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Cartographic Futures On A Digital Earth

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Introduction

This paper is written with some trepidation, since I am not a cartographer, and would certainly not want to be perceived as trying to prescribe cartography's future. But the organizers of the conference have asked me to address the second part of the conference theme, "Touch the Past, Visualize the Future", and I hope what follows will be of some interest. It is written from the perspective of someone who cares greatly about the cartographic aspects of what we do, who like many of us grew to love maps at an early age, and who sees cartography as an indispensable part of any future for my own discipline of geography, and the broader enterprise that we variously know as geomatics, geoinformatics, or geographic information science.

The paper begins by introducing two broad trends that provide a context of vital importance for cartography: the digital transition, which began some decades ago but seems to dominate more and more of our vision of the future; and what appears to be an increasing interest in society generally in geography, the stuff of maps, and in all things geographic. These two themes come together in a discussion of how the digital transition will affect the production, dissemination, and use of maps; the institutions that manage and regulate those activities; and ultimately, the nature of maps themselves. This leads to the identification of a basic paradox between the increasing marginalization of cartography within the larger digital geographic enterprise, and the increasing need for good cartographic practice in visual communication, as more and more people are empowered by new technology to make maps. The final section of the paper discusses the concept of Digital Earth, a popular idea that seems to serve both as a conceptual framework for much of the preceding discussion, and as a 'moonshot' that can mobilize a substantial technical and scientific effort.

"This leads to the identification of a basic paradox between the increasing marginalization of cartography . . . and the increasing need for good cartographic practice in visual communication . . ."

The digital transition

The idea of communicating in code is as old as language itself, requiring only the establishment of standards within a community regarding the code's meaning. An even older code is the alphabet of four bases used to communicate genetic information between parent and offspring; incredible as it may seem, the entire architecture of the human body, and the instruction to a chick to begin pecking after 21 days of incubation, are somehow successfully coded in a permutation of A, C, G, and T. But the explosive growth of digital communication that has occurred in the past 30 years relies on several other factors besides a universal code of zeroes and ones. The code is readily processed at great speed by digital computers; it can be stored virtually indestructibly (although practice often falls well short of theory); modern standards include automatic error-checking; and it can be transmitted at close to the speed of light. Today, virtually all human communication-at-a-distance passes through a digital coding and decoding at some point. Telephones, FAX, written text, photographs, music, all have associated and generally accepted standards of coding in digital form. Only the mail remains as a predominantly analog method of communication, although most sorting of the packages themselves is now digital. In principle, the entire contents of a major research library in the form of printed text could now be digitized, stored on a device no larger than an average office, and made available to everyone connected to the Internet at a cost roughly comparable to that of a Boeing 747-400.

"Digital technology is already pervasive, but its impacts are only just beginning to be felt in the ways humans organize and conduct their activities."

Digital technology is already pervasive, but its impacts are only just beginning to be felt in the ways humans organize and conduct their activities. Take, for example, the case of geologic mapping. Figure 1 shows the stages of mapping from the work of the field geologist through to eventual use, storage in libraries, and archiving. Each person or group in the chain communicates with the next person or group: the field geologist gives notes and sketches to the cartographer, while the printer sends paper maps to the distributor and on to the library and user.

The first infection by the digital virus occurred among cartographers who were persuaded as early as the late 1960s that the time and cost of preparing and editing maps could be greatly reduced by adopting digital technology, initially by fixing simple encoders to the arms of plotters to capture locations, and later by replacing drafting tables by digitizers. Today, it is hard to find a single drafting pen in many map production operations and cartography classrooms. Then users began to demand digital product, because of the obvious potential of digital analysis and the simultaneous growth of geographic information systems (GIS) as analysis engines for map data. But this second round of infection had a more significant impact, since it created a new path that bypassed the traditional printing and dissemination arrangements. More recently, the World Wide Web strain of the digital virus has further infected the distribution function, as digital spatial data libraries (such as the Alexandria Digital Library, *alexandria.ucsb.edu*) and spatial data clearinghouses (such as the U.S. National Geospatial Data Clearinghouse, *www.fgdc.gov*) provided an alternative to the traditional library as a source of archived information.

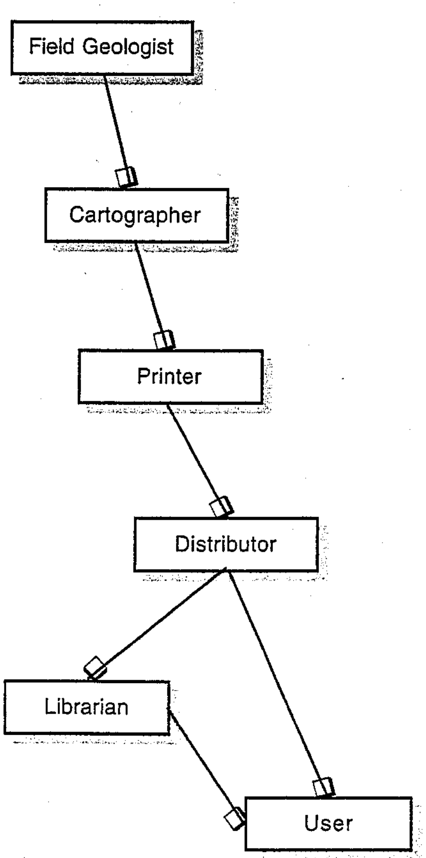

Figure 1. Schematic of the geological mapping process as communication.

Digital technology has yet to infect the work of the field geologist to a significant degree, although it is common today to find laptops at field sites. The sketches and field notes that a geologist passes to a cartographer are still largely in analog form, and suitable software for capturing and processing such information is still primitive. But the technology already exists to allow the field scientist to download images of a project area from the WWW, to annotate it digitally with sketches and notes, and to link digital photographs to field locations. Information technology in the field promises to improve greatly one of the most severe impediments to the various stages of communication shown in Figure 1, and one that underlies much of the subsequent discussion in this paper: the inability of the field geologist to communicate more than a small fraction of what he or she discovers in the field to the eventual end user, because of the highly restricted nature of the traditional communication channels. In the longer term, extensive application of information technology in the field promises to open up novel channels of communication. For example, it will be possible for field scientists to share information remotely as soon as it is collected or interpreted; to communicate directly with end users; and in the long run to bypass entirely the traditional stages of cartographic production.

In recent years, massive investments have been made in digital libraries, metadata (data about data, the digital equivalent of the catalog record), new search mechanisms, and other developments aimed at making it possible to find geographic data in the massive, distributed archives of electronic networks. Moreover, it seems clear that investments to date are tiny compared to what is to come, as the information economy heats up. Surfing the Web for data is providing an increasingly effective alternative to visiting one's local map librarian.

The digital transition is affecting the *geography* of map production as well, as the traditional arrangements break down or are modified by new technology and changing economics. Much cartographic software is now cheap and affordable, allowing anyone with a personal computer and access to the Web to make maps. Farmers with access to the technology of precision agriculture can build maps of their fields at much higher resolution than traditional soil maps, and can capture and compile detailed spatial information on inputs and yields using devices attached to harvesters and tractors. Local governments can rent vans equipped with GPS units, drive along every street, and produce street maps at higher accuracy and much lower cost than the traditional production arrangements of central governments. In short, changing technology and economics are moving map production from a system of unified central production to a local patchwork, and the old radial system of dissemination is being replaced with a complex network.

"The digital transition is affecting the geography *of map production as well . . ."*

In the early stages of the digital transition much use was made of the new technology to perform operations more quickly, at lower cost. But as the transition advances it is the operations themselves that come into question, along with the organizational structures and arrangements that evolved around them. The survivors in this world will be those who can think beyond past practices, and adapt quickly to new opportunities.

The stuff of maps

As a U.S. citizen I share what is now a widespread feeling of awe for the sublime geographic ignorance of many of my fellow citizens, and nowhere is this better revealed than in U.S. ignorance about Canada. Yet this is a period in political history of devolution of power down the geographic hierarchy. We are encouraged to think globally but act locally; increasing local autonomy makes it more and more difficult to achieve widespread consensus. There are new standards for teaching geography (Bednarz *et al.*, 1994), greater interest in travel, more interest in the diversity of places and less in standardization.

In the past few years many new services based on geographic information have appeared on the Web. Microsoft's Terraserver (*www.terraserver.com*) began as an effort to build and demonstrate a capability to serve information at a massive scale, with geographic data chosen as the content because it was cheap and comparatively unencumbered by issues of intellectual property. But Terraserver has been very successful as a pioneering effort to serve imagery to a vast population of users, many of whom had never had access to easy-to-use Earth imagery before. Microsoft's Home Advisor (*www.homeadvisor.com*) provides GIS-like services in the form of home listings and social data about surrounding neighborhoods. MapQuest (*www.mapquest.com*) is one of many sites offering maps, georeferencing, and optimal routing services.

"One of the greatest impediments to effective use of geographic data has been the inability to integrate information about a place."

One of the greatest impediments to effective use of geographic data has been the inability to integrate information about a place. Our traditional arrangements for production of geographic information emphasized horizontal uniformity; one government program produced all topographic maps, another all soil maps. These arrangements have been largely inherited by the digital world, so that one goes to one site to obtain an image (e.g., the MIT server of digital orthophoto quadrangles, *ortho.mit.edu*), and another site to obtain a topographic map, and still a third to obtain a soil map. It has been virtually impossible to approach a library, or the Web, and ask for all information about one place; and equally difficult to integrate such data once obtained because of variations in formatting and terminology, and positional inaccuracies.

The U.S. Geological Survey provides an interesting case in point. The traditional organization of the Survey into four divisions (with responsibilities for mapping, geology, water resources, and biological resources) has also determined the face it presents to the world as a source of information. Thus a user approaching the USGS Web site finds it much easier to obtain information about one theme for places, than information about many themes for the same place. The Survey's *Gateway to the Earth* project proposes to replace this external view by a more integrated one that will allow the user to find everything the Survey knows about a place. This idea of *place-based search* is already implemented to a degree in the U.S. Environmental Protection Agency's site (see the ZIP code search feature of *www.epa.gov*).

"This idea of place-based search *is already implemented to a degree in the U.S. Environmental Protection Agency's site."*

These place-based search mechanisms resemble what I have called a *geolibrary* (Goodchild, 1998), or a library that one can approach with the query *"What do you have about there?"* Place-based search has been very difficult in the traditional library for numerous reasons, but promises to be comparatively easy in a digital world, and provides yet another instance of how the digital transition is changing our arrangements for producing, disseminating, and using geographic information.

Geographic information and maps

But maps are only one form of expression of geographic information. Very broadly, one could define geographic information as information about well-defined locations on the Earth's surface; in other words information associated with a geographic *footprint*. But that definition fits guidebooks, photographs of landscapes, even pieces of music with geographic associations. Possession of a footprint is the minimal requirement for place-based retrieval. Maps, on the other hand, are:

"Very broadly, one could define geographic information . . . associated with a geographic footprint.*"*

Visual forms of geographic information, rather than textual, verbal, acoustic, tactile, or olfactory; though tactile maps have been developed to address the needs of the visually impaired.

Flat, requiring the Earth's surface to be expressed in a distorted manner.

Exhaustive, expressing a uniform level of knowledge about every part of the area covered by the map.

Uniform in level of detail, although no flat map can ever have a perfectly uniform scale.

Static, since a map once drafted and printed cannot be substantially changed.

Generic. The strong economies of scale in map production ensure that maps will be produced only when demand reaches a sufficient level. Thus maps tend to be produced to satisfy many uses and users simultaneously. They present a *shared* perspective that cannot be user-centered, and thus is almost always vertical.

Precise, few methods being available for display of uncertainty.

Slow, due to the lengthy time required for all of the different stages of production, as shown for example in Figure 1.

None of these constraints is inherent to geographic information, however, especially in a digital world that changes the economics of map production, provides the tools for interacting directly with information, and allows information to be compiled and delivered at electronic speed. In the digital world all information is expressed in bits, whatever its origins; it is stored in the same places, and transmitted using the same techniques. It does not matter to the Internet whether a 'bag of bits' represents text, an image, or a map. Thus we hear more and more about multimedia systems that handle data irrespective of the media on which they were traditionally stored in the analog world. The term *multi-valent document* (Phelps and Wilensky, 1996) refers to the ability to link images, text, sketches, notes, etc., that refer to the same subject, and to handle them as if they were a single unit. In this multi-media world, old arrangements based on the problems of handling different media will be challenged, and may be abandoned completely.

"It does not matter to the Internet whether a 'bag of bits' represents text, an image, or a map."

The paradox of contemporary cartography

It follows from the previous discussion that the map[2] is only one form of expression of geographic information in a digital world, competing with other forms on a playing field that is increasingly level. For example, flat views of the world and the distortions they embody must compete with orthographic views such as those provided by the current version of Microsoft's Encarta atlas. To the average citizen, working with and manipulating a digital globe may be far more straightforward and comprehensible than working with a digital Mercator projection; and children may be able to understand a globe more easily and at an earlier age than its projected version.

It is widely believed that geographic information systems are being absorbed into the information technology mainstream: that in the near future such standard applications as spreadsheets, e-mail, and word processors will include support for geographic information. The magazine *GIS World* recently changed its name to *GeoWorld*, to reflect "GIS's transition from a standalone technology to one benefiting from the integrated nature of today's spatial technologies and the enterprisewide solutions they offer." (Hughes, 1998). GIS has made it possible for anyone who can afford a basic personal computer and cheap software to display geographic information in the form of a map: By offering these functions through such common applications as Microsoft's Excel, software developers are now putting these tools into the hands of everyone, irrespective of their credentials and sensitivity to cartographic principles. In a world in which everyone can make a map, who needs the cartographer?

"It is widely believed that geographic information systems are being absorbed into the information technology mainstream . . ."

Only a few institutions have had the wisdom to elevate cartography to the status of a department. Instead, cartographers have historically found themselves rubbing shoulders with geographers or surveyors. Today, rapid growth in interest in geographic information systems and related fields has led to an emergence of new collaborations, under a variety of names: geomatics, geoinformatics, or geographic information science. Cartography finds itself a small part of a larger academic enterprise, and at the same time increasingly marginalized by the rapid spread of map-making tools.

Much of the attraction of GIS lies in its visual focus: colorful maps appear on the screen to be manipulated and explored by the user at the touch of a mouse. GIS communicates primarily through the visual channel, especially when used in efforts to influence public opinion and policy. But such communication is never simple and straightforward. Only one color can be assigned to each location in the visual field, which is then mapped through the optics of the visual system to the human retina. While a database makes the link between an object and its name explicit, the eye-brain system does this through complex rules of visual association that must be understood by the map designer and made the basis of map design. Map designers must devise complex and sophisticated rules to make it possible for a map to communicate more than one attribute of an object; and yet none of these rules are needed when information is communicated in other forms, such as through tables.

"While a database makes the link between an object and its name explicit, the eye-brain system does this through complex rules of visual association that must be understood by the map designer and made the basis of map design."

Despite this complexity, or perhaps because of it, a large number of the maps produced using today's software are simply awful. As David Rhind has been known to remark, GIS technology lets us produce rubbish faster, more cheaply, and in greater volume than ever before. Paradoxically, then, the world that is marginalizing cartography is also the world that needs cartographic principles and skills more than ever. It is also a world of unprecedented opportunities for cartography as the digital transition removes many of the inherent barriers and impediments of the traditional map, and makes communication of geographic information between people richer and more efficient than was previously possible. To restate the previous list, communication of geographic information need no longer restrict itself to the visual field; flatten the Earth; cover every part of an arbitrarily defined area that happens to include the area of interest in uniform detail; maintain a uniform level of detail and a vertical perspective irrespective of the content's focus; remain static irrespective of the acquisition of new information or change in the landscape; serve the interests of a large number of users to overcome high fixed costs; fail to reveal anything of its own inherent uncertainties; or take substantially longer than any other form of communication.

Digital Earth

The term *Digital Earth* has a number of meanings. U.S. Vice President Al Gore, in the text of a speech, described an immersive environment that would allow its users to explore and learn about the Earth and its human and physical environments (the full text is at *www2.nas.edu/besr/238a.html*; a summary was delivered in Los Angeles in January 1998):

"U.S. Vice President Al Gore ... described an immersive environment that would allow its users to explore and learn about the Earth and its human and physical environments."

> "Imagine, for example, a young child going to a Digital Earth exhibit at a local museum. After donning a head-mounted display, she sees Earth as it appears from space. Using a data glove, she zooms in, using higher and higher levels of resolution, to see continents, then regions, countries, cities, and finally individual houses, trees, and other natural and man-made objects. Having found an area of the planet she is interested in exploring, she takes the equivalent of a 'magic carpet ride' through a 3-D visualization of the terrain. Of course, terrain is only one of the numerous kinds of data with which she can interact. Using the system's voice recognition capabilities, she is able to request information on land cover, distribution of plant and animal species, real-time weather, roads, political boundaries, and population. She can also visualize the environmental information that she and other students all over the world have collected as part of the GLOBE project. This infor-

mation can be seamlessly fused with the digital map or terrain data. She can get more information on many of the objects she sees by using her data glove to click on a hyperlink. To prepare for her family's vacation to Yellowstone National Park, for example, she plans the perfect hike to the geysers, bison, and bighorn sheep that she has just read about. In fact, she can follow the trail visually from start to finish before she ever leaves the museum in her hometown.

She is not limited to moving through space, but can also travel through time. After taking a virtual field-trip to Paris to visit the Louvre, she moves backward in time to learn about French history, perusing digitized maps overlaid on the surface of the Digital Earth, newsreel footage, oral history, newspapers and other primary sources. She sends some of this information to her personal e-mail address to study later. The time-line, which stretches off in the distance, can be set for days, years, centuries, or even geological epochs, for those occasions when she wants to learn more about dinosaurs."

Several principles and challenging ideas underlie this piece of technological fantasy. First, the immersive environment provides a very rich form of communication between the information store and the learner, unimpeded by the constraints of a single medium, and not limited to the visual channel or to the narrow concept of *map* defined earlier. Second, the vision mixes types of data that are readily communicated by *rendering* into something resembling their true appearance, such as topography and land cover, with other types that will have to be communicated symbolically. This second type includes information on population, health, or environmental quality. Cartographers are familiar with the problems of mixing these two types of data through their experience with symbolic enhancement of orthographic images. Other information mentioned in the speech is geographic only in the sense of having a footprint; the contents of newspapers and oral histories will have to be represented iconically, and their contents communicated in some appropriate way, since they are not geospatial and therefore cannot be mapped onto the Earth's surface.

". . . the immersive environment provides a very rich form of communication between the information store and the learner . . ."

More fundamentally, perhaps, DE embodies a novel metaphor for the organization of digital information and construction of user interfaces. The current generation of computer operating systems, such as Windows 98, makes use of the metaphor of the desktop, with its clipboards, filing cabinets, and briefcases, because this is the environment most familiar to office workers. This tradition goes back to work at the Xerox PARC laboratories in the 1960s, but came to dominate Microsoft operating systems only in the late 1980s with Windows. Yet the office is not a natural environment for thinking and learning about the surface of the Earth, and *office* is not the first thing that comes to mind when we think of Shackelton, or von Humboldt. Since all such information relates to some geographic location, it would be far more effective to use the Earth's surface itself as the organizing metaphor. For example, rather than look in a filing cabinet under Z, someone interested in Zimbabwe would find it much easier conceptually to reposition a digital globe to the right part of Africa (or to look up Zimbabwe in a digital rendering of the back-of-the-atlas gazetteer, and see the globe repositioned automatically). DE replaces the office with the Earth as the dominant user interface metaphor.

"More fundamentally, perhaps, DE embodies a novel metaphor for the organization of digital information and construction of user interfaces."

DE seems an appropriate focus for this discussion not because it is real (although several prototypes have appeared since the text of the speech was released), but because it provides a vision for the future communication of geographic information that reflects the removal of all of the impediments identified above. It also presents some very substantial challenges.

The range of scales implied is over at least four orders of magnitude, from a resolution of 10km that would be appropriate for rendering of the entire globe, to the 1m resolution needed to render a local neighborhood. Cartographers have long struggled with relationships between maps at different scales, but not over this large a range.

Perspectives in DE will be user-centered, whereas almost all cartographic tradition is focused on user-independent perspectives (vertical, with uniform detail). We know very little about how to vary resolution with distance for effective communication, although much work has been done on the necessary algorithms in computer graphics.

"We have little in the way of cartographic technique for indicating the presence *of information, rather than the content."*

As noted above, DE will have to mix rendering with symbolic and iconic representations. We have little in the way of cartographic technique for indicating the *presence* of information, rather than the content. New forms of representation of metadata are called for.

The speech implies that a DE environment would somehow know about and have access to some significant portion of the information that exists about a given place. This raises a host of interesting technical questions about information search and discovery in digital libraries, clearinghouses, and the WWW; institutional questions about quality assurance and credibility; and societal questions about privacy and intellectual property.

Although the child in this scenario enters an immersive, virtual environment, the principles of DE could be applied equally well to the conventional configuration of a user, keyboard, screen, and pointing device. Although the screen renders images in two dimensions, a user with the ability to manipulate rendered objects has no difficulty imagining the object as three-dimensional. But the conventional configuration clearly misses the potential for tactile communication.

Although the speech refers only to historic data, it is easy to imagine DE being used to communicate simulations of Earth processes that could help the child learn the principles of geomorphology or urban planning and growth; or help decision-makers deal with the projected impacts of current actions.

DE appears to have many attributes that qualify it as a suitable *moonshot*, a vision or rallying point for a rather ill-defined collection of disciplines and interests, comparable to the 1960 commitment to "put a man on the moon before the end of the decade." Moonshots like these are not grand challenges in the sense of fundamental unsolved problems for a discipline, but they can help to orient a community, such as the current community interested in geographic information, in pursuit of a common goal and the research problems that will have to be solved to reach it. Moreover, many of those solutions are likely to have benefits far beyond the immediate context of the moonshot.

CONCLUSION

A technology that began as a way of making large numbers of numerical calculations possible has turned into something that, if the pundits are to be believed, has the potential to reorganize much of what we do. Cartographers first felt that impact in the early 1970s when computers began to be used to reduce the production costs of paper maps. Since then, digital technology has affected almost all aspects of mapping, created an entirely new application in geographic information systems, facilitated many other new geographic information technologies, and spawned a new partnership of the mapping sciences known variously as geomatics or geographic information science.

"For the traditional cartographer, what began as a useful aid has turned into a monster . . ."

For the traditional cartographer, what began as a useful aid has turned into a monster, empowering virtually everyone with access to the tools that used to be the exclusive preserve of specialists. In a world in which everyone can make a map, who needs cartography? Or as Judy Olson titled her Presidential Session at the Association of American Geographers annual meetings in Charlotte in 1996, "GIS has killed cartography". But paradoxically, the need for good cartographic design is now stronger than ever.

Faced with this situation, it seems to me that a suitable strategy for visualizing the future while touching the past would have the following components:

(1) Establishment of clear principles underlying the communication of geographic information. Such principles should be independent of media and technology, and thus robust against a major technological transition such as the one we are currently experiencing. These would not be the principles of paper maps alone, or of digital displays alone, or of visual communication alone, but of the communication of geographic information from one person to another. Different communication channels and media would be represented through different parameters, constraints, and rules within this general framework.

(2) Anticipation of the full impact of the digital transition. It is hard to see the wood for the trees in times of fundamental change, and to think beyond the immediate impact of computerization on a single task. But in the long term, the world will reorganize itself according to principles such as those suggested in (1) that are truly fundamental. These include function, economics, and the basic forces that drive society, including the distribution of power and influence.

(3) Identification of a moonshot, an articulated vision of what communication of geographic information might mean at some point in the future. Without such a vision it is difficult to see how a prioritized agenda for cartographic research can emerge. Curiosity will always be around to drive research, as will immediate economic gain, but it is much more difficult to identify a clear sense of common purpose that can both drive research and appeal to potential sources of funding.

REFERENCES

Bednarz, S.W., N.C. Bettis, R.G. Boehm, A.R. DeSouza, R.M. Downs, J.F. Marran, R.W. Morrill, and C.L. Salter (1994) *Geography for Life; National Geography Standards*. Washington, DC: National Geographic Society.

Goodchild, M.F. (1998) The geolibrary. In S. Carver, editor, *Innovations in GIS 5*. London: Taylor and Francis, pp. 59–68.

Hughes, J.R. (1998) GIS World is now GeoWorld!. *GeoWorld* 11(11): 8.

Phelps, T.A., and R. Wilensky (1996) Multivalent documents: inducing structure and behaviors in online digital documents. *Proc. IEEE Int. Conf. System Sciences, University of Hawaii, Maui, HI, January*. http://www.cs.berkeley.edu/~phelps/papers/hicss96-abstract.html

NOTES

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2. As used here, the term implies a paper product or its direct digital equivalent produced by scanning or digitizing; both are therefore subject to the constraints identified earlier.