The Digital City : Inventory and Prospect

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Abstract: The digital city is an instance of a class of systems representing large real-world complexes that are embedded in spatio-temporal frames. Current technology makes it possible to deliver the services of the digital city through standard desktop hardware and communication networks. However the current data supply limits the digital city to a view that is essentially static and coarse. The paper reviews recent advances in digital libraries, visualization, modeling and simulation, and sensors, all of which are potentially relevant to the digital city. Three major impediments are identified to further development of the digital city: the lack of a common, integrated data model; the difficulty of modeling continuous phenomena in object-oriented data models; and the variable accuracy of diverse data sources.

1. Introduction

The term *digital city* carries many connotations (for discussion of relevant concepts see Dodge and Kitchin, 2001; Janelle and Hodge, 2000; Kotkin and Siegel, 2000; Leinbach and Brunn, 2001). First, it might refer to a *virtual* city, a large community of people connected and interacting through electronic networks. Unlike the traditional city, however, a virtual city would have no need for geographic proximity, since electronic networks would provide the same degree of connectivity that has traditionally been achieved through geographic concentration. In the world of cyberspace there is no need for geographic concentration to overcome the costs and impediments associated with distance. Virtual cities clearly exist, in the chatrooms of the Internet and elsewhere. But they fail to replicate traditional cities in one important respect: the community that forms around one issue or common interest may bear no relationship to the community that forms around another. In traditional cities, on the other hand, many issues and common interests create a single agglomeration. This lack of scale economies among activities, issues, and interests seems bound to ensure that the virtual city remains of only minor importance compared to its traditional precursor.

Second, the term suggests a *wired* city, or a city fully enabled by digital technology. The city would be wired at several scales, ranging from the single household with its multiple computers, sensors, and devices controlling appliances, lighting, heating, and security, to the scale of the city as a whole, and its network of coaxial and fiber connections. Somewhat paradoxically, the wired city would also make full use of wireless technology, allowing its citizens to remain fully connected at all times. The wired city would be characterized by computing that is ubiquitous, in the sense of being available everywhere; itinerant, in the sense of traveling with its users; and distributed.

The focus of this paper is on a third connotation, and one that I suspect is of most interest to participants at this conference. Here, the digital city refers to a digital representation of the city. The phrase *digital x* has become fashionable in recent years, as it has become increasingly possible to create comprehensive digital representations of many large systems denoted by *x*. Digital Earth (www.digitalearth.gov) is one instance of *digital x*, and it is easy to find many more described on the World-Wide Web (WWW): digital human, digital cosmos, digital human genome, digital Los Angeles, *etc.* All of these instances share certain basic characteristics:

- a large and complex real-world system distributed within a spatio-temporal frame (in many instances time is comparatively neglected, if the system is essentially stable);
- a comprehensive data model providing the framework for description and representation of the real-world system;
- diverse sources of information that are integrated through the common data model;
- a distributed architecture, allowing parts of the representation to be stored separately from other parts, perhaps on different servers in different locations;
- access mechanisms that use the spatio-temporal frame as an organizing structure and a basis for search, both through a coordinate system and through a catalog of named areas and time periods within the frame (a *gazetteer*);
- tools for visualization and analysis; and
- multiple applications and services.

For example, Digital Earth (DE) is envisioned as a distributed system of sources of geospatial information, coordinated through common standards and specifications (the term was coined by Gore, 1992, and further elaborated in a 1998 speech). It would allow a user to obtain information about relevant aspects of the Earth by accessing a single portal, and using the portal's services to support search, discovery, access, assessment of fitness for use, and retrieval. The user would not need to be aware of the actual locations of discovered data sets, since all interaction would occur through the portal. In addition, DE is envisioned as a high-end visualization system, capable of supporting virtual field trips to areas of the Earth's surface, at any point in the past, present, and future (Goodchild, 1999a). To support visualizations of the future, DE must clearly possess the ability to simulate future scenarios, based on models representing our understanding of the operations of human and physical aspects of the Earth system.

Instances of *digital x* clearly have great potential benefits. All information about a system is available through a single source, instead of being fragmented across many sources. Common specifications and protocols ensure that the user receives a unified view, irrespective of the original formats and structures of data sets. Integration of multiple sources ensures that comparisons across data layers and similar constructs are easy. The availability of metadata ensures that users are always aware of such matters as data quality. Support for simulation allows users to evaluate what-if scenarios, by experimenting on a digital version of the system rather than the system itself. Such ideas have proven very attractive in digital flight simulators, in courses on human anatomy, and other areas where there are serious risks associated with experiments conducted on real-world systems. SimCity (DeMaria, 1999) is a simple and familiar instance of the value of these ideas applied to urban design.

Such instances of *digital x* have caught the imagination of science fiction writers, and also of scientific visionaries (Siegfried, 2000). The possessor of *digital x* would be capable of responding to any kind of query about *x*, such that the originator of the query would not be capable of determining whether the possessor had access to the real *x*, or only to *digital x*. *Digital x* would contain all of the details necessary to recreate *x*, and the transmission of *digital x* recalls the science fiction concept of teleportation.

In this sense, *digital city* implies a comprehensive digital representation or model of an urban area, and that is the meaning that is explored in this paper. Like DE, the digital city would possess a comprehensive representation of aspects of the city across a wide range of scales, from centimeter to kilometer. It would integrate diverse sources of data within a common data model. It would support visualization, allowing its users to explore the city at various levels of detail, and to visualize future scenarios, including new buildings and the effects of disasters. It would integrate data and services from distributed servers, allowing each data set to be maintained by its originating agency. It would also support extensive analysis and modeling services.

In this paper I explore this notion of the digital city in depth. The next section reviews the current state of development of the necessary data sets, and associated issues of scale, accuracy, custodianship, and intellectual property. The third section looks at new technologies, and their likely impact on the concept of the digital city. The fourth section addresses various underlying issues and impediments that are likely to impact progress on the development of the digital city. The paper ends with a short concluding section.

2. The Data Supply

Data for the digital city ranges in spatial resolution from centimeters to kilometers, a range of five orders of magnitude. Some scales within this range are particularly well supplied by traditional data sources, and in this section I briefly list and discuss some of these. This leads to an identification of major gaps, either where data acquisition is not feasible at reasonable cost, or where applications have not justified extensive acquisition.

The census is perhaps the oldest effort to gather information in large quantities about the city. Its focus is on population, including a range of demographic, economic, and social factors. Today, spatial resolutions of available census data range from several hundred meters (the block, block group, and comparable reporting units) to kilometers. However, spatial resolution of census data is not precisely controlled, as the primary criterion for reporting unit design is equality of population. Consequently the sizes of units vary substantially at each level of aggregation, often by more than an order of magnitude. For example, the census tracts used to report statistics in the U.S. Census for aggregates of approximately 5,000 people show marked variation in size from the smallest units in the city center to much larger units in the periphery, generally following patterns of population density. Boundaries of reporting zones are often available in digital form to positional accuracies of tens of meters.

The locations reported in census data for the population are home locations, and consequently the census provides an accurate picture of the city at night, but a much less accurate picture of social and economic variation during the day. Goodchild *et al.* (1993) and Janelle *et al.* (1998) have shown that the city repeatedly reorganizes itself during the diurnal cycle, displaying three distinct phases of organization: at night, during working hours, and during the evening. Between these phases the degree of organization is markedly less.

Many cities now possess accurate cadasters, or data sets describing land ownership, and make them generally available. The spatial resolution of cadasters is again not precisely controlled, since land parcel dimensions range from tens to hundreds of meters. Such data sets are the result of accurate surveys, and position land parcel boundaries to centimeters. They also provide information on ownership, assessed value, use, and taxation. They are often integrated with similarly accurate data on the footprints of buildings and other structures.

The initial development of massive data sets describing the positions of street centerlines is often attributed to the U.S. Bureau of the Census and its DIME program of the 1960s. Today, street centerline data are available for most developed countries, and address some combination of three objectives: geocoding, or the positioning of street addresses by linear interpolation along street segments using defined address ranges; navigation, or the automated computation of driving directions between defined points; and the prediction of traffic flows (Goodchild, 1998) from models of travel behavior. The first task, geocoding, relies on the custom of numbering houses along streets in approximately linear fashion, an assumption that applies in many urban areas but not all, a notable exception being Japanese cities. Street centerline data sets typically partition streets at intersections. The positional accuracy of street

centerline geometry is often roughly ten meters, though better accuracies can be obtained with GPS surveys or photogrammetry.

Cities are also well supplied with topographic data, in the form of data on terrain (digital elevation models), hydrography, and cultural features. Such data are often available at spatial resolutions of ten meters, with similar positional accuracy.

Finally, many cities now possess detailed data sets describing other aspects of infrastructure, notably the utility networks that deliver water, electric power, telecommunications, and waste water services. Often these data sets are created by private sector utility companies, through partnerships with other companies and public agencies. Utility networks are often positioned with respect to property boundaries, and hence to the cadaster, which they use as a common framework. As a consequence positional accuracy is typically of the order of one meter.

Remote sensing is a valuable source of geospatial data for many purposes, but it is relatively unsuccessful as a source of data for the digital city (Liverman, 1998). Social and economic variables are typically invisible from above, although Sutton *et al.* (1997) have derived interesting estimates of population density from night-time imagery. Remote sensing is a useful source of land classification, but in urban areas the most distinguishable spectral signatures —— grass, trees, concrete, asphalt —— are too detailed to be of great value in land cover or land use classification. However, remote sensing has proven to be a useful source of information, particularly in relatively cloud-free regions. Specifically, remote sensing may be a viable source of information for updating street centerline data in areas of new development, and high-resolution remote sensing from aircraft is an important source of raw data for the development of accurate cadasters.

Most conspicuously missing from this inventory are data on urban dynamics. The census, the cadaster, street centerlines, and utilities are all relatively static aspects of the city. This timeless view has two basic causes. First, the costs of data collection are high, and the benefits must therefore be maximized, by acquiring data that will remain valid for as long as possible. Data on comparatively short-lived phenomena are too costly to collect. Second, data on dynamic phenomena require either continuous and expensive updating, or the calibration of valid models. Some aspects of urban dynamics, such as the diurnal variation of traffic volumes or trip generation to shopping centers, are comparatively predictable based on limited observations (Fotheringham and O'Kelly, 1989). But other aspects, such as new subdivision development, tend to be too chaotic and detailed to be amenable to modeling. Nevertheless, some powerful models of urban growth and sprawl have been constructed (Clarke *et al.*, 1997) that successfully predict the gross characteristics of growth.

Also missing from the inventory are data on individuals. The census provides only aggregated data, because of concerns over privacy. The same concern prevents any large-scale effort to collect data on individual spatial behavior, despite the potential value of such data for planning urban infrastructure and for commercial use. Various approaches are available, however, to a company wishing to acquire such data. First, credit card use provides card companies with detailed information on behavior that is often mined to detect fraudulent use (for example, if a card is used several times in quick succession in an unusual location). Second, cellphones can be positioned accurately, and the distribution of accurate data on cellphone user locations is now authorized in the U.S. in support of emergency services (for example, when a cellphone user is unable to describe accurately the location of an emergency). I return to this theme later in the paper, and discuss the use of such novel technologies for data acquisition.

Given the data sources already identified, it is possible to develop a sense of how a digital city might be constructed today. It would be capable of displaying information derived from the cadaster, including perhaps buildings, though these would likely have to be visualized as solids with uniform cross-sections, since virtually no information would be available on roofs and other complications of building geometry. It would include roads, together with their names, and perhaps sufficient detail on traffic densities to simulate the movement of vehicles, though these would almost certainly be limited to conditions averaged over the day. It would contain coarse detail on population distributions and social and economic variables, though these would have to be rendered in some standard cartographic form, such as through the use of color, in the absence of any more realistic rendering. Clearly, however, there would be no individuals, and with the exception of simulated traffic, no movement. There would also be no detailed information on the internal structure of buildings, or of the distribution of population during the day. Today's potential for the digital city is extremely limited, and the views that could be rendered through such a digital city would be virtually static, coarse, and variously out of date.

The next section examines current trends and developments in geographic information technologies, in an effort to foresee the likely future potential for the digital city.

3. New Technologies

1) Digital Libraries

In recent years massive strides have been made in technologies that support sharing of geospatial data, and ultimately support the vision of the digital city. Projects such as the Alexandria Digital Library (www.alexandria.ucsb.edu) allow users to search massive archives of geospatial data, using cataloging systems based on common definitions of metadata. Many of these *geolibraries* (Mapping Science Committee, 1999), or libraries whose primary search mechanism is based on location, use metadata specifications based on the U.S. Federal Geographic Data Committee's Content Standard for Digital Geospatial Metadata (www.fgdc.gov). Using this standard, the U.S. National Geospatial Data Clearinghouse (www.fgdc.gov) supports search over a distributed archive of over 300 servers worldwide. The Alexandria Digital Library has developed technology to permit many servers with different metadata formats to be searched simultaneously, through the concept of *buckets* which map to each server's definition of the common dimensions of search.

Such digital libraries are clearly one element in a technological approach to the concept of the digital city. Ultimately, they will allow a user to search across distributed archives as if they were integrated, and to extract relevant data for display, analysis, and modeling. Several impediments lie in the way of full implementation, however. Most serious perhaps is the lack of *collection-level metadata* (CLM), or metadata that describe the contents of each archive or server. Without CLM it is impossible for a search engine to know which sites to search as likely to contain useful information, and without them the task of searching across all sites on the Internet is clearly impossible. There are many possible solutions to the CLM problem, including the integration of all geospatial data through a single portal such as the National Geospatial Data Clearinghouse; a formal system in which each server's coverage is defined within a global scheme; and a new generation of search engines that are capable of detecting the presence of geospatial data at a site, and creating appropriate catalog entries. Until a solution emerges, the best strategy for the digital city would appear to be the creation of one portal for each major city, where all geospatial data relevant to the city are registered and described in an appropriate metadata structure, and through which the user can gain a homogeneous view. To date there are many instances of such portals for nations, states, and provinces, but few for major cities.

A major concern in the development of digital libraries for geospatial data has been the need to achieve greater geographic integration of data. Traditionally, geospatial data has been produced by layer, with different agencies or departments responsible for each layer. For example, topographic information has been the responsibility of national mapping agencies, while street centerline information has tended to be produced either by census agencies, or by the private sector. As a result, integration of all information about a given place has been problematic, and has consumed much of the time and effort expended in GIS applications. A key element of the vision of Digital Earth is the vertical integration of access mechanisms, such that a single search would discover all of the information available about a given place, rather than all of the information in a given layer. This concept is also clearly important for the digital city.

2) Modeling and Simulation

The digital library emulates its predecessor, the library of books and journals, but adds substantial capabilities in the archiving, discovery, and retrieval of data. But books and data are only two of the many forms of information devised by humanity for the storage of knowledge. Another form that is particularly significant for this discussion is the digital simulation model, an executable code that simulates some dynamic aspect of reality. In the case of the digital city, relevant models include simulations of urban growth and sprawl; models of individual travel behavior; and models of traffic flows. Such computational models are capable of taking some existing state of the system, together with appropriately calibrated parameters and boundary conditions, and creating a representation of the system at some future state. Models must of course be validated by comparing their predictions with some form of ground truth or reference.

A digital city clearly needs access to models, if it is to provide predictions of the future of the city, and evaluations of what-if scenarios. To date, however, there has been little interest in the problems of archiving, sharing, and using such models. Recently, we have invested substantial effort in the development of a metadata schema for models as an essential part of an infrastructure for model sharing. Models are regarded as collections of bits, just as geospatial data sets, but with the important distinction that the collections are executable. Our proposed metadata standard for computational models has been described by Hill *et al.* (2001), and is available at http://www.geog.ucsb.edu/~scott/metadata/index.html.

3) Visualization

The digital city requires advanced visualization techniques, in support of rapid pan, and zoom over five orders of magnitude. The speech in which Vice-President Al Gore described Digital Earth refers to a "magic carpet ride", or a simulated fly-by. Applied to the digital city, this would imply that a user should be capable of generating a rendering of the city at 25 or 30 frames per second, constantly changing the viewpoint. This would require on the order of 10 megabits per second of data flow, fast graphics processing, and high-bandwidth access to data sources. Elsewhere (Goodchild, in press), I have shown that such requirements are just within the capabilities of today's personal computers and broadband communication networks, provided one is willing to make modest but realistic assumptions about spatial resolution. Certainly they are within the capabilities of many of today's video game systems, which often have more advanced graphics specifications than personal computers.

4) Sensors

In recent years there have been very rapid advances in the capabilities of sensors that can provide new sources of data for the digital city. These include ground-based sensors, as well as airborne sensors and instruments carried on satellites. For example, we now have several sources of high-resolution imagery from satellites with pixel sizes of 1m. Hyperspectral data with very high spectral resolution is becoming available, and is capable of making very fine distinctions between land covers, for example in identifying makes of vehicles from their paints, and identifying types of roofs or qualities of road pavement. Very economical imagery can now be obtained from cheap pilotless aircraft. Lidar sensors provide a source of very accurate information on elevation, that can be used to improve the quality of data on buildings and other urban structures.

More exciting perhaps are new ground-based sensors. Omnidirectional cameras provide a cheap source of imagery, that can be processed to identify vehicles by their license plates, identify pedestrians and drivers by comparing facial features to databases, and identify anomalous incidents such as traffic accidents or possible crimes, in addition to more conventional uses in measuring traffic volume. Loop detectors embedded in roads can differentiate vehicles by type.

The Global Positioning System (GPS) and other location-measuring systems such as triangulation of cellphone signals provide an effective source of real-time information on location. In the next few years many cellphones will be equipped with GPS. Many vehicles also have GPS transponders, that provide information on the locations of buses and trains, or can be used following vehicle collisions to transmit locational information to an emergency dispatch center. Some extensive data sets on human space-time behavior have been created by installing GPS recorders in vehicles.

Many other ground-based sensors besides GPS are readily used in a mobile context. The term *location-based service* (LBS) implies an application of a form of technology that knows where it is, and is capable of responding accordingly. A GPS unit that tracks the location of a vehicle is providing an LBS, as is a cellphone that is equipped to respond to a query such as "give me the locations of the nearest hotels". LBS are powerful tools for data acquisition for the digital city, if coupled with appropriate sensors. For example, a vehicle equipped with an accurate GPS unit and a camera can be used to record observations of street signage, buildings, and commercial establishments, that can then be used to construct detailed databases. Insurance and real-estate companies use such technology to build databases that include pictures of buildings. *Wearable* computing technology has now advanced to the point where it is feasible to consider equipping anyone conducting a survey, such as a census worker, with GPS, a fully featured PC, a heads-up display, and a wireless communication link, all integrated with the worker's clothing and eyeglasses.

4. Impediments

In this section I review some of the impediments that currently exist to the development of the digital city. The list is far from complete, and reflects personal biases rather than an accurate assessment of severities and priorities.

1) Data Modeling

The scenario painted earlier assumes that the digital city would be integrated through a single, comprehensive data model. Data modeling has advanced dramatically since the earliest days of rasters and vectors, and the applications of the relational model that began in the 1980s. Today, GIS offer various forms of object-oriented data models, incorporating concepts of encapsulation, inheritance, and polymorphism. A series of specialized data models that identify the essential elements of particular application domains has been developed by ESRI (Environmental Systems Research Institute, Redlands, California, USA; http://www.esri.com/software/arcgisdatamodels/index.html), covering such areas as electrical utilities and transportation. The digital city would clearly require the development of a similar model.

In object-oriented modeling, every object or feature is regarded as an instance of a class. For example, a data model for the digital city might identify single-family residence as an object class. The principle of inheritance allows classes to inherit the properties of more general classes, so single-family residence might inherit the properties of residences, which might inherit the properties of buildings. Each class specializes the parent class, by adding more properties that are meaningful only to that class. Encapsulation allows objects to have associated behaviors that are unique to the class, that can be used to ensure integrity in the database, or to provide intelligence during editing. For example, the building class might be associated with methods that can be used to ensure that appropriate building corners are represented as precise right-angles.

If the current lack of a comprehensive data model is an impediment to the development of the digital city, then it would seem straightforward to develop one, using similar processes of consultation to those used in the development of other domain data models. However, object-oriented data models take a particular perspective on geographic representation, which is often described as the discrete object view (see, for example, Worboys, 1995). In this view, the Earth's surface is conceptualized as an empty plane, with discrete points, lines, and areas scattered on it. The objects are sufficiently well defined to maintain integrity, and to be countable. This view of the world is obviously suitable for the representation of people and vehicles, both of which maintain their integrity as they move. It may also be compatible with buildings, traffic lights, and other features of urban infrastructure. But it is problematic for streets, which are continuous, and which must be broken somewhat arbitrarily into discrete pieces in this model. Commonly streets are broken at intersections, which is problematic for several reasons: attributes may change at locations that are not intersections; attributes such as street name are constant over several adjacent objects, creating the potential for error; and data must be restructured if new intersections are created, or existing ones removed.

More problematic are instances of two-dimensional fields, representing variables that are conceptualized as continuous functions of location. This view is compatible with such concepts as population density, crowding, and elevation, and with the data collected by remote sensing. Moreover it underlies many theoretical constructs, such as land rent and value, and perhaps such social variables as poverty and deprivation. Two-dimensional fields, and their one-dimensional equivalents of variables that change continuously along linear features such as streets, are not easily incorporated into the object-oriented model, and tend to be marginalized by systems that adopt it. Clearly a comprehensive data model for the digital city will have to recognize and represent fields as well as discrete objects.

2) Accuracy

A very significant problem has emerged as geolibraries and other technologies have made it easier to integrate data sets from disparate sources, and the problem applies in principle to any instance of *digital x*, because of the use of a spatio-temporal framework. It is impossible to determine position within any such framework perfectly, and in the case of the Earth's surface the ability to determine position is limited by the capabilities of positioning technologies such as GPS and surveying, and by the lack of a perfect mathematical model of the shape of the Earth. Positional accuracy is often no more than is required by the application, since additional accuracy always involves higher cost. It may also be determined by the accuracy of available sources, if data are not acquired specifically for the application. Thus in practice the positional accuracies of data sets available for the digital city vary from centimeters to tens and even hundreds of meters.

Such inaccuracies are exposed whenever data sets of different lineage are superimposed, merged, or compared. Thus two street centerline databases may differ by as much as 10 meters, two versions of the cadaster by as much as a meter, and two sets of reporting zone boundaries for aggregate data by as much as several hundred meters. The problem of bringing such disparate data sets into sufficient coincidence to satisfy visual and application-specific requirements has been termed *conflation*.

Unfortunately it is rarely possible to identify one data set as the most accurate, and to use it as a reference for other data sets. Ideally the most detailed data set, probably the cadaster, would perform this function. Instead, one data set must be chosen somewhat arbitrarily as the reference. Moreover, the fundamental structure of geospatial data sets, in which all objects are georeferenced to a global system, makes it difficult to adjust data sets partially. Goodchild (1999b) has proposed the concept of a *measurement-based GIS* as a way around this problem. In such a GIS, position would be determined by storing original measurements rather than coordinates; for example, the location of a building would be referenced to a property boundary, or *vice versa*, depending on whether the building or the property boundary had more accurate position.

3) Privacy

The digital city would require the acquisition of massive amounts of data. Many of these data, particularly the comparatively static items, are already acquired. But many types of dynamic data, including data on the positions and movements of individuals, are potentially sensitive, because they raise issues of privacy. Much has been written about the potential role of GIS in surveillance, and about how linking data sets through common geographic location allows agencies and corporations to assemble unprecedented amounts of information about individuals and their behaviors (*e.g.*, Curry, 1998; Pickles, 1995). These issues will have to be addressed if the concept of the digital city is to be implemented to any degree. The current supply of data reflects economic concerns, but it also reflects the compromises that agencies such as the census have had to make in order to preserve basic confidentiality in records.

5. Concluding Comments

In this paper I have explored the concept of the digital city, as an instance of a large class of integrated systems termed *digital x*. Like many members of the class, the digital city is appealing from many perspectives. It would allow people in remote locations to learn about a city, perhaps in anticipation of business or recreational travel. It would allow managers to experiment with various development options, and to explore their implications and consequences. It would provide a single environment in which citizens could find important information, such as transit schedules, development plans, or the locations of businesses.

Today, it is possible to provide the services of the digital city through available broadband connections, digital libraries, and the kinds of graphics capabilities now widely available in desktop PCs. The view that would be presented through such a system would reflect the current availability of data, and would thus be largely static, coarse, and variously out of date. Emerging sensors will vastly expand the set of available data in the coming years, from satellites, aircraft, and ground-based sensors. But many of these devices raise important questions of privacy, since they allow the gathering of detailed information on individual movement and behavior. Commercial databases already include such detailed information, as a result of the use of credit cards, cellphones, and various kinds of preference cards; in such cases the potential loss of privacy is compensated by offering small discounts to users, or by convenience.

One of the most critical impediments to the development of the digital city is the lack of a common, integrated data model. The technology now exists to define such a data model for the essential elements of the digital city. But like all object-oriented models, it would pose difficulties in the representation of continuous phenomena, including streets, and field-like variables.

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