answer some questions such as what level of protection we actually want and how ethical concerns should constrain the availability of geospatial, especially lifeline, data in the years ahead. Not alluded to in this book, despite its international authorship, are the very different levels of privacy incursion found acceptable in different societies. Given the global nature of the problem, awareness of these varying attitudes should inform any discussion.

15.2.4 Overall View (JD)

data mining approaches for motion data could share for some time the problems of the space time aquarium, remaining an elegant and promising concept, yet suffering from a lack of true applications. (14)

only the widespread application of geographic knowledge discovery *in practice* can prove its usability. Only as more applications are developed which address the special challenges laid down by the *dynamic* nature of spatio-temporal motion data will we be able to say that the integration of Geographical Information Science and data mining shows why *spatial* (and of course spatio-temporal) is *special* with respect to knowledge discovery. (14)

If non-photorealistic graphics do have advantages over photorealistic graphics for the delivery of mobile maps, they may also have benefits in other areas of cartography. The application of non-photorealistic representations in other areas needs to be explored. This could include risk analysis and communication, spatial decision making, and geographical visualisation. As these application areas currently make extensive use of photorealistic techniques, and although this is an effective method for many applications, perhaps some practices may be better off employing non-photorealistic techniques (8)

improved processing of GPS data & map matching algorithms in navigation systems could help identify erroneous map data (10)

15.3 Future Research

15.3.1 Spatio-temporal Information Theory and Spatio-temporal Analysis (now completed by RB)

Considering dynamic or mobile GIS without accordingly extending the available spatial analyses tools would be meaningless. Besides technical advances, a deep reflection of core spatio-temporal information concepts must be undertaken. In this respect, the work still to be done is tremendous.

Clearly considering events, processes or dynamic objects, instead of static objects, is a huge conceptual evolution impacting every aspect of information capture, maintenance, analysis and visualization. In a way, an upper-level ontology of dynamic geographic phenomena has still to be defined. New sets of spatio-temporal relationships should be described which will have the same impact on modelling strategies as topological relationships had on 2D GIS in the last quarter of the 20th century.

From the subjects tackled in this book, we can detect some important future directions.

First of all, getting true 3D (2D + time) and 4D (3D + time) models remains a challenge. Multi-dimensional motion patterns (i.e. encompassing two of more motion properties such as speed, change of speed, motion azimuth and sinuosity) indicate another promising direction research could take (chapter 14). Likewise work concerning the analytical and statistical methods needed to test the significance and similarities among event patterns is needed (chapter 4).

In summary, one needs, at least, to define and implement new indexing strategies, new query languages, new visualization methods, new analytical tools, advanced spatial analysis, statistical functions and new spatio-temporal constraints. Concrete examples are the definition of optimization algorithms, for the rapid processing of spatial information accommodated in a small capacity memory, fast extraction and compression of spatial information in the context of large user groups, and concurrent data manipulation (chapter 1).

15.3.2 Equipment and Devices (DF)

Currently the flux simulation environment is constrained to small models due to problems of computational complexity. To use this approach for models of larger spatial scale and of greater detail would require a significant rewrite of the software and consideration of advanced methods for accessing larger scale computing resources (5)

new open and flexible modelling platforms are needed that can easily incorporate new data models and new analytical and visualisation methods. (5)

Lack of comprehensive user interface designed specifically for Mobile GIServices. Most current mobile GIS software still follows the legacy concepts of desktop GIS interfaces. The tiny, sensitive stylus pen and the small on-screen keyboard input method are not the right choice for Mobile GIServices at least in an emergency context. Direct voice commands and an easy, touchable screen simply used by human fingers are more appropriate for emergency responders and in-field workers. (12)

Lack of real-time data collection and distribution mechanisms. (12)

Difficult to verify the accuracy of submitted geospatial data from field work. Currently, a GIS professional has to manually convert the data submitted from field workers to the Web-based GIService framework . Some predicted advances in Web Services technologies and improvement in distributed database functions might solve these technical problems in the future. However, it is always dangerous to rely on automatic data conversion without verifying the data accuracy and data quality. (12)

Integration of spatial analysis and GIS modeling into Mobile GIServices. Many emergency tasks and disaster management works will need advanced GIS analysis functions which required significant computing power and computer memory. Most mobile GIS devices are tiny and only have very limited computing capability. The pre-processing and post-processing time for spatial analysis and remote sensing images might prevent the adoption of Mobile GIServices for real-time response tasks due to the hardware limitations. One possible solution is to send the complicated GIS model and spatial functions via the Internet to remote GIS engine services. Then, the analysis results will be sent back to the Mobile GIS devices via the network. (12)

lack of alternative display methods for Mobile GIServices. Since most mobile GIS devices are small and fragile, emergency responders and managers might be reluctant to use small screens on Pocket PC or cellular phones to share their maps with others. One possible alternative is to print out paper maps directly from Mobile GIS devices since paper maps are easy to carry and there will then be no need for batteries in the field. It will be great if users can print out paper maps directly from their Mobile GIS devices via wirelessly portable printers or from built-in printer inside a Pocket PC or a notebook computers. (12)

How can mobile phones be equipped to make them environmental monitoring kits? Which sensors are available? Which can be integrated and which should be coupled? (13)

Future work will concentrate on refining the simulated annealing technique through the use of additional constraints (9)

15.3.3 Data and Accuracy (now completed by JD)

It seems quite strange to still be talking about data quality and accuracy as issues to be placed on the GIS research agenda, given that there are at least two international conference series, namely: International Seminar on Spatial Data Quality (ISSDQ, 2005); and, Spatial Accuracy Assessment in Natural Resources and Environmental Sciences (ACCURACY2006, 2005), devoted to the topic and that it has been sessioned in all GISRUK conferences. Nevertheless Maguire reminds us, in this book's first chapter that "we need to develop techniques for reducing, quantifying, and visually representing uncertainty in geographic data and for analyzing and predicting the propagation of this uncertainty through GIS-based data analyses". But we are now talking about a different set of practices. Perhaps the advent of mobile GIS, with its limited visualization and processing capabilities and less GIS-attuned users will really focus our minds on these issues of data and accuracy? Certainly it would be irresponsible not to be, at least, considering **ways of transmitting the quality of geospatial information to this potentially huge group of GIS novice users.**

Mobile GIS is not just about information display. It can also be about data capture. 'Traditional' experienced GIS users are aware of several primary data capture methods, and their relative qualities. A danger with mobile GIS is that low resolution GPS positioning techniques will be the only primary data capture methods implemented. **Are there ways of prompting the user to achieve appropriate data capture standards?**

Information generation not only uses data, it also needs processing models. If they are of low quality so is the information. Rietsma and Albrecht, in chapter 5, suggest that they do not know of any measurement approach that quantitatively records process information. This probably ignores the long history of error estimation supported by Least Squares Adjustment which will be familiar territory to those GIS workers with a Geomatics background (e.g. Mikhail, 1976), and more recent developments in crisp and fuzzy set theory where the probability or certainty of a rule holding (Drummond, 1991) can be determined from observing the outcome of information generation procedures. But certainly **these procedures need more of an 'airing'; a wider consideration by the dynamic and mobile GIS community.**

The tenor of this section, so far, has been that this book has not 'grown' the 'data, accuracy and scale' research agenda in any way. But this is far from the case if we turn to the dynamic aspect of this book's title. As Laube and his co-authors say in Chapter 14 "tracking data are in many cases not perfect". One should never expect them to be perfect. How can the imperfection be quantified? **How can the effect of imperfect tracking data on generated information be known?** This must be a research item.

A cautionary note. Apparently tracking data are in short supply. Are there the sources to carry out research into the quality of these data? Again Chapter 14's authors have a suggestion, "where real observation motion data are lacking or suffer from poor quality, carefully synthesized artificial motion data offer a feasible alternative to studying some processes ….. artificial life forms are always visible, healthy, don't die, don't get shot, don't loose their GPS receiver, don't need privacy, and are willing to report their location at any desired time."

15.3.4 Behaviour (now completed by JD)

Do we need to consider behaviour as a component of the Dynamic and Mobile GIS research agenda? We may consider human behaviour, but as indicated in the previous section, animal behaviour is an issue too. We may consider the behaviour of the GIS user gathering, transmitting and processing data at a remote location. We may consider the GIS user as an economic being. We may consider the behaviour of the dynamic objects we represent in our databases. We may consider research into behaviour as being something which raises privacy or other ethical issues.

Considering the last of these, it has already been noted by Duckham and Kulik (Chapter 3) that existing approaches to location privacy are static in nature and **the development of truly spatio-temporal models of location privacy are needed.**

Turning to the user, given the level of GIS skill expected amongst the majority of future mobile GIS practitioners, issues related to the nature and orientation of geospatial visualization are of concern. Plesa and Cartwright in Chapter 8 make a case for adding **an assessment of realistic visualization** to the research agenda, claiming a "need to develop some system of classification of images between abstract and photorealistic" as an early step in this research.

Dynamic and Mobile GIS offers several technologies, each with cost implications. Which business models support the use of mobile technologies and which will be acceptable? **How will this new pool of GIS users behave economically?**

The accurate representation of a tracked object's movement, between recordings, requires **research into interpolation methods based on an understanding of the object's behaviour.** This involves the integration of geometric properties of the object's motion with semantic information (such as cultural background, socio-economic status, transport mode) and details of the geographic environment harbouring the motion. As suggested by Laube and coauthors in Chapter 14, any assumption of objects moving through undifferentiated space does not hold for the complex motion of genetically imprinted or intelligent objects, following their chosen corridors, valleys or ridges.

15.4 Recommendations for Future Practice

15.4.1 Standards (now completed by RB)

Important work has been done on the formalizing of 2D geo-spatial information. This has given birth to several norms and standards. Such work, prompted by the need for interoperability between data and systems, has mainly arisen after the first commercial GIS emerged. Although norms and standards should be used at the early stages of GIS or spatial database implementation, it is not uncommon that organizations using GIS or maintaining spatial databases are still occupied by defining core or domain ontologies, building data dictionaries or conceptual data models, upgrading data models and data structures. This is obviously not good practice, but is sometimes the result of the non availability, poor understanding or poor definition of norms and standards.

While dynamic and mobile GIS are still in their early stages it is essential not to make the same mistakes as were made with 2D GIS. Norms and standards should be adopted which are based on deep theoretical reflection, particularly taking into account this new representation of real world processes. Citing Maguire (chapter 1): "*…LBS standards, for spatial information abstraction, mobile services integration, spatial data compression, positioning, and data transformation in Mobile GIS should be based on OpenGIS specifications of OGC, wireless application protocol (WAP) forum, mobile location protocol of Open Mobile Alliance, mobile location service, web services specifications, GSM (including GPRS and EDGE) and W-CDMA specifications (Adams, et al., 2004) from third generation partnership project (3GPP), UMTS (Universal Mobile Telecommunications System) technical specifications, and the standards from W3C including Scalable Vector Graphics (SVG), Mobile Web Initiative and Web Services …*". This incomplete, but already impressive list, demonstrates the variety and complexity of norms, specifications and standards which have to be considered.

15.4.2 Institutional Aspects

The possible implementation of the suggestion posed by Mateos and Fisher in Chapter 11 (and summarized in Section 15.1.3), that mobile devices might form the basis of a new spatial reference system to analyse population, has institutional consequences. New legislation would be needed to govern the sampling of the location of the population, for example on selected survey days. Mateos and Fisher propose that similar guidelines to the national census of population could require coverage of a large part of the population while at the same time safeguarding anonymity (e.g. individual privacy could be assured by only publishing and visualising information in aggregated ways).

Accuracy and privacy issues are absolutely key and need to be addressed before starting an extensive collection and analysis of mobile data (see Mateos and Fisher, Chapter 11, on spatio-temporal accuracy in mobile phone location, and Matt Duckham and Lars Kulik, Chapter 3, on location privacy and location-aware computing). The likely large-scale systematic storage of location data in the future is a key challenge to Geographical Information Science not only in terms of database storage and processing capacity, but also on GIS data models and the ontology of spatio-temporal representation.

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Bits taken out that Elsa does not know how to include them – delete them altogether or are they relevant to your bits?:

analysis of the extent to which the predefined road classifications in OSCAR® dataset are affected during the schematization process with respect to the original map (9)

The map database used by the authors is off-the-shelf and frequently used in today's navigation systems. Errors of up to 40 metres with respect to ground truth data have been encountered. (10)