GIS as a Tool for Map Production.

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When geographic information systems (GIS) were first used to manage spatial data, high-quality cartographic products were not a priority (Tomlinson 1988, 252), despite maps being inherently associated with GIS. By the 1990s, GIS included analysis of data and geographic information management as well as automated mapmaking (Taylor 1991; Pratt 1985). Early GIS specialists viewed maps as the source of data and cartography simply a means of illustrating the results. To many early GIS specialists, cartography was not considered necessary for their analysis of geographic data: the geographic analysis was the important product, and emphasis was not placed on designing high-quality maps. As a consequence, in these early years the mapmaking capabilities of GIS were limited. In 1991, geographer D. R. F. Taylor identified two ways to view GIS and its mapmaking capabilities: GIS could include mapmaking or provide a separate superstructure for computer-assisted cartography (Taylor 1991, 5). Michael F. Goodchild (1988) described geographic analysis and GIS as developing almost independently of cartography, and noted that this occurred because early GIS users were not guided by knowledge of cartographic traditions.

The limits of technological advances and the disparate backgrounds of the individuals using GIS interfered with integration of the fields of GIS and cartography. Another factor that contributed to this separation was that GIS hinged on the relatively recent invention of computers while cartography had existed for many centuries. Even after computer-assisted cartography systems became available, some cartographers viewed the systems only as a way to produce maps more cheaply and quickly (Taylor

1991, 3), still viewing hand-drawn maps as superior. When computer graphics from both screen displays and printers improved near the end of the twentieth century, cartographers started using computers consistently. During the 1980s, the two fields began to merge, with GIS used for geographic analysis and cartography for data display within the same projects (Goodchild 1988, 315; Keller and Waters 1991, 109). By the end of the century, arguments arose about whether the conflation of cartography and GIS would render cartography obsolete.

The emphasis on geographic analysis is seen in early inventories of GIS functionality in GIS World, an early GIS trade magazine. Their first GIS software survey (Anonymous 1988) itemized thirty-nine characteristics offered across thirty-six GIS vendors, with only six particular to map production: raster output maps, vector output maps, on-screen map annotation, and support for pen plotters, inkjet printers, and electrostatic plotters. Similarly, the second survey (GIS World, Inc. 1989, 32–46) itemized over eighty characteristics of sixty-three systems, with the same items listed for display and output and adding support for laser and dot matrix printers. The bulk of other items were specific to geographic analysis, such as nearest neighbor search and terrain slope computation. Two items in the surveys, converting map projections and generating elevation contours, straddled analysis and map production concerns.

At the Auto-Carto 5 conference in 1982, the U.S. Geological Survey (USGS) identified a shift from cartographers using computers for computation to using computers as an aid in map production, the change credited to the decreasing cost of output peripherals (Borgerding, Lortz, and Powell 1983). As early as 1973, the Canada Geographic Information System (CGIS) had produced over 200 resource maps (Taylor 1974, 37–38). Goodchild (1988) argued that with adequate investment, manual mapmaking could be replaced by computer technology. David P. Bickmore at the Experimental Cartographic Unit (ECU) in Great Britain was a strong influence in the change from analog to digital map production. After working on The Atlas of Britain and Northern Ireland (1963), produced without computer assistance, Bickmore was criticized for out-of-date content. He subsequently determined that the only way to produce something in a timelier manner would be to use a computer (Rhind 1988, 278–79). As early as 1966, the ECU laid plans for the development of geographic databases and viewed maps as a result of combining data sets. This incentive continued to drive cartographic projects toward GIS until 2000. Cynthia A. Brewer and Trudy A. Suchan (2001) led a successful effort to publish decennial U.S. census 2000 data distributions using GIS.

With the improved database capabilities of GIS, cartographers discovered they could use GIS as an effective tool in their discipline (Goodchild 1988; Tomlinson 1988; Taylor 1991). One example of cartographic database use was automated name placement. By automatically placing labels for point, line, and polygon features, labeling software allowed faster mapmaking, and it was one of the first popular forms of database use among cartographers. In some of the earliest papers on automated name placement, computer scientists Herbert Freeman and John Ahn (1984) encouraged an expert systems approach, and Steven Zoraster (1986) countered by recommending integer programming. Several types of feature names databases were presented at Auto-Carto 7 in 1985: A Cartographic Expert System (ACES) (Pfefferkorn et al. 1985), Geographic Names Information System (GNIS), and Name Database (NDB). At the same conference, Scott Morehouse (1985) presented current mapping functions of ESRI (Environmental Systems Research Institute) ARC/INFO GIS: drawings based on points, lines, and polygons; automatic text placement; legend generation; and interactive map queries. These are all capabilities found in late twentieth-century GIS.

An early cartographic project using GIS software for production of high-quality cartography was the second volume of the Historical Atlas of Canada (1993). Of the fifty-eight plates created for the project, fifty were created using ARC/INFO as well as Interleaf desktop publishing software. The three-volume project had begun in 1979, but GIS-based production was not adopted until 1990, initially to save money because the project had outlasted its funding stream and a software donation was offered. The editor was gratified by the results (Figure).

The lack of good output peripherals available for early GIS was the biggest impediment to creating printed maps directly from the software. The main capability of GIS was the performance of numerical and statistical analyses (Goodchild 1988, 315) that supported cartography, and these analyses do not require high-quality printing. The U.S. Census Bureau was using computers as early as the 1960s to assign and print class intervals for choropleth maps, but the maps were not computer-generated (Trainor 1990, 28–29). The high cost of computer peripherals in the early years of GIS and the poor graphic quality of these devices were deterrents. In the 1960s, printing graphic images, fonts, and multiple colors were still in the future; the monochrome line printer was the only output device available to mapmakers (Goodchild 1988, 313). Once the pen plotter became available in the 1970s, it gave users a way to create maps that emulated the pen-and-paper character of hand-drawn cartography. Pen plotters were invented in 1959 by Calcomp, which offered a line of single-pen drum plotters as peripherals by 1962. Cartographic uses were introduced in the 1970s, and software was adapted to make the best of this change in technology. Early map prints were not far from what had been created with a line printer, with jagged edges and very simple fonts, neatlines, scales, and legends (Figure). These plots evolved to forms that could represent more complexity. Plotting technologies finally evolved to the point that higher quality maps could be produced using computers (Figure).

Howard T. Fisher, the founder of the Harvard Laboratory for Computer Graphics and Spatial Analysis, wanted to generate whole maps on the computer, without relying on graphic overlays combined using additional processing (Chrisman 2006, 2). The SYMAP program first emerged from the Harvard Lab in the 1960s, but with no memory or backspace option, the line printer severely limited the map output capabilities of the software. Despite the low-quality printing, poor screen displays demanded that analyses occur only after the map was printed (Chrisman 2006, 19–40). Line printer gray tone shading was created by lining up specifi c letters sequentially, and the letters O, X, A, and V were overprinted to produce near-black areas. SYMAP was successful because it drew attention to "the possibility of digital cartography and paved the way for the more useful graphics technology. . . . It was . . . effective in one particular form of mapping: the rapid production of crude but informative choropleth maps based on constant boundaries" (Goodchild 1988, 313).

Multicolor mapping, beyond hand-coloring a black and-white print, remained out of reach with early GIS. In 1967 most Harvard Lab scientists sought ways to produce color maps and, programmer Donald F. Cooke worked out a technique to run the paper through the printer three times, changing carbon papers to produce color differences (Chrisman 2006, 155). Pen plotters offered the option of inserting or selecting from multiple pen colors while the map was drawn, and they were a primary method of color map production into the mid-1990s (Hewlett Packard discontinued its last large-format pen plotter model in 1995, and Calcomp disbanded in 1999). Pen plotter technology in GIS mapping was echoed by a preponderance of line and cross-hatch textures in filled areas and fishnet plots for perspective views of terrain in volumes of ARC/INFO Maps from the early 1990s. Several other approaches were taken to create color maps: color film recorders, electrostatic plotters, and fi nally inkjet and laser printers (Dangermond and Smith 1988). Color film recorders were the first color media to be used with GIS software, but they were expensive and required photographic film processing. Electrostatic plotters like Electroplot soon followed. By 1987, maps and other graphic products could be directed to what Hugh W. Calkins and Duane F. Marble (1987, 109) considered fast and sophisticated color printers. Laser and inkjet printers were commonplace by the end of the twentieth century, both providing high-quality map printing to a wide range of paper sizes.

Although GIS historically has lacked cartographic elements, computer-assisted cartography systems also relied heavily on geographically referenced data. Computer assisted cartography systems provided users with improved graphics, editing, and the capability of plotting their data (Tomlinson 1988, 258–59; Coppock 1988). The most popular of these computer-assisted cartography systems were variously called automated cartography, computer-mapping systems, and computer-aided design (CAD). Taylor (1974, 35) defined automated cartography as automation of mapmaking processes. The maps that were produced with automated cartography were intended to resemble existing printed maps. In Canada in the early 1970s, automated cartography software was used to replicate topographic and marine charts. In contrast, Taylor defined computer mapping as map production using the analytical power of computers. The maps produced from computer mapping software were different from those of an automated cartography system in that they were designed to be the rough products from a GIS rather than high-quality cartography for commercial distribution. CAD, which continued to be used for mapping through the 1990s, did not provide users with the database capabilities of GIS, but did provide detailed and accurate graphics (Pratt 1985). David Rhind (1988, 286) argued that, as a spin-off from GIS, computer-assisted cartography systems were unlikely to be viable economically. By the end of the twentieth century the systems had nearly disappeared, but they were considered distinct from GIS at the height of their use.

The early inventories of software functions by GIS World also attempted to divide systems into types. The 1989 survey used seven categories: GIS, automated mapping, desktop mapping, facilities management, image processing, computer-assisted design, and computer- assisted engineering, with some companies selecting three or four of these choices to describe their systems. This partitioning seems quite detailed, but market sectors were being established and they could be contentious. For example, GIS World (Anonymous 1989, 11) reports that Daratech's study, GIS Markets and Opportunities, was criticized for concluding that Intergraph controlled 49.9 percent of the GIS market worldwide because the study defined the subject broadly to include hundreds of automated mapping systems not considered to be "true GIS."

Lesser-known computer-assisted cartography systems also relied on geographically referenced data. Electronic mapping systems (EMS) produced maps used in electronic media such as the electronic atlas and included functionality similar to GIS along with good cartographic display (Taylor 1991, 6). The digital cartographic database described by Calkins and Marble (1987) ran much like GIS in that its associated database contained information about the map and provided greater flexibility for the cartographic designer. Because many GIS specialists did not have specific cartographic training, several systems were invented with the intention of having the system become the cartographer. One type of such computer-assisted cartographic systems was expert systems or intelligent knowledge-based systems (Robinson and Jackson 1985). The Digital Cartography Program was developed in the mid-1980s at the USGS to produce maps from a GIS to increase production efficiency. In one part of this program, base maps and other digital data were available to produce thematic maps quickly and easily once imported from a GIS (Southard and Anderson 1983).

Finally, the Digital Chart of the World (DCW), a small-scale vector data set developed by ESRI in the early 1990s for the U.S. Defense Mapping Agency, became available on CD-ROM for anyone to use. While not a software program, the DCW (later called VMAP) did offer data digitized from more than 250 Operational Navigation Charts and Jet Navigation Charts from four different countries by the U.S. National Imagery and Mapping Agency (NIMA). The DCW was valuable because it brought a great amount of data together in one place and was relatively easy to access. It also prompted consternation among European partners who accused the United States of data dumping—of freely distributing what had been their intellectual property in a manner that undercut their cost recovery efforts through selling the same data (discussed at the International Cartographic Association 15th Conference, Bournemouth, 1991).

Intermediate computer-assisted map production solu tions were also common, such as printing separations by choropleth categories and combining these with traditional manual production methods (see, for example, health atlas production as reviewed in Pickle 2009). Another combination was to use GIS to plot boundary or contour lines and then copy them at reduced scale on photographic negatives to create finer lines. The negatives were then used to expose Peelcoat material and produce open-window negatives for color separated area fills. Judy M. Olson's students at Michigan State University, University of Minnesota, and Boston University experimented with these combinations of automated and traditional methods, producing process-color printed, postcard-sized maps throughout the 1980s.

As graphic design software such as Aldus FreeHand and Adobe Illustrator developed more complete functions for editing lines, areas, and labels in the early 1990s, cartographers took advantage of GIS to prepare selected map elements using existing databases, such as projecting a coastline from digital data, exporting the lines, and continuing production in a graphics software environment that supported PostScript printing. These exported maps from GIS were often mediated through early versions of the Adobe Illustrator format and output with dramatic color differences so they could be separated into particular line styles with more nuanced differences using design tools such as variable line weights and dashing. This meant that unfinished GIS maps were garish before export and completed in a graphics software environment. This combination also allowed the use of service bureaus with image setters that produced professional quality fi lm negatives at 12,000 dots per inch and higher. These dot densities are needed to produce halftone screens required for creating a full color gamut from process color ink combinations used in traditional high-quality lithographic printing.

M. J. Blakemore (1985), in his short history of digital mapping from line printer maps to GIS, says that the emergence of digital mapping established a long period of aggravation among cartographic specialists. Byron Moldofsky (personal communication, 9 February 2011) reflects on GIS-based production of plates for volume 2 of the Historical Atlas of Canada as an intricate process requiring separate EPS (encapsulated PostScript) fi les for maps, other graphics, and English and French labeling and text layers, which were sent to a service bureau on floppy disks where they were recombined to make negatives, proofs, and eventually plates. Likewise, Bickmore predicted that just as bad programmers waste computer time, poor information handling would hamper automated cartography if expertise were not improved in this new domain. The cartographic conversations at academic conferences at the end of the century were rife with hand wringing about bad maps wrought with GIS, but there are numerous examples of reasonably professional mapping on a wide range of topics displayed in annual volumes of the ESRI Map Book (initially titled ARC/INFO Maps in 1984). For example, volume 15, published in 2000, presents 111 map projects, including hillshading and hypsometric tints, proportioned traffic flows, bike routes, 3-D buildings, one- and two-variable choropleth maps, soil and geology classifications, land cover distributions, environmental risks, orthophoto and vector map combinations, cadastral maps, infrastructure detail, and political boundaries, to name a subset. This series also provides ways to look back on GIS mapping: volume 25 of the ESRI Map Book (2010) presents four pairs of maps by the same agencies, contrasting rough black-and-white line maps from the first map books with modern full-color high-resolution products to show the evolution of GIS as a tool for map production. The map authors may have been aggravated or wasted their time in the course of map production, but they were certainly doing publishable cartography using GIS by the end of the twentieth century.

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