# REDISCOVERING THE WORLD THROUGH GIS

## Prospects for a Second Age of Geographical Discovery

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The First Age of Discovery began with Prince Henry the Navigator's sponsorship of scientific exploration, and ended when the last white areas on the map of Africa were filled. It took place in an era of growing political stability, intellectual renaissance, and commercial incentive. Rediscovery can be interpreted in four ways: going there again; reassessment and new insight; virtual travel; and more effective and productive interpretation. A second age of geographical discovery will be more about personal than about collective discovery; and will have access to immensely powerful information and sensing technologies. Two themes are proposed for the builders of the geographic information technologies that will enable a second age. Digital Earth is defined as an immersive environment providing access to the planet at any level of detail, and to invisible as well as visible information. Field GIS is defined as GIS in the field, in the presence of the reality represented by the digital database. The final section of the paper presents an outline of research agendas in both areas.

**KEYWORDS:** Age of Discovery, GIS, Digital Earth, Field Computing.

### INTRODUCTION

GIS PlaNET '98 is taking place in conjunction with EXPO '98 in Lisbon, approximately 500 years after the peak of Portuguese dominance of the Age of Discovery, and the voyages of Bartolomeu Dias and Vasco da Gama. Lisbon is the home of GIS in Portugal, and of a vibrant GIS research community that has made many important contributions to the field. 1998 is also 604 years after the birth of Henry the Navigator, the man who is credited with initiating the development of the European concept of scientific exploration that characterized the Age of Discovery. So the conference provides an ideal venue for talking about GIS as a mechanism for *re*discovering the world. But it is not at all clear what that might mean, or what the GIS research community represented at the conference ought to do to support and foster it. This paper explores those issues, outlines the possible nature of a second age of geographic discovery, and discusses two among the many research directions that might be pursued in order to make it possible.

The first part of the paper presents a very brief overview of the conditions that fostered the Age of Discovery. The second section moves forward 500 years, to examine what the term *rediscovery* might mean today. Four solutions are offered. It then moves to a discussion of roles for the research community in the third section, and to outlines of the two proposed research agendas.

### THE AGE OF DISCOVERY

Henry the Navigator, or Henrique, Infanta of Portugal, was born in Porto in 1394, in the chaos of late 14th Century Europe, and died in 1460 in the relative stability of the mid 15th Century and the beginning of the Renaissance. He had an English mother (Philippa Lancaster, daughter of John of Gaunt) and a Portuguese father (King João I). He appears to have been many things—at times a war hero and at times a war loser, at times driven by commercial gain and at times by scientific curiosity—but it is above all in his role as a sponsor and facilitator of exploration, as a patron of discovery, that he is known by posterity. The early success of Portugal and Portuguese explorers in the Age of Discovery seems to have been due more than anything to his bringing together of a school of experts in Sagres, and in encouraging and financing expeditions from there.

Three conditions seem to have been most important to Henry's success:

- Relative political stability. The Age of Discovery began as the Islamic influence on the Iberian Peninsula was in its final decline, and as Europe was recovering from the impact of the Black Death (Henry's mother died of the plague).

- Commitment to exploration as a science. Henry gathered the best European and Islamic map-makers, shipbuilders, and astronomers to Sagres, just as today one might assemble a multidisciplinary team to form a research center. He saw discovery as having many of the same characteristics that we now ascribe to science: the drive of curiosity, commitment to accuracy, and common ownership of results.

- Sufficient financial support. Henry's father brought new lands in North Africa under Portuguese control, and Henry was able to use first his Governorship of Algarve, and later his position of Grand Master of the Order of Christ to finance his school and expeditions. Later still support came from the diversion of trade following the collapse of Islamic power, particularly trade in slaves and gold, although Henry forbad the former after 1455. Nevertheless, he lived simply, never married, and died heavily in debt.

**Figure 1. Prince Henry the Navigator, 1394–1460**

The actual discoveries of Henry's lifetime were modest: they included the Cape Verde Islands, which redefined the westernmost limits of the known world, and the coast of West Africa only as far as Sierra Leone. The great discoveries came later; but Henry clearly laid the foundation, particularly through the notion of discovery as a collective, scientifically-motivated endeavor, in which economic gain was strictly secondary, and in which the economic value of secrecy was outweighed by the collective value of sharing information [10] (though for a contrary view see for example [2], [3]). Sharing of knowledge is of course a fundamental given of science, which struggles constantly with the tension between public ownership and private career advancement. It is also a principle that the geographic information community struggles with more than ever today [6], given its position at the interface between the needs of science and those of commerce. It seems that after Henry's death the balance may have swung a little: Portuguese expeditions may have mapped much of the coast of Australia before 1536, and the Portuguese may have known about the existence of Brazil long before claiming it in 1500, and before the Treaty of Tordesillas in 1494, which divided the new American discoveries between Spain and Portugal along a line 370 leagues west of the Cape Verde Islands [7].

## THE NATURE OF REDISCOVERY

If discovery is about being the first to visit, record, and report, then *re*discovery suggests somehow that what was once discovered has been lost, and that a new cycle of visiting, recording, and reporting is needed. Rediscovery often has negative connotations in science, implying that knowledge presented as new is in fact no more than a repetition of knowledge acquired and published some time before by someone else. Knowledge that is new to one discipline may turn out to be old hat to another, and the same knowledge may be associated with different names, and different dates. Thiessen was certainly not the first to *discover* that a set of points could be used to tesselate a space if every location were assigned to the nearest point, and perhaps not the first to propose its use as a interpolation rule, but the operation is often associated with him in GIS, and his paper is frequently cited [5].

Moreover, in the contemporary post-modern view the Age of Discovery really wasn't, in that an embarrassingly high proportion of places discovered by Europeans were already occupied by non-Europeans, or had been visited by Europeans before. Although the Portuguese reached India in 1498 during the golden era of the Age of Discovery, Christianity had reached the coast of South India over 1200 years before, during a period of active trade with the Roman Empire, and Alexander the Great had invaded India in 325 BC. What was different this time around was not discovery, but map-making, scientific curiosity, and the notion of knowledge as a collective human asset. The Age of Discovery was about describing and documenting for others across the European world, through the medium of the newly-invented printing press, and thus about the notion of European society as a collective, integrated whole with its own store of knowledge. It was about generalizing and abstracting from observation in a context that was increasingly free of the domination of early Christian church dogma, although still anxious to see the hand of God in the workings of the planet, and still anxious to spread the word of God to all of its corners. The supreme example of abstraction from geographic observation must be Charles Darwin's development of the theory of evolution as a result of his travels.

So if discovery can be characterized as abstraction from observation, what might *re*discovery mean, when every part of the planet has been discovered? The following sections suggest four different solutions.

### 1. Rediscovery is going there again

Caves are one of the few areas of the planet where there is still the opportunity for discovery in its traditional sense. Cavers (the preferred term; *spelunker* appears to have been coined in 1937 and to have caught on as a term the rest of the world could use to describe this exotic group with its incomprehensible enthusiasms [8]) use the term *virgin cave* to describe a new discovery, a cave entered for the first time by a human. Non-virgin cave almost always shows evidence of previous entry, leading Taylor to describe caving as "unique in the way it destroys its own environment" [8, p.11]. Non-virgin cave has footprints, smudges where bodies have dragged themselves, bolts used to secure climbers, marks made for surveying, and

at a less professional level, names, garbage, string, plastic tape, and other aids to wayfinding.

Virgin cave has enormous kudos to cavers, who can be divided into two clear categories: those who are driven by the quest for virgin cave, for whom other cave has very little attraction; and those whose satisfaction comes from entering an area that they *themselves* have not visited before. People in the latter category are content to *re*discover, and define discovery at a personal rather than a collective level. Prior to 1970 it was common practice for cavers to survey new caves, and to publish both the cave maps and the locations of entrances (e.g. [1]). Since then, the negative consequences of caving have led to a reversal of practice: knowledge is no longer published and collective, but passed largely among friends; and the caving world has fragmented into a number of distinct *information communities*.

In that sense caving has become more like conventional tourism, which is much more about personal discovery, and being the first on your block to visit Iran, than about finding parts of the world where no one has trodden before. In this New Age of personal discovery there is no shortage of opportunity for revisiting interesting places.

This interpretation of rediscovery is problematic for science, of course, which is about collective rather than personal discovery. If every part of the world has been discovered, then is there any more *science* in discovery, or are we scientists condemned to the life of the tourist, rediscovering things that other disciplines already know? How can rediscovery have scientific value?

## 2. Rediscovering is finding more

Virgin cave often comes as a result of pushing a bit harder at the edges of known territory, through a tighter squeeze, or through a flooded section, or by removing a few rocks. Discovery in science is similary about digging a bit deeper, reworking old data, abstracting to a higher level of generalization, finding a link that was previously elusive, or having an insight that was invisible to the people who did the experiment [11]. In that sense, geographical rediscovery means visiting old places with new eyes, new tools, and greater insights.

Of course this is the ideal territory for GIS. GIS lets us observe at scales, and from viewpoints that were simply not available to the first explorers. We can literally see the wood for the trees, link and correlate the layers, apply powerful methods of analysis that go far beyond intuition, interpolate and extrapolate, and generalize. We can build simulation models that change the landscape by applying processes to what we see and observe.

Hundreds if not thousands of people must have visited the Galapagos Islands before Darwin, but none had his insights. In that sense Darwin *re*discovered the Galapagos, discovering the theory of natural selection by visiting an area that is superbly designed to reveal a general process that we now know occurs everywhere, but is also invisible almost everywhere (except perhaps to Alfred Wallace in Indonesia and Brazil at roughly the same time).

Darwin had the insight to see that connection between geographic distribution and process. He obtained his insights without GIS, though he did have a map. It seems reasonable to believe that he would have got there quicker if he had had a GIS, and a team of people to make his observations for him and to enter them for analysis, because by today's standards his insights came with excruciating and uneconomic slowness.

## 3. Virtual rediscovery

Does discovery have to mean being there at all? Today we understand increasingly that "there is no more there, everywhere is here" [4]. The Internet, Microsoft, and Hollywood offer to deliver the world to our desktops and living rooms, making virtual tourists and discoverers of us all. In the ultimately democratized society there is no value at all in an Age of Discovery that makes heroes of a few but offers nothing to the masses, and creates no product that can be shrink-wrapped and marketed.

Vice President of the United States Al Gore dreams of a Digital Earth (DE) that will make us all potential participants in a new age of discovery, and particularly the children who most need to discover the planet they live on. The vision of Digital Earth has two distinct parts. *Triana* is a camera pointing at Earth from a position directly between it and the sun, providing a constant digital video feed through television and the Internet; a constant whole-Earth perspective available to anyone. The second, which is more relevant to GIS, is an immersive environment through which a user, particularly a child, could explore the planet, its environment, and its human societies. This DE environment might be available at museums or libraries, and a more modest version might be accessible to all through standard browsers. Users would be able to access imagery and also statistical data, and would also be able to analyze, model, and simulate using the capabilities of GIS. DE would be far more than a virtual tourist experience, because it would provide access to the best of scientific data and understanding of human and physical systems.

## 4. Rediscovery is more productive

Hopefully the previous three sections have provided a sound basis for belief in rediscovery as a useful and productive enterprise, with the potential to yield new insights, new learning, and new personal experience. If so, one might then ask how to make the most of rediscovery, how to maximize the chances of new insight, how to make the process as effective as possible, since GIS is as much about increasing productivity as it is about enabling the previously impossible.

All discovery and rediscovery must have a human subject, the person who is learning, having the new insight, doing the exploring, or reporting for others. As members of the GIS community, we assert frequently that human discovery, particularly of a geographic kind, is aided by geographic information technologies. These are ideally co-located with the human subject, who makes use of a human-computer interface (HCI, or CHI) to interact with the technology: a personal computer with a keyboard, mouse, and screen if the location is the desktop; a palmtop with a stylus; or a thin web client. The

technology is connected via copper, fiber, or wireless link with additional data and processing power.

The human is far from neutral in this interaction, however. Besides intelligence and the powers of reason, he or she also is able to draw on personal memory of relevant facts, geographic context, memories of past visits, or the content of courses in regional geography. All of these provide context to the interaction, and help to ensure that the decisions made by some, better-informed and better-educated users of GIS will be better in the long run than those made by others. Geographic information techologies augment the power of the human brain, they do not replace it.

But this world of HCI is the world of the darkened room, the glowing screen, and the half-chewed pizza, in which the geographic reality that is the subject of analysis has no role other than that provided by the computer database or the human memory. In Al Gore's vision of Digital Earth the school child visits the museum to learn about the world, not the real thing: DE is a substitute for expensive field trips and the sheer messiness of interactions with the real geographical environment: the complications of foreign languages, unfamiliar food, and threats to personal safety. DE perpetuates the notion of the detached scientific observer, with natural phenomena and human societies equally the subjects of observation and analysis.

Yet the computer does not *have* to substitute for reality, especially when the economic incentive of not having to travel is outweighed by the value of greater insight. Perhaps it is time to think about HCRI—Human-Computer-Reality Interaction—by acknowledging the value of reality as a context for geographic decisions, as a third and valuable element in the decision-making environment. Can we build an HCRI interface to augment the value of being there with computer technologies, rather than replacing it? If interaction with the computer must occupy part of one or two senses (sight, or touch), then the remaining senses are still available for additional input. HCRI would allow GIS analysis to occur in direct contact with the ground truth, supporting decisions in the field where surely decisions are best-informed.

## RESEARCH FOR REDISCOVERY

The GIS research community is not the group who will rediscover the world through GIS: that opportunity will exist for a far larger population, if the preceding arguments are valid, and will be characterized by personal as much as by collective discovery, and by immensely powerful information technology and information resources. In the best of circumstances the GIS researchers are the ones who do the basic work in geographic information science that enables the development of better technology, that in turn enables rediscovery, so we are two stages removed from the rediscovery process itself. This begs two questions: what tools will best enable rediscovery, and what research needs to be done to allow those tools to be developed?

One can imagine an almost unlimited range of new forms of geographic information technology, but I would like to focus in this section on just two, both of which emerged in the previous discussion: DE, and the HCRI.

### Building Digital Earth

If Al Gore's vision is sufficiently well-defined, then we can ask what research needs to be in place to enable its realization. What don't we yet know how to do, in delivering immersive services that allow their users to explore and rediscover the planet? I would like to suggest five:

- *Access to data.* Currently, our methods for disseminating and accessing geographic data mirror our traditional production methods. The production of data has been dominated by national agencies in most countries, by the public sector, and by production of data by theme. Thus it is comparatively easy to obtain a digital elevation model or topographic vector data, although in some countries one may have to pay for the service; and it is much easier to obtain digital elevation models of two parts of the same country than it is to obtain two types of data (digital elevation model and topographic vector data) for one part. The respective servers may be managed by different agencies, the standards will be different, and the two data sets may not register perfectly to each other. Digital Earth will require a very different approach, in which it is easier to obtain all data about one place than to obtain the same type of data about all places, but the technology to make that possible is not yet in place. Moreover, we do not yet know how to search distributed information resources for all of the information about one place, or how to build the necessary search engines to discover the data. Having found the data, we do not know how to divide the process of selection between the client and the server, or how to transmit the data usefully over limited bandwidth.

- *Data integration.* Assuming that it is possible to discover all of the information about a place, and to retrieve that part of it that is useful, Digital Earth will need novel techniques for integrating data to remove conflicts and to present the user with what is most useful. We do not yet have the comprehensive approach to conflation that will be needed, and that we can use to merge data from different sources with different scales and levels of accuracy, and potentially different semantics.

- *Tools for visualization.* DE will be very different from traditional approaches to geographic visualization. Because everything will be done on the fly, all displays will be user-centered, and the field of view will always have a clearly-defined high-resolution center and a low-resolution periphery. DE will require smooth zooming, across up to 5 orders of magnitude (from 10km resolution for the whole Earth to 1m or less for local detail), and possibly across different semantics and ontologies. For example, a user wanting to see population will want to zoom from a population density surface at the whole-Earth scale to a view of individual towns and

- cities, and perhaps individual people at the finest scale.

- *Tools to access invisible and non-sensory data.* In Al Gore's vision, DE is a mechanism for accessing not only how the planet actually looks, but also themes and variables that are invisible or non-sensory, such as atmospheric conditions, or economic statistics. DE will have to have means for signalling the presence of such information to the user, through icons, and for visualizing it on demand. Thus it will need to merge two powerful traditions—imaging and cartographic—in powerful and probably novel ways.

- *Tools for analysis and simulation.* Finally, DE will have to incorporate what we now think of as GIS functionality within an environment that bears a much closer resemblance to the services of a data library than an analytic GIS engine. Thus far these have been separate worlds, with very little overlap. Few developers of digital libraries have had to provide sophisticated and powerful services for the analysis of the data they deliver; and few developers of GIS have paid much attention to tools for information discovery, search, access, evaluation, and retrieval.

Since Al Gore first defined Digital Earth in early 1998 there has been much discussion of how it might be realized, and several efforts are under way to develop prototypes. The speech itself can be found on the OGC web site, *www.opengis.org*, and a commentary on the ESRI web site *www.esri.com*. The U.S. National Research Council's Mapping Science Committee has an effort under way to explore the concept of Distributed Geolibraries, which have much in common with DE; further details can be found at *www2.nas.edu/besr/230a.html*. Finally, the U.S. University Consortium for Geographic Information Science is developing a perspective on the DE research agenda based on its own ten Research Priorities: see *www.ucgis.org*.

## 2. Building the human–computer–reality interface

The field is where the remaining senses that are not engaged with the computer can engage with reality. If the reality is the one represented in the database, then those remaining senses can provide context for decisions; detect what is not in the database; and provide ground truth. Thus the field is where the third part of the HCRI can be found, and the logical location for GIS if technological and other constraints can be overcome. Of course, GIS has not been a field technology to date in part because of the severity of those constraints, but there is every sign that they will be removed rapidly in the next few years.

In this section I discuss six areas in which research is needed if the HCRI is to be realized, and if GIS is to become a field technology.

- *Sampling and measurement.* Traditionally, sampling campaigns have been conducted on the assumption that all of the analysis must occur in the office, where the computational power is located, and much of the field work is delegated to assistants, since the important decisions will have to be made at the time of analysis. Field computing offers to change these priorities fundamentally, since it allows analysis to take place in the field as the results come in. Sampling can be adapted [9], and transects can be redirected in midstream, if there is the possibility of analyzing the data on the fly. Field computing also changes the importance of data volume, since it allows data to be collected very economically, without much attention to potential analytic value. This raises the importance of *context*, or information that may potentially be of value in analyzing and interpreting the observations that were the main purpose of the field work.

- *Cognition and human–computer interaction.* It seems likely that interaction in the field will have to avoid some of the traditional modes, such as the keyboard, since they cannot be sufficiently ruggedized, and are unsuitable for the tough conditions of the field. Pen computers are already here, and speech recognition appears to be the basis of choice for interaction in the vehicle. We do not understand much about how people think in the field, or attempt to interpret their surroundings, so we currently have little formal basis for the design of field interfaces.

- *Computation.* Computing in the field will need new data models, to deal with new modes of interaction, such as sketch recording of ideas. If Charles Darwin had had a field computer, it would have had to have anticipated and accommodated his own preferred methods of recording field observations. Field computing will also need new data structures that are capable of reliable upload and download over unreliable communication channels of limited bandwidth.

- *Communications.* Field computing will need to make use of wireless communications, and will have to work transparently across a range of technologies, including the various cellular standards, satellite-based systems, beacon transmitters, and others. Many of these channels are inherently asymmetrical, with much higher bandwidth in one direction. Field computing will need to be able to download existing data from stores as well as to upload new data. The ability to direct information to a particular geographic location would be invaluable, but is currently not supported by the Internet, which is based instead on a concept of a one-dimensional branching network instead of a two-dimensional geographic space.

- *The where of computing.* This concept of field computing is based on the notion that computing can occur anywhere, and thus that human–computer interaction can occur in the presence of the relevant reality, and engage with it. Computing must occur somewhere, but with today's and tomorrow's technologies it will be possible almost anywhere. This raises an interesting and complex question: where *should* computing occur? Is it possible to build a theory of the location of computing activities and

related predictive models that can direct optimal decisions, and evaluate other ones?

- *Social and institutional impacts.* Finally, field computing will raise many social, economic, and institutional concerns. Who owns the data that are captured on someone's private property? Under what circumstances will field GIS invade privacy? What impact will it have on existing institutions and arrangements for the production and use of GIS?

## CONCLUDING SUMMARY

This era—the last decade of the 20th Century and the beginning of the 21st—has every opportunity to become a second age of geographic discovery, or rediscovery. The necessary technology largely exists, or is expected in the next few years. Much research remains to be done, but the broad outlines of what is needed already exist in published research agendas. The needed political stability also exists. One element is missing that was present at the outset of the first Age of Discovery—a royal patron. We don't have an Infanta, though we do have many public and private sponsors. We have places where the necessary skills have been assembled, in universities and corporations, and we have meetings like this to share progress.

I have argued that the second age of discovery will be as much about personal discovery as about additions to collective knowledge, whether personal discovery implies learning by children, or information-gathering by adults. It may be as much about creating new knowledge from old data as about new data collection, and it will be about making visible what has previously been invisible.

Finally, I have argued that the second age of discovery should be about integrating human intelligence, the computer, and reality in a three-sided interaction that takes GIS out of the office and into the field where it is most effective, and where it truly belongs. The second age of discovery will be about using computers to augment the human experience, in the presence of ground truth.

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