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The use cases of digital earth

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The formal process of system design begins with the identification of use cases. No such cases are readily apparent for the current generation of geobrowsers, though the text of the 1998 Gore speech refers to several. An analysis of the use cases of geographic information systems (GIS) reveals similarities with the functionality of geobrowsers, inviting the view that the two forms of geographic information technology will eventually converge. However, experience suggests that users are finding very different ways of exploiting geobrowsers, and two examples are discussed in detail. These uses can be interpreted within a broad framework of spatial concepts, and the paper concludes that this framework provides a better guide to the future of geobrowsers and Digital Earth than current GIS technology.

Keywords: use case; geobrowser; GIS; spatial concept; digital earth

Introduction

Advances in the past few years have demonstrated that many aspects of the Digital Earth that Gore envisioned in 1992 (Gore 1992) and later in his 1998 speech (http://www.isde5.org/al_gore_speech.htm) are now technically feasible. While geobrowsers such as Google Earth offer spatial resolutions that fall somewhat short of the universal sub-meter goal described by Gore, and while many potential sources of geographic data are not yet fully accessible through geobrowser portals, nevertheless it is already possible to imagine a time when these goals will be reached. Digital Earth as a single portal to all that is known about the surface and near-surface of the planet is clearly much closer today than it was 15 or even 10 years ago.

In software engineering the standard approach to system design begins with a formal functional requirements study. A set of use cases is identified that provides a workable sample of the eventual uses planned for the system. These are then elaborated, and become the basis on which design decisions about user interfaces, conceptual and logical data models, and software functionality are made. This process is intended to ensure that the eventual system meets the needs of its planned user community, by involving members of that community throughout the process.

By contrast, no such process appears to have been used in the design of geobrowsers, though one may have existed during the very early days of what eventually became Earthviewer. Instead, the design philosophy appears to have been 'build it and they will come', in other words, that wise design decisions will have

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created a service whose value will be immediately recognised by users. While the community response to Keyhole's Earthviewer was lukewarm, the subsequent acquisition, rebranding, and redesign by Google created something of a sensation among hundreds of millions of users, many of whom had had no prior experience with sophisticated geographic information technology (Butler 2006). From the system design perspective, several questions remain open and are the subject of this paper. First, if a formal set of use cases for Digital Earth were developed, what would it include? Second, what uses have people found for the geobrowsers, beyond the initial 'wow'? Third, how do the uses of geobrowsers compare to those of more traditional geographic information systems (GIS), and how is the relationship between these two geographic information technologies likely to develop?

The paper is structured as follows. The next section discusses GIS, outlining what is known about its use cases as a benchmark for subsequent discussion of geobrowsers. The second and third major sections identify use cases for geobrowsers, first by examining the 1998 speech in detail, and then in more abstract terms, and discuss the degree to which the current set of geobrowsers addresses them. The final section summarises the paper's conclusions.

The use cases of GIS

Initial efforts to construct software systems for handling geospatial data were specialised and uncoordinated (Coppock and Rhind 1991, Foresman 1998). In Canada, Roger Tomlinson and IBM developed a system for ingesting the maps being produced by the Canada Land Inventory, and developed functions to achieve two purposes: the overlay of different thematic maps of the same area that differentiated land according to appropriate classification schemes; and the measurement of area devoted to combinations of one or more specified classes. In the US, the Bureau of the Census developed a system for representing the streets and addresses of the responding public, and the reporting zones of the Bureau's summaries, and used it to administer and tabulate the results of the 1970 census. At the same time, researchers working on urban issues such as transportation planning developed systems to handle the many distinct geographic data types needed for these applications. In the UK, the Experimental Cartography Unit was working on novel computer-based methods for editing and publishing maps. Eventually these efforts converged, and by the late 1970s a single vision emerged for a computer application that would handle a variety of geographic data types and perform a variety of functions. By the 1990s, such systems were available commercially, and could perform virtually any conceivable operation on geographic data.

Comprehensive lists of the capabilities of GIS are notoriously difficult to construct. While it is easy to write that such systems are capable of 'virtually any conceivable operation', it is difficult to point to a union list of such operations, especially given the confused terminology prevalent in the field. One of the most comprehensive efforts to formalise the GIS planning process has been made by Tomlinson (2003), who describes in detail a procedure involving ten steps. The elicitation and description of use cases is Step 4, coming after earlier steps that define the overall strategic goals and introduce users to the nature of GIS. Other useful sources include books by Huxhold and Levinsohn (1995), Campbell and Masser (1995), Longley *et al.* (2005) and Masser (1998).

Tomlinson (2003, pp. 255–276) provides a list of 74 functions under 13 headings. The current version of ESRI's ArcGIS includes several hundred in its pull-down menus, basic extensions, and ArcToolbox, and many more in other extensions. One of the simpler compilations is that of Longley *et al.* (2005), who summarise GIS functions in six categories, based on each one's conceptual sophistication:

1. Query and reasoning. Functions that present data to the user in different views, allowing simple responses to queries.
2. Measurement. Functions such as the measurement of area that motivated Tomlinson, taking advantage of the superior ability of the digital computer to make accurate measurement from maps.
3. Transformation. Functions such as overlay that transform data, creating either new digital objects or new attributes for existing objects.
4. Descriptive summaries. Functions that summarise one or more collections of digital objects based on their attributes and geometric shapes.
5. Optimisation. GIS applications that attempt to provide solutions to problems cast as maximisation or minimisation of objective functions, and used in planning and design.
6. Hypothesis testing. Forms of spatial analysis that employ inferential statistics to generalise from samples to the populations from which they were drawn.

Behind these six classes lie a host of possible use cases, in which one or more functions are employed to obtain useful information from geographic data. GIS is often used as a decision-support system, implying that its functions are used to aid the user in support of some decision-making process.

Large numbers of planning studies have been conducted using functions such as these over the past three decades, and many successful systems have resulted. Broadly, GIS use cases are concerned with inventory and support for decisions, using a battery of methods of query and analysis, as well as the functions needed to visualise and display geographic data in useful ways. There is no doubt that traditional GIS use cases have tended to lean towards analysis and the support of science, and it is easy to find pejorative phrases such as 'merely making a map' and 'simple inventory' in the GIS literature. Databases tend to be highly structured, using relational, object-relational, or object-oriented models, and there is a strong emphasis on procedures that are both replicable in a scientific sense and defensible in court.

Use cases: the Gore speech

The next sections examine specific references in the text of the 1998 speech, as well as the functionality presented by today's geobrowsers, in an effort to address the three questions posed in the paper's introduction.

Visualisation

The speech includes many references to display and visualisation, and it is clear that the idea of replicating the appearance of the planet's surface is a strong theme in Gore's vision. 'A new wave of technological innovation is allowing us to ... display an unprecedented amount of information about our planet and a wide variety of

environmental and cultural phenomena'. The 'young child going to a Digital Earth exhibit at a local museum ... zooms in ... to see continents, then regions, countries, cities, and finally individual houses, trees, and other natural and man-made objects'. '... she plans the perfect hike ... (and) can follow the trail visually from start to finish ...'. Visualisation had a significant impact on the Bosnian peace negotiations: 'At one point ..., the Serbian President agreed to a wider corridor between Sarajevo and the Muslim enclave of Gorazde, after he saw that mountains made a narrow corridor impractical'.

Visualisation is clearly one of the strongest use cases for the current generation of geobrowsers. The ability to see the Earth's surface as it actually appears from above has attracted millions to zoom into their own neighbourhoods, marvelling at the fine spatial resolution now routinely available from such sensors as IKONOS and Quickbird and from aerial photography, and experiencing acute disappointment when their homes lie in areas of comparatively coarse imagery. This is Digital Earth as a mirror world, a faithful digital rendering of the real thing, based on draping imagery over a digital elevation model, and offering views that to the average person would otherwise be available only briefly, by paying for a ride in an airplane or hot-air balloon.

Ease of use

Much of Google Earth's success is attributable to the extreme ease with which users can learn to manipulate its interface. While GIS is typically taught in the upper division of university undergraduate programs and in specialised training courses for professionals, Google Earth meets what might be termed the child-of-ten standard of user interface design: a child of ten can learn to do something useful with it in ten minutes (Gore talks of a 'young child' in his 1998 speech.) Google Earth achieves this in part by avoiding all reference to the technical details of georeferencing, projections, and figures of the Earth, and presenting the planet as it would appear from a user-controlled viewpoint, in as close as possible to its actual appearance. There is none of the false colour of remote sensing or the complexity of flattening the Earth, in order to cover it with uniformly shaped pixels. The difficult concept of scale is avoided by the simple expedient of allowing the user to raise or lower the position of the viewpoint; if measurements of distance are needed, they are computed as Great Circle arcs and given in units of ground distance.

These achievements were the cause of no small degree of consternation in the GIS community when Google Earth first appeared. Instead of treating a fly-by as the crowning achievement of a lengthy training course in GIS, users of Google Earth were able to generate one using a simple, intuitive interface that fell well within the child-of-ten standard. Google Earth was termed 'the democratisation of GIS' (Butler 2006), since it exposed geographic information technology to virtually anyone, and stimulated thousands to envision and develop novel applications.

Gore refers in his 1998 speech to the desktop metaphor that dominates current computer use, and comments that it is 'not really suited to this new challenge'. In GIS data sets are typically represented in the conventional way as organised into a hierarchy of folders, using an approach designed to replicate the operation of an office. Far more intuitive is the notion of geographic data sets distributed over the surface of the Earth, in positions roughly corresponding to their geographic

footprints. Thus, users of Google Earth will be familiar with icons that signal the presence of additional information about a place, and reveal it on demand.

Interoperability and mashups

The notion of Digital Earth as a mechanism for integrating data from multiple sources is the primary motivation for Gore's first reference to it in his 1992 book (Gore 1992), and occurs at several points in the 1998 speech. Digital Earth is 'A multi-resolution, three-dimensional representation of the planet, into which we can embed vast quantities of geo-referenced information'. It would include 'the mechanisms for integrating and displaying information from multiple sources'. Interoperability and metadata are identified as two key technologies in enabling this vision.

GIS is often presented as a technology for integrating data, based on location as the integrating mechanism. The concepts of layers representing disparate themes, and of overlay as the integrating procedure, have achieved almost iconic status over the years, appearing on the front covers of many textbooks. Google Earth implements essentially the same concept, but in a much more restricted sense. Two layers, the base imagery and elevation, are given foundation status, and all other layers are superimposed only in a visual sense, with no capabilities for analysis of any kind. Overlaid layers can if necessary be made partially transparent, allowing the base imagery to be seen through them, but this falls far short of the equivalent capabilities of GIS. Thus there are no capabilities for topological overlay, for logical and arithmetic combination of layers, or any of the basic concepts of GIS analysis.

On the other hand, Google Earth goes substantially beyond traditional GIS in the ease with which data can be integrated on the fly from distributed sources. The concept of a mashup is no more than a GIS user would identify as a graphical rather than topological overlay, but it allows two- and three-dimensional structures to be superimposed on the Google Earth base using scripts written in the interface language KML. Third parties were quick to offer software to simplify the task of programming in KML; Arc2Earth (www.arc2earth.com), for example, allows users of ESRI's ArcGIS to output data directly in KML using a simple extension. Today, a vast number of such mashups can be found by web search, providing a dazzling array of georeferenced information, including all of the places found in the life and novels of Jane Austen (<http://bbs.keyhole.com/ubb/showflat.php/Cat/0/Number/411188/an/0/page/0>), historic maps of many areas of the world (many maps from the David Rumsey collection, <http://www.davidrumsey.com>, are available in Google Earth's Featured Content), the campaigns of Alexander the Great (<http://bbs.keyhole.com/ubb/download.php?Number=126402>), three-dimensional representations of the buildings of central London (<http://bbs.keyhole.com/ubb/download.php?Number=420893>), and the subway systems of many cities (<http://bbs.keyhole.com/ubb/showthreaded.php/Cat/0/Number/579229/page/vc/vc/1>). All of these have been contributed by third parties using simple procedures. While it is possible to identify thousands of data warehouses and geoportals, the integration of their contents in GIS applications has never been as simple and straightforward as a Google Earth mashup.

Modelling and simulation

One of the more ambitious sections of the speech concerns the simulation of social and environmental phenomena. Models of the social and physical processes that impact and modify the geographic world, such as erosion, migration, urban growth, or extreme weather events, could be implemented in Digital Earth, allowing its users to visualise future states of the planet's surface, giving 'new insights into the data that we are collecting about our planet' and allowing decision makers to evaluate the effects of policy options. Gore sees high-performance computing as offering a third kind of science – a 'computational science' – that 'allows us to overcome the limitations of both experimental and theoretical science', a theme that is echoed in recent discussions of cyberinfrastructure (<http://www.nsf.gov/od/oci/reports/toc.jsp>).

Unlike the ideas reviewed in previous sections, this one has no presence in the current generation of geobrowsers. NASA's open-source World Wind comes closest to providing a platform for the visualisation of simulations, reflecting the interests of the agency in the applications of models of environmental processes. Google Earth has limited capabilities for the display of dynamic information, but its comparatively closed architecture makes an awkward platform for computationally intensive simulation.

To date, then, this aspect of the Gore dream remains almost entirely unrealised. Nevertheless, it is possible to outline a research and development agenda that would allow modelling and simulation to be implemented. Models of the dynamic behaviour of spatial objects, such as pedestrians or vehicles might be implemented on servers, initiated by users, and their results fed to geobrowsers. On the other hand, models of the dynamic behaviour of fields, such as are common in the environmental sciences, might be implemented on the client side using the finite-element structure of the geobrowser itself, and the results displayed as isolines. Given a standard for the description of models, it would be possible to implement mechanisms that would allow users to search for, access, and execute suitable simulation codes (Crosier *et al.* 2003).

Use cases: geobrowsers and spatial concepts

With the exception of a few measurement tools, the analytic procedures of GIS are almost completely absent in Google Earth. Thus, an immediate and logical response from the GIS community to its release was to imagine a future in which analytic capabilities gave it something approaching the power of GIS. ESRI's response to Google Earth was to introduce ArcGIS Explorer (<http://www.esri.com/software/arcgis/explorer/index.html>), an implementation of server GIS with a stronger orientation to the analytic user. But the dominant paradigm of Google Earth remains visualisation – the manipulation of a virtual body whose appearance matches that of the real Earth as closely as possible. Point features, such as landmarks and linear features, such as roads and rivers can be rendered as symbols and overlaid graphically, but it is much more difficult to render information associated with areal features, especially when such information is not inherently visual. Mashups that attempt to render census statistics for reporting zones on top of the Google Earth base (e.g., <http://gecensus.stanford.edu>) produce very confusing hybrids of the visual and symbolic. Moreover, it seems inevitable that any attempt to

integrate analytic power into geobrowsers will lead to much more problematic user interfaces, and fall far short of the child of ten standard.

Perhaps, then, the notion of a logical development trajectory from Google Earth to some kind of analytic engine that more closely resembles GIS is mistaken, and one should look elsewhere for the use cases of Digital Earth. People who have used Google Earth to visualise their neighbourhoods do not seem to be clamouring for greater analytic sophistication, but instead to be finding a new set of use cases that bears only a weak relationship to GIS. The following sections explore this possibility, based in part on the author's own experience. They suggest that the use cases of Digital Earth are better understood within a broad framework of spatial concepts than in the comparatively narrow framework of GIS functionality. The next few sections examine some of these concepts and their relevance to Google Earth.

Spatial context

Consider the following example, drawn from a recent class in introductory GIS. The D8 algorithm (O'Callaghan and Mark 1984) is a well-known GIS function, designed to take a digital elevation model (DEM) and compute an expected hydrologic network. Water is assumed to drain from each cell of the DEM in one of nine ways. Either the cell's elevation is no higher than that of any of its neighbours, in which case the cell is classified as a pit and has no outlet; or at least one neighbour is lower and water is assumed to drain to the lowest of the cell's eight neighbours. Water is allowed to accumulate downhill, and when the volume passing through a cell (measured in the number of upstream cells) exceeds a certain threshold a channel is predicted. Figure 1 shows the channels predicted based on a DEM of Orange County, CA (with square cells 30 m on a side); the thickness of each channel represents the volume of water predicted to flow along it.

Next the predicted network is compared to the actual network, as represented by a hydrographic layer (Figure 2). Certain differences are immediately obvious, particularly the substantial difference between the predicted and actual course of the largest channel. A query of the hydrographic layer reveals this to be the Santa



Figure 1. Computed channels for an area of Orange County, California. Emphasis is proportional to accumulated water flow.

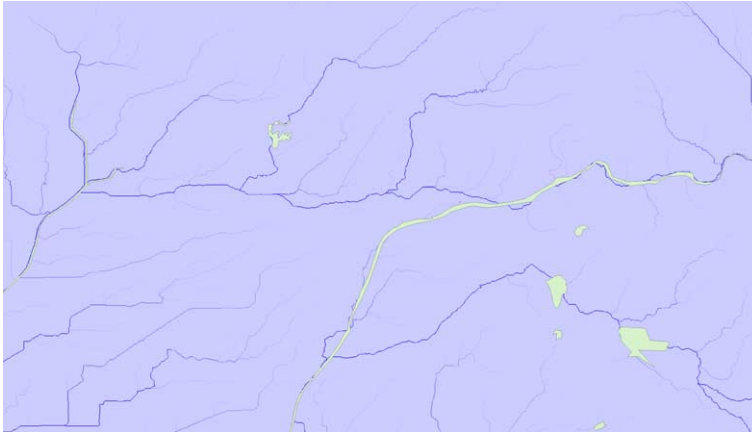


Figure 2. Major water bodies (light green) and computed channels (blue). The Santa Ana River runs from right to bottom, and begins its major deviation from the computed channel at approximately 117.78 W, 33.86 N.

Ana River, which rises in the eastern part of the county, flows through a narrow canyon, and spills onto the coastal plain. But the GIS analysis provides very little context or basis of explanation. While the DEM is detailed and accurate, and the D8 algorithm provides a very useful means of predicting hydrography, the landscape of Orange County looks very abstract when viewed through the lens of GIS.

Context is abundant in Google Earth, however, and while the imagery of Orange County constitutes no more than a simple rendering of the landscape as viewed from above, the ability to explore it interactively provides a very powerful complement to the GIS analysis. As Figure 3 makes clear, downstream of the canyon the Santa Ana River enters a floodplain with very little relief, and is confined to its current channel by a system of levees. These are not large enough to be detectable in the DEM, and thus have no impact on the D8 algorithm. Differences in elevation in the DEM are very small, leading to very large uncertainties about the river's route. Moreover, a quick search of Orange County historic information reveals a long history of flooding and movement of the river's channel, until the levees were finally built. The flood of 1825 was particularly notable in changing the river's ocean outlet by several miles (<http://www.hbsurfcity.com/history/floodhis.htm>).

Spatial anomalies

Another strong argument for a spatial perspective concerns anomalies or outliers: areas of the Earth's surface that are unexpected, and thus invite explanation. One of the most powerful principles of the spatial perspective is the concept known as Tobler's First Law, after Waldo Tobler (Tobler 1970, Sui 2004): 'All things are related, but nearby things are more related than distant things'. Spatial anomalies are counter-examples, where an area stands out as unexpectedly different from neighbouring areas. Such anomalies often lead to speculation about cause: what factors have led this area to be so different from its neighbors?

Consider, for example, the City of Milwaukee and the distribution of its African-American population. The 1990 census provides data on the percentage African-

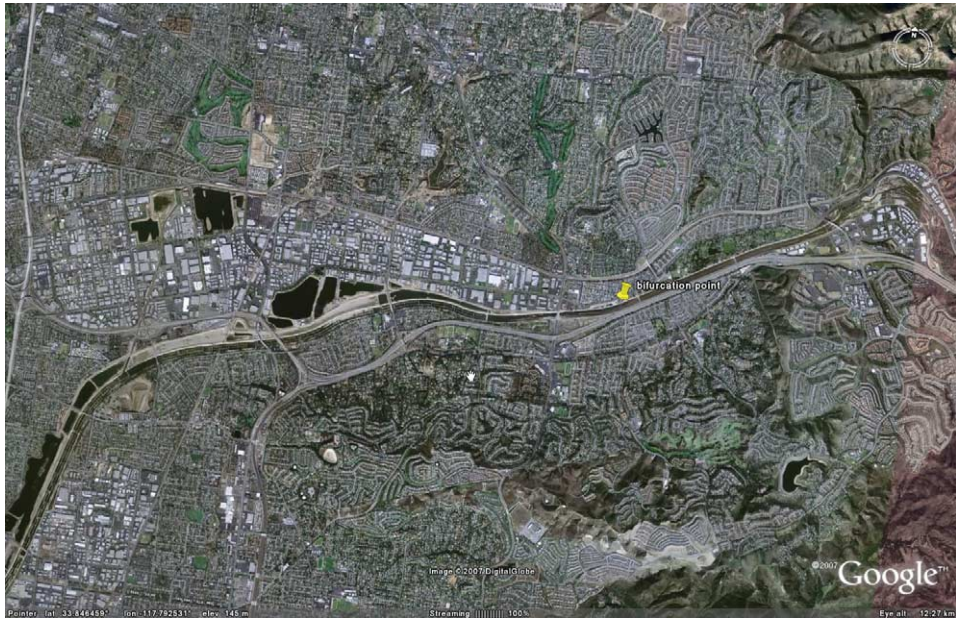


Figure 3. Google Earth visualisation of the area surrounding the point of bifurcation between the computed Santa Ana River channel and the real channel. The river flows out of the canyon onto the floodplain at the right.

American for each census tract (an approximately homogeneous area of roughly 5000 population), and as Figure 4 shows African Americans are concentrated in an area to the north and west of downtown. But one tract stands out, with a high

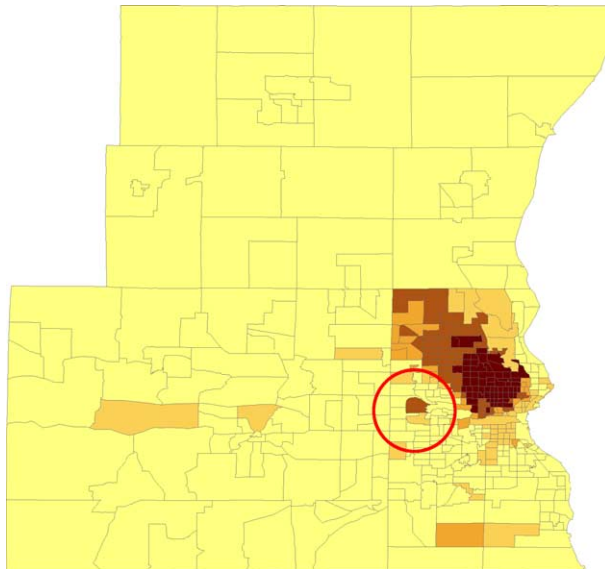


Figure 4. Milwaukee, Wisconsin by census tract, showing the percent African American in 1990. The anomalous tract is circled.

percent African-American in an area that is otherwise primarily white. In this example GIS provides excellent tools for mapping the census data, for measuring the degree to which any area stands out from its neighbours, and for determining whether the anomaly is statistically significant. But it provides no other context or basis of explanation. However, Figure 5 shows the area at fine spatial resolution in Google Earth, revealing clearly that it is dominated by a few institutional structures, which a little investigation identifies as a medical school.

Access to imagery per se is not what distinguishes these examples, since with a little work one could have introduced an image layer into the GIS. But no GIS has ever managed to achieve the same ease of access and use that characterises Google Earth and the other geobrowsers. There is no lengthy period of search, licensing, download, format conversion, and import that would be necessary if comparable imagery were to be combined with GIS; instead, the Google Earth service is free, fully integrated in a single server, and available within seconds.

Conclusions

As these examples demonstrate, people are finding uses for the geobrowsers that are very different from typical GIS applications. They have none of the analytic, modelling, and inferential power of GIS, and while oriented to visualisation are nevertheless very limited in what can be visualised, because of their insistence on content that is inherently visual. In other ways, however, the uses of geobrowsers go well beyond those of GIS, reaching into a broad and rich domain of spatial concepts that can be very powerful aids to understanding and insight.

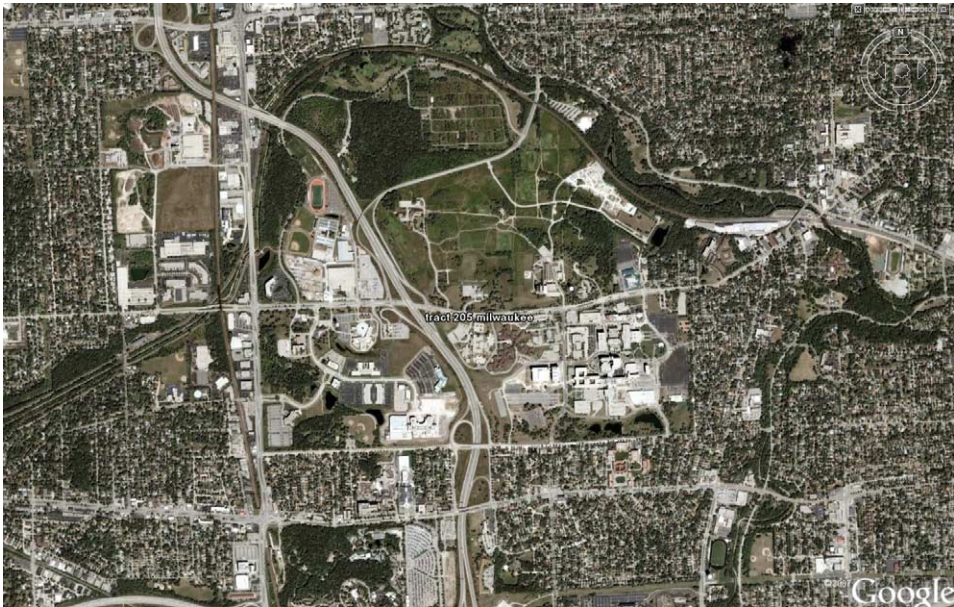


Figure 5. A Google Earth close-up of the anomalous tract, showing its current mix of park and institutional land use.

Although only two spatial concepts have been discussed in this paper, several recent publications have attempted to enumerate a much larger set. A recent report of the National Research Council (2006) discusses the importance of spatial thinking in primary and secondary education, arguing that spatial concepts can be effective paths to learning in a wide range of disciplines, and examining the role of geographic information technologies in facilitating the learning process. de Smith *et al.* (2007) include a comprehensive list of spatial concepts as an introduction to their recent guide to geospatial analysis, while Di Biase *et al.* (2006) provide a comprehensive guide to the concepts underlying GIS. Goodchild (2006) has argued that recent developments in geographic information technologies, including the introduction of Google Earth, have created a need for a radically different approach to GIS education that focuses much more on fundamental spatial concepts, and on spatial thinking in general. He argues that spatial thinking is one of the fundamental forms of intelligence needed to function in modern society, and that the development of such skills should be part of everyone's education.

The central purpose of this paper has been to examine the use cases of Digital Earth. It is evident both from the Gore speech and from recent history that these use cases are not simply limited versions of the use cases of GIS, but something different and in some respects more important, since the community of geobrowser users is far larger by orders of magnitude than the community of GIS users. There are lessons to be learned in the ease of use of geobrowser technology, the value of its integrated and accessible patchwork of imagery, and the uses people have found for it. Nevertheless the current generation falls short of the Gore vision in several important respects, and is stimulating interesting and significant research that will help to define the next generation.

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