V

Vegetation Map. See Biography and Cartography

Vehicular Navigation System. See Wayfinding and Travel Maps: In-Vehicle Navigation System

Velhagen & Klasing (Germany). In 1873 the publisher Velhagen & Klasing, founded in 1835 by August Velhagen, established the Geographische Anstalt von Velhagen & Klasing in Leipzig, Germany. Originally, the firm had been based in Bielefeld. By 1930 it had become the most successful privately owned cartographic institution in Germany. Between 1875 and 1928 its *Volksschul-Atlas* had seen 172 editions and had sold over a million copies in Germany alone. Beginning in 1879, foreign versions were produced for the Baltic region, Italy, and Finland. In 1877 the firm began publishing *F. W. Putzgers historischer Schul-Atlas* (known as "the Putzger"), with Friedrich Wilhelm Putzger, a schoolteacher from Saxony, as its main editor. There have been numerous small- and medium-sized variants as well as special versions for Austria (beginning in 1889) and Switzerland (1924), and foreign-language versions in Polish (1900), Czech (1896), and Croatian (1904). Beginning in 1903, an American edition of the Putzger appeared as *F. W. Putzger's Historical School Atlas*. In 1909, under the editorship of William R. Shepherd, the title was changed to *Historical Atlas*. It was published under this title until 1964. In 1970, a Hebrew version of the Putzger was produced for Israel. For political reasons, its contents were based on the Swiss version. (On Velhagen school atlases, see *AtlasBase*, Atlas-Systematik, no. 104.)

From 1880 to 1939 Velhagen & Klasing also published Andree's *Handatlases* (fig. 1077), which was the world's best-selling large-format, scholarly world atlas prior to World War I, when more than half a million copies were in print (Espenhorst 2003, 556–604; *AtlasBase*, Atlas-Systematik, nos. 5.1–5.3). A total of nine editions were produced for the German market. Its contents grew from 120 map sheets in the second edition (1887) to over 275 map sheets in the eighth edition (1922–30), including a separate index containing 310,000 names. The 1930 edition contained 30.6 square meters of map area and was for decades the most comprehensive world atlas anywhere. Its greatest scholarly recognition came when the language maps in the sixth edition were used in determining the areas within which plebiscites were held as part of the negotiations at Versailles in 1919.

Altogether thirty different versions totaling 150,000 copies were produced for sale outside Germany: Sweden (1881, 1899, 1907, 1924, the latter as *Bonniers Världsatlas*), France (1882, 1883, 1884, 1900–1905, 1906–13, the last two as *Atlas universel de géographie moderne*), England (1891 as *The Universal Atlas*; 1895, 1896, 1897, 1898, 1899, 1900 as *"The Times" Atlas*), Italy (1899, 1914–15 as *Atlante Andree*), Austria (1903, as *Andrees Neuer Allgemeiner und Österreichische-ungarischer Handatlas*), Denmark (1882 and 1922–23), Norway (1882 and 1923), and Finland (1899). Between 1901 and 1930 an abridged version containing 100 map sheets was published under the title *Neuer Volks- und Familienatlas* (Espenhorst 2003, 605–25).

The firm also published twenty-three editions of the *Großer Volksatlas* between 1935 and 1941, including a special version titled *Großer Wehratlas* (*AtlasBase*, Atlas-Systematik, no. 5.4). All of its atlases were printed in Leipzig using raised letterpress technology with zinc plates, which made it possible to produce economically priced multicolored maps that met the highest cartographic standards.

In December 1943 an Allied bombing raid on Leipzig completely destroyed the area in which the major publishing houses were located, and all of the firm's archives were lost. In 1954, Cornelsen Publishing bought what remained of Velhagen & Klasing in West Germany, while in East Germany, VEB Tourist Verlag absorbed its assets.

JÜRGEN ESPENHORST

SEE ALSO: Marketing of Maps, Mass

FIG. 1077. DETAIL FROM *DIE SCHWEIZ* IN *ANDREES ALLGEMEINER HANDATLAS*, 1:750,000, 1914. This map is drawn in typical German style, using hachuring to indicate mountainous terrain and slanted illumination to give a three-dimensional effect.

Size of the entire original 39.8 × 48.5 cm; size of detail: ca. 13.5 × 17.3 cm. From *Andrees Allgemeiner Handatlas*, 6th new and enl. ed., ed. Ernst Ambrosius (Bielefeld: Velhagen & Klasing, 1914), sheets 83/84.

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AtlasBase Project. Online database of atlases in the German language, 1800–1955. In public-private partnership, hosted by the Staatsbibliothek zu Berlin. Administered by Robert Michel, Jürgen Espenhorst, and Markus Heinz.

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Verlag Ed. Hölzel (Austria). After spending time in German book trade centers, Prague native Eduard Hölzel, age 27, settled in Olomouc (then Austrian Empire, now Czech Republic) in 1844. He opened a book, art, and music shop and began publishing lithographs. After editing a newspaper, *Die neue Zeit*, during the 1848 revolution, he opened more shops and continued publishing, issuing an album of 100 views of Bohemian and Moravian towns in 1860.

Moving to Vienna in 1861, Hölzel continued fine-art printing and publishing but also founded the Geographisches Institut Ed. Hölzel. He invited Blasius Kozenn, an Olomouc geography teacher and author of an 1858 geography textbook, to collaborate on a school atlas. The *Geographische Schul-Atlas für die Gymnasien, Real- und Handels-Schulen der österreichischen Monarchie* appeared in 1861 with maps by Friedrich Köke's lithographic institute, also in Vienna. The popular so-

FIG. 1078. *SÜD-AMERICA, BERG- UND FLUßKARTE* FROM KOZENN ATLAS, 1912.
Size of the original: 28.2 × 37.6 cm. From *Kozenns Geographischer Atlas für Mittelschulen*, 42d ed. (Vienna: Hölzel, 1912), pl. 40. Image courtesy of the Rare Book Collection, University of North Carolina at Charlotte Library.

called Kozenn atlas, frequently updated throughout the twentieth century (fig. 1078), appeared in German, Czech, Hungarian, Polish, Croatian, and Italian.

The 1870s saw Verlag Ed. Hölzel surpass Artaria & Co. as the leading Viennese publisher of maps. During the 1880s Hölzel's scientific director, Vinzenz Haardt von Hartenthurn, improved its school wall maps and recruited experts. Josef Chavanne included innovative thematic maps in *Physikalisch-statistischer Hand-Atlas von Oesterreich-Ungarn* (1887), which he edited. Franz von Le Monnier compiled the *Sprachen-Karte von Österreich-Ungarn* (1888), and Haardt von Hartenthurn created the *Süd-Polar-Karte* (1895). *Geographische Charakterbilder für Schule und Haus* (1881) contained chromolithographic views, geographical descriptions, and maps. Output included an annual railway map of the Austro-Hungarian Monarchy and, from 1895, a twenty-six-centimeter-diameter school globe in different languages. Hugo Hölzel, the founder's son, contin-

ued the geographical tradition with outstanding travel books.

In 1918, after World War I, Hölzel's former multilingual market abruptly shrank to German-language schools in the Republic of Austria. However, Wilhelm Schier's historical school atlas, the *Atlas zur allgemeinen und österreichischen Geschichte*, appeared in 1935, the year Hölzel inaugurated a road map series for the Österreichischen Automobil-Club. Eventually previous markets were regained and expanded into Poland, Yugoslavia, Bulgaria, and Turkey.

During World War II the Hölzel firm was declared essential to the war effort, but the war's end brought its future into question. However, Moshe Brawer, an academic who had been in Vienna as a British officer, decided to collaborate with the Hölzel firm on the first Hebrew-language school atlas for the new state of Israel, using the Kozenn atlas as model.

Lacking Eastern European markets, the Hölzel firm

concentrated on the domestic market during the 1950s. In 1951 the seventy-fifth edition of the Kozenn atlas, revised by Hans Slanar, Sr., appeared as the *Österreichischer Mittelschulatlas*, along with five regional editions of the *Österreichischer Hauptschulatlas*. There followed foreign editions for France (Bordas), Germany (Keyser), the United Kingdom (Faber), the United States of America (Prentice-Hall), Belgium (de Sikkel), the Netherlands (Meulenhoff), and Turkey (Kanaat). After Austrian school requirements changed, Hölzel revised its school atlases in 1979–80 with new economic maps by Wigand Ritter, maintaining popularity then and after requirements changed again in 1995.

A new 1998 venture was the English-language *Resources and Environment World Atlas* in two volumes with 190 maps and satellite images, the largest thematic world atlas produced in Austria. Hölzel entered the twenty-first century with a versatile range of cartographic products: town plans and a city atlas of Austria, road maps of Austria and the South Tyrol, school atlases in four editions (fig. 1079), and the *Geothek* electronic world atlas.

INGRID KRETSCHMER

SEE ALSO: Atlas: (1) Thematic Atlas, (2) World Atlas; Marketing of Maps, Mass; Travel, Tourism, and Place Marketing

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Viewshed Mapping. A location is judged to be visible if the line of sight between it and a person standing at a viewing point in a landscape (urban, agricultural, or natural) is not interrupted by either the terrain or anything built or growing on the terrain (fig. 1080). A viewshed is the total area that is visible from any single location or set of locations (fig. 1081, top).

Before the advent of computers, several strategies were available for mapping viewsheds (Felleman 1986). The easiest was to visit the field, stand at the viewing point, and sketch on a map those areas that could be seen. Sometimes a map author would create a scale model of the terrain, together with any obstructions to visibility, and

FIG. 1079. DETAIL FROM *ALTE WELT: VÖLKERWANDERUNG*, 2004. The publisher describes this school atlas as presenting historical topics in their geographical setting by means of maps of the most modern design; on this map of early Old World folk migrations, the bright palette of colors bears out this comment.

Size of the detail: ca. 10.3 × 8.4 cm. From *Hölzel-Universalatlas zu Geographie und Geschichte* (Vienna: Ed. Hölzel, 2004), 133. Image courtesy of Ingrid Kretschmer. Permission courtesy of Ed. Hölzel Gesellschaft, Vienna.

use a point source of illumination or an optical device to delineate the viewshed. Another approach used a contour map in constructing multiple profiles through the terrain. The investigator added the observer and the line of sight to each profile and traced the outline of the visible area.

Since the advent of computers and the representation of terrain with digital elevation models (DEMs; fig. 1081, middle), viewshed analysis has been based on the electronic calculation of profiles and lines of sight. The U.S. Forest Service (Travis et al. 1975) developed one of the first viewshed analysis programs and used it to identify efficient locations for fire observation towers. By century's end, most geographic information systems (GIS) packages offered viewshed analysis.

Viewshed applications in GIS typically require the user to specify two parameters: the height of the observer above the ground and the maximum distance from the observer to be checked for visibility. An additional operation, not supported by all viewshed software, focuses

on incoming rather than outgoing lines of sight to determine areas from which a given location can be seen. In this case, the height above the ground at the target location is as important to the calculation as the height of the observer. This so-called reverse viewshed is not the same as the forward viewshed because a tall structure at the target point—for example, a wind turbine or a multistory building—will be visible from a wider area than the ground or a shorter structure (Fisher 1996). Indeed, it is possible to delineate areas from which an observer can see a location without being seen from it. Additional parameters might include left and right bearings that limit the field of view in order to indicate visibility by an observer looking in a particular direction.

A viewshed calculated by a GIS is usually recorded as a fine grid with pixels coded 1 for locations that can be seen from the viewing point and 0 for those that are hidden. This result is called the binary viewshed (fig. 1080A). An extension of the binary viewshed is the addition of multiple binary viewsheds, calculated for different viewing locations to produce a cumulative or proportional viewshed reflecting the relative extent to which each location in the landscape is visible from a specific set of vantage points (fig. 1081, bottom).

Peter F. Fisher (1996) pointed out that an evaluation of a landscape's aesthetic quality might require mapping the positions of intermediate (nearby) horizontal as well as global (more distant or ultimate) horizons (fig. 1080B). He also suggested using vertical offsets from the line of sight to the closest point on the land surface so that a negative offset value represents a pixel that is hidden whereas a positive offset represents a pixel that is visible. This strategy increases the map's usefulness as an analytical tool (fig. 1080C and D) insofar as a location where a structure with a particular height is planned can be evaluated to see whether it rises above the line of sight and whether its base is visible or hidden. As of 2000 no commercial software incorporated these extensions of viewshed mapping.

The viewshed is potentially problematic inasmuch as the DEM on which it is based is composed of thousands of estimates of elevation. Because it is highly unlikely that all of these elevation estimates are correct, error in the DEM—including limitations related to resolution or cell size—can have a marked effect on the size and extent of the visible area (Fisher 1991). And because so many different calculations are involved, the extent of the mapped viewshed is also affected by the choice of algorithm (Fisher 1996). The algorithm, the way the terrain is modeled, and the interaction between the line of sight and the terrain are significant sources of variation (Fisher 1993). Moreover, the masking effect of buildings and vegetation, such as trees and hedges, can cause the visible area to be dramatically overestimated. Because of these issues a more suitable approach might use a simulation of DEM error to generate a probable viewshed, in which pixel values ranging between 0 and 1 reflect the probability that the pixel is visible from the viewing point (Fisher 1996).

Viewshed mapping has been used in landscape planning, tactical battlefield planning, environmental impact assessment, the siting of transmission towers for mobile telephone networks, and diverse academic endeavors (Rana 2003). For example, viewsheds mapped at strategic points along scenic landscapes and highways have been used to evaluate the extent to which new construction or land management practices such as clear-cutting might impact the quality of a view. In this vein viewshed maps have helped organizations in New York State protect the viewshed of Olana, the home of Frederic Edwin Church, a leader of the Hudson River School of landscape painting. Viewshed mapping has also been used to evaluate plans to erect wind turbines along ridge crests, but the likely impact is a matter of interpretation because whether the turbines are detrimental to scenic quality—or actually enhance it—is a matter of opinion. Furthermore, viewsheds have given archeologists a more cognitive interpretation of an archeological site's location.

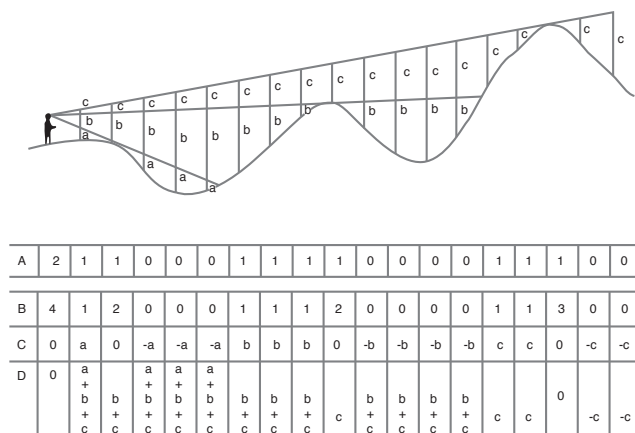| A	2	1	1	0	0	0	1	1	1	1	0	0	0	0	1	1	1	0	0
B	4	1	2	0	0	0	1	1	1	2	0	0	0	0	1	1	3	0	0
C	0	a	0	-a	-a	-a	b	b	b	0	-b	-b	-b	-b	c	c	0	-c	-c
D	0	a+b+c	b+c	a+b+c	a+b+c	a+b+c	b+c	b+c	b+c	c	b+c	b+c	b+c	b+c	c	c	0	-c	-c

FIG. 1080. LINE OF SIGHT. The line of sight can be conceived of in several ways: A shows a binary viewshed when calculated through a terrain profile, from a viewing point at the left of the figure with coding as 0 for the area out of view, 1 for the area in view and 2 for the viewing point; B is a horizon viewshed with four numerical codes, 1 indicates locations simply in view, 2 local horizons (where the horizon is not the skyline), 3 the global horizon (or skyline), and 4 the viewing point; C stores the vertical height or offset from the lines of sight to the next horizon; and D retains the vertical height from the line of sight to the skyline. In C and D when a location is out of sight a negative number is stored, when in sight a positive number. Note that the binary viewshed can be recovered by recoding any of the other viewsheds and the horizons viewshed from a combination of the local and global offsets.
Based on Fisher 1996, figs. 1 and 5.
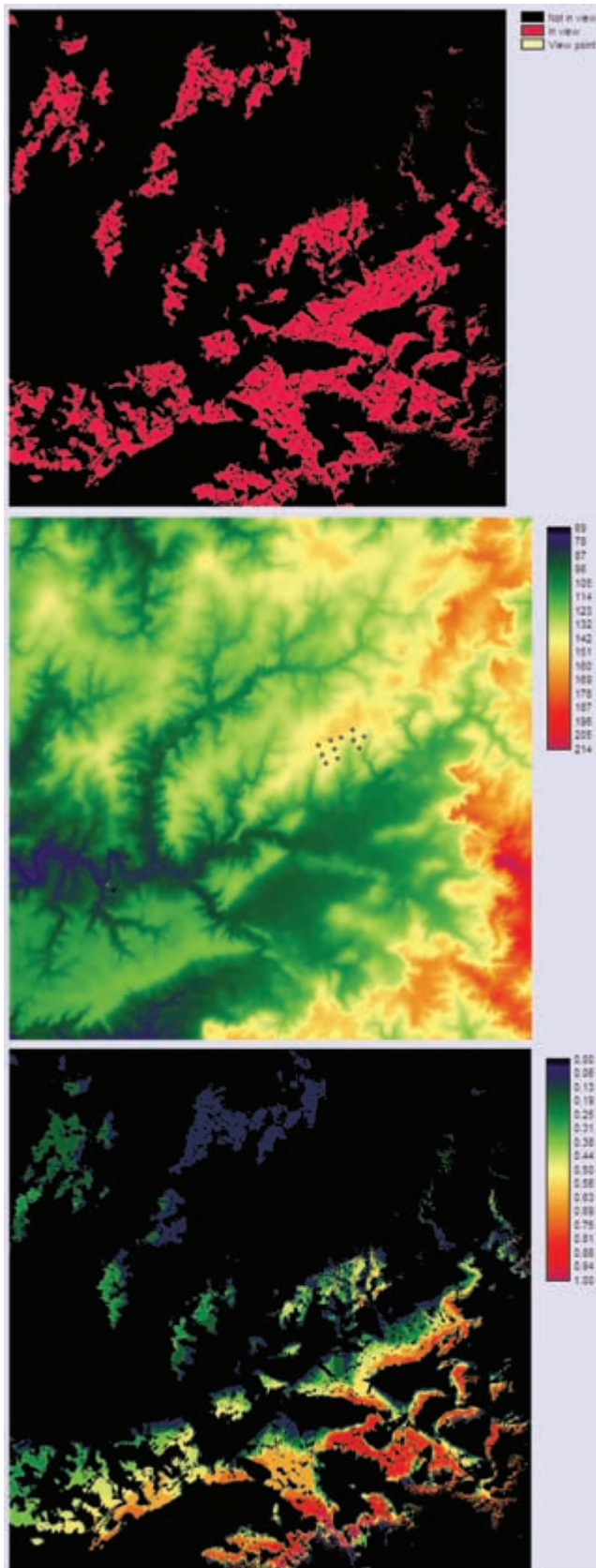
PETER F. FISHER

FIG. 1081. TOTAL VIEWSHED, DEM, AND CUMULATIVE VIEWSHED. The top shows the total viewshed for a person with eyes at 1.7 meters above the ground from the viewing points to the extent of the map; the middle shows a digital elevation model with eleven viewing points superimposed as open circles; and the bottom shows a cumulative viewshed of the same area where each pixel is coded to show the proportion of the eleven viewing points from which it is visible. The area covers a 20 × 20 kilometer area of terrain south of Leicester in the United Kingdom.

Image courtesy of Peter F. Fisher. © Crown Copyright Ordnance Survey. An EDINA Digimap/JISC supplied service.

SEE ALSO: Landscape Architecture and Cartography; Oblique and Perspective Views; Terrain Analysis and Cartography; Warfare and Cartography

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Vinland Map. In Switzerland in 1957, Laurence C. Witten of New Haven, Connecticut, bought a manuscript volume, in a relatively recent binding, containing a world map and an account of John de Plano Carpini's 1245–47 mission to the Mongols (Skelton, Marston, and Painter 1965). Executed in unevenly disintegrating carbon-based ink, the asymmetrical black-and-white map covers most of a double-paged, patched parchment of poor quality (fig. 1082); the well preserved paper-and-parchment text employs iron-gall ink and contains mid-fifteenth-century watermarks (Seaver 2004; Shailor 1987, 183–86).

The volume's provenance has never been proved beyond the Italian antiquarian dealer Enzo Ferrajoli de Ry, and the map's likely author and purpose are still debated. The anonymous map had a name by 1959, when Witten sold the "Vinland Map" volume and four separately bound sections of the "Speculum historiale" by Vincent of Beauvais to the American financier Paul Mellon, who subsequently placed the items in Yale Uni-

FIG. 1082. THE VINLAND MAP. The anonymously authored Vinland Map first became known to the public in 1965 when Yale University Library announced that it owned this manuscript work purportedly dating from the 1440s and illustrating eleventh-century Norse contact with North America. Chemical and historical analyses indicate that the map is a modern fake made between about 1920 and 1957.

Size of each page: 28.5 × 21.2 cm. Image courtesy of the Beinecke Rare Book and Manuscript Library, Yale University, New Haven (MS 350A).

versity's custody. A shared wormhole trajectory was said to connect the texts and to validate the map as a mid-fifteenth-century work, possibly inspired by and at the Council of Basel, formally constituted in 1431 and dissolved in 1449.

Besides a roughly mid-fifteenth-century concept of Eurasia and northern Africa, beyond Greenland in the northwestern Atlantic the Vinland Map shows a large island identified by two legends as Vinilanda Insula. This allusion to eleventh-century Norse contact with North America caught the public imagination in October 1965, when Yale publicized the map and a book-length commentary (Skelton, Marston, and Painter 1965). The actual American region encompassing Vínland (Wine Land) remains unascertainable because the medieval Norse neither used nor made maps and the literary sources are vague. Prior to 1965, the earliest known depiction of the Norsemen's Vínland had been Sigurður Stefánsson's speculative Skálholt Map of about 1590,

which combined Norse saga descriptions with late-sixteenth-century geographical concepts of the far north (Seaver 2004, 56–59).

Putting the map's two halves together in reverse order places the Vínland representation of North America in the center, with an ocean on either side, in a design conceiving of earth as a globe. Five widely dispersed map legends noting Roman Church outreach also stress the world-encompassing intent of a design that incorporates several bafflingly precocious geographical concepts and names (Seaver 2004, 256–60, 282–84).

The Vinland Map is sui generis. Since 1965 the lack of copies, antecedents, and descendants has therefore featured prominently in questions about the map, as have misgivings about the worm holes, the paleography, the source of the map's fabric and the map's "sister" texts, and the likely composition of the original codex involved. In 1974, McCrone Associates in Chicago found that the residual yellowish ink line on the map contains anatase

crystals modified by methods available only after about 1920 (Wallis et al. 1974, 212–14). While the anomalous composition of the map's ink has remained important in the authenticity debate, the McCrone analysis has been confirmed by later independent studies, resulting in a general (but not unanimous) scholarly conclusion that the Vinland Map is a modern fake. This conclusion is supported by the longer legend in the upper left corner with its demonstrably spurious nineteenth-century-colored information about the medieval Norse, both of which point to Father Joseph Fischer, S.J., as the map's likely author (Seaver 2004, 256–96).

KIRSTEN A. SEAVER

SEE ALSO: Antiquarian Maps and Grand Larceny; Collecting, Map: Canada and the United States; Histories of Cartography

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Virtual Reality. Virtual reality (VR) refers to a class of human interface technology that allows users to interact with computer-generated virtual environments (VEs). These environments are typically three dimensional in nature and can simulate real geographic spaces, imagined virtual worlds, and abstract data spaces. The term "virtual reality" was introduced by Jaron Lanier in the 1980s, but originated from the concept of virtual worlds attributed to Ivan Edward Sutherland, who outlined a vision for virtual worlds and ways to interact with them (Sutherland 1965). Virtual worlds is a popular descriptor for many different forms of computer-generated virtual spaces. By using the word *world* instead of *space*, Sutherland opened a possibility that has been appropriated by researchers, pop culture, and society—the idea that one or more persistent virtual worlds could run in parallel to our everyday existence. This concept gained considerable popularity in society as a result of Neal Stephenson's 1992 novel *Snow Crash*.

These terms have come to describe combinations of technology that support the use and navigation of synthetic VEs, computer-assisted sensory experiences, and the synthetic computer-generated virtual spaces themselves. Scholars, researchers, and engineers of 3-D user interfaces have gravitated toward the term "virtual environment." This resulted from increased experience and knowledge of the capabilities, applications, and limits of virtual reality as a concept and term. One of the major authorities on VR, Howard Rheingold (1991, 79), suggested that the 1960s and 1970s trend of tightly coupled human-computer systems resulted in VEs being environments "in which the brain is coupled so tightly with the computer that the awareness of the computer user seems to be moving around inside the computer-created world the way people move around the natural environment." In the human-computer interaction domain, Doug A. Bowman and his colleagues (2005, 7) define a VE as: "A synthetic, spatial (usually 3D) world seen from a first-person point of view. The view in a VE is under the real-time control of the user."

VR environments are predominantly visual sensory experiences supplemented by sensory information such as sound and force feedback. Due to the pop-culture impact of movies such as *The Lawnmower Man* (1992), VR often conjures up an image of an individual wearing some form of head-mounted display (HMD, or VR goggles) and tracking devices, allowing them to view and look around inside a 3-D synthetic computer-generated space.

Various configurations of VR display systems exist: computer displays paired with stereo shutter glasses, stereo HMDs, semi-immersive desk environments, and display spaces such as immersive CAVE 3-D theaters. More sophisticated systems provide additional sensory feedback and interaction possibilities. These include haptic feedback (tactile user input and feedback and physical resistance to user inputs) and other forms of force feedback. To date, force feedback has most frequently been used in popular game console controllers and in tactile surgery simulators.

Users interact with VEs by using various input and control devices that function as transducers between the real environment and the virtual world. These include keyboard, mouse, data gloves, electromechanical armatures, electromagnetic tracking systems, and treadmill devices. Devices most frequently associated with VR are HMDs and apparel that can track a user's motion and body position in three dimensions, such as data gloves and suits. Depending on how each VR interface has been designed, these transducers enable users to navigate and move within and through virtual spaces and to manipulate and interact with virtual objects and other content. These devices and technologies also track user hand, head, and body position, enabling the establishment of a three-dimensional correspondence between the user in the real world and their virtual self (avatar) in the VE.

VR evolved from research and development in military training, computer science, electrical engineering, and the movie industry. Between the 1940s and the 1960s, engineers and scholars were keen to develop systems that delivered dynamic visual and spatial experi-

ences for applications in military simulation and large field of view (FOV) displays for entertainment. In the late 1950s, researchers assembled by the U.S. military to design and build a classified computerized nuclear defense system (SAGE, Semi-Automatic Ground Environment) initiated advances critical to the future development of VR (Rheingold 1991, 88–89).

Along with fellow SAGE researcher Morton L. Heilig (inventor of the telesphere mask, Sensorama display, and Experience Theater), Sutherland is considered to be one of the fathers of VE research and interactive human-computer interfaces. Sutherland created the first computer HMD and almost single-handedly invented the field of interactive computer graphics, starting with the world's first conversational human-computer system. Sutherland's Sketchpad allowed the user to interact with information using a light pen to draw and modify visual models on a computer screen. This was the first time interaction between human and information space had been so seamless and not require the keyboard.

The technologies of advanced human-computer interaction gained substantial momentum with researchers in academia and government. One result was the refinement of HMD devices and other technologies that would support Sutherland's vision of being able to interact with and move around in virtual worlds. Several key research labs emerged including: Virtual Environment Technology Lab (VETL), University of Houston; the Entertainment Technology Center (ETC), Carnegie Mellon University; MIT Media Lab, Massachusetts Institute of Technology; the Human Interface Technology Laboratory (HITLab), University of Washington (founded by Thomas A. Furness, the former director of the U.S. Air Force's VR program); and the Electronic Visualization Laboratory (EVL), University of Illinois at Chicago (the inventors of the CAVE VR theater and ImmersaDesk).

VEs take many forms. They can be used to simulate real environments, with highly photorealistic content for civilian and combat training simulations. At the same time, VEs can be used to visualize highly abstract virtual worlds, such as exploratory data spaces. The field of VR has progressed mainly from innovations in computer-mediated interfaces. These innovations focused on developing interface platforms, visualizing many types of information, and interacting in three dimensions rather than responding to inherently geographic challenges. These innovations resulted in a steep learning curve for geographic scholars wanting to explore this research domain and apply it to cartography, geographic information systems (GIS), and geovisualization.

Geographers' interest was stimulated by a number of projects in the 1970s and 1980s. One such project was the 1978 Aspen Movie Map Project, developed by MIT's Architecture Machine Group. The system provided an interactive, user-driven experience of a real street environment in Aspen, Colorado (see fig. 401). An inventory of video media and imagery assets of every street and turn (at three-meter intervals), organized and accessed using clever interface design, resulted in a seamless user experience. It provided a glimpse of the technology (and user interface design) that we now see in mainstream geographic interfaces such as Google Street View, allowing users to "walk" or navigate to specific locations, or alternatively, to point to a location and be transported there.

The last decade of the twentieth century saw a groundswell in cartographers integrating dynamic, interactive, and three-dimensional elements into multimedia interfaces (Raper 1989; Peterson 1995; Shepherd 1995; Cartwright 1997; Dykes 1997; Peterson 1999). During the same period, researchers started to explore the potential of VR and VEs for geographic and cartographic applications, using a variety of platforms. These ranged from Virtual Reality Modeling Language (VRML) applications on desktop computer interfaces (Dykes, Moore, and Fairbairn 1999), to semi-immersive tabletop displays (MacEachren et al. 1999), to fully immersive VR systems using HMDs and tracked input devices (MacEachren, Kraak, and Verbree 1999; Winn, Windschitl, and Hedley 2001).

A number of potential benefits for cartographic visualization in VEs were perceived (Moore 1999, 206). These included: visualizing 3-D shapes and volumetric phenomena; 4-D visualization (seeing three geographic dimensions and time); simulations of complex motion and behavior; ways of interacting with and moving through virtual cartographic visualizations; using other senses such as sound and touch; the integration of other media such as streaming video and clips; collaborative visualization environments; additional visual variables, such as emissive color, transparency, lighting models, and atmospheric attenuation.

Ian D. Bishop (1994) was one of the first geographers to consider the potential of VR for geographic work exploring photorealism in VEs, as did Alan Collinson (1997). L. H. van der Schee and G. J. Jense's GIS2VE interface enabled users to participate in exploratory geographic visualization, navigating and querying data. A typical user experience would be to "fly" through the VE, triggering data visualizations as the user moves into each new area (Van der Schee and Jense 1995). Researchers at Pennsylvania State University's GeoVISTA Center made contributions to three-dimensional, interactive, and immersive geographic visualization. One example was the use of ImmersaDesk semi-immersive tabletop environments to collaboratively visualize and interact with 3-D geographic data (MacEachren et al. 1999). In the same period Nick Hedley and Bruce D. Campbell (1998) de-

signed and implemented the Collaborative Distributed Virtual Environment (CDVE) system, which supported synchronous and asynchronous multiuser collaboration with high-resolution 3-D data sets in a shared VE. Unlike many of the other systems of the period, the CDVE system was designed to enable users, distributed anywhere in the real world, to use a range of interface platforms (desktop PC, ImmersaDesk, immersive VE) to enter and collaborate in the shared VE.

The field of VR contains far more than a description of interface technology. Michael Heim (1993, 110–16) identified seven capabilities that VR enables, each of which opened conceptual territory for cartographers to consider: simulation, interaction, artificiality, immersion, telepresence, full-body immersion, and network communications. At the close of the twentieth century, geographers and cartographers were continuing to explore and develop geographic VEs. Increasingly, there was evidence that cartographers were starting to accumulate experience in geographic VE applications, enabling them to suggest a number of cross-cutting issues and challenges in the development, application, and use of geospatial VEs. In short, geospatial VEs were far more than their constituent parts.

Once focused on VEs, cartographers and geographers began to observe and experience a number of properties of VEs that computer scientists and usability engineers had known about for years (Heim 1993). The result was the integration of a set of new ideas, concepts, and questions into geographic visualization research: about how we perceive real and virtual spaces, how we learn from them, and how we might design geospatial VEs in order to maximize geographic learning based on these properties. Having now experienced a range of interface technologies, geographers had a better understanding of what nonimmersive, semi-immersive, and fully immersive VEs were.

Researchers began to consider new forms of perceptual relationships with geographic visualizations, and the phenomena they represent. Cartographers began to consider how varying degrees of user immersion enabled by different combinations of display devices, input/output devices, and interaction design could produce a wider range of user experiences. For example, one was the notion of presence, "the subjective experience of being in one place or environment, even when one is physically situated in another." Another was the notion of immersion, "a psychological state characterized by perceiving oneself to be enveloped by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences" (Witmer and Singer 1998, 225, 227).

Other capabilities of geospatial VEs include the ability of users to explore data visualizations and simulations that have themselves considerable autonomy. A user might be able to navigate freely through the virtual geographic landscape but not have any control over the flood simulation event being portrayed. In the late 1990s, a team of researchers from the University of Washington built Virtual Puget Sound, an integrated immersive VE using HMDs that portrayed a virtual geographic region in which topographic, bathymetric, salinity, advection, and 3-D ocean circulation models were combined with the objective of supporting interactive experiential learning about complex ocean science processes. The system enabled users to fly around, switch 3-D data sets on and off "on the fly," pause or rewind time, and take multivariate samples from anywhere within the VE (Winn, Windschitl, and Hedley 2001). This project demonstrated some of the greatest capabilities of VEs—to go where we otherwise would not be able to go, perceive phenomena that are not directly perceivable in the real world, yet interact with and explore them in 3-D (and 4-D in which temporal representation was possible).

To help the cartographic/geographic community make sense of these new capabilities and considerations, Alan M. MacEachren, M. J. Kraak, and Edward Verbree (1999) proposed four factors to consider in creating geospatial VEs: immersion, interactivity, information intensity, and intelligence of objects. In addition to this framework, other scholars began discussing the role of representation versus visualization in VEs, and how VEs always fall short of the real world. William Cartwright (1997, 451) also warned against complacency, suggesting that highly immersive VEs could be misleading or disconnected from reality.

NICK HEDLEY

SEE ALSO: Electronic Cartography: Data Structures and the Storage and Retrieval of Spatial Data; Interactive Map; Visualization and Maps

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Vision. See Perception and Cognition of Maps: (1) Vision and Discrimination, (2) Perceiving, Understanding, and Remembering

Visualization and Maps. Maps give their users the ability to present, to synthesize, to analyze, and to explore facets of the real world. Maps do this well because they only present a selection of the complex reality and visualize it in an abstract way. Over the years the cartographic discipline has developed a rich set of design guidelines to create the most suitable map for a particular purpose that offers insight in spatial patterns and relations (Robinson et al. 1995; Kraak and Ormeling 2003). This translation or conversion of geospatial data into maps is called the cartographic visualization process. During most of the twentieth century, these data were in an analog format, and the final map was presented on paper. During the last two decades the source data became predominantly digital and, along with paper, computer screens became the medium on which to present maps.

This switch to a digital map world has given the word "visualization" an enhanced meaning. In addition to visualization as the process of forming a mental picture or vision of something not actually present to the eye, the term also means the action or process of rendering visible. Both definitions relate to "making visible," which has always been the domain of cartographers. However, progress in other disciplines over the last few decades has linked the word to more specific ways in which modern computer technology facilitates the process of making visible in real time, which links current cartography more to the second meaning of visualization.

The digital revolution has not only introduced new media to present maps but also changed the traditional approach to cartography. Maps are no longer used only for presentation purposes; they are also very suitable for interactive and dynamic exploration. Presentation fits into the traditional realm of cartography, where the cartographer works on known geospatial data and designs maps that are often created for multiple uses. Dynamic exploration, however, often involves an expert in some field who is producing maps that deal with with newly obtained data. These maps are generally for a single purpose: an expedient in the expert's attempt to solve a problem. While working with data, the expert should be able to rely on cartographic expertise provided by the software or some other means. This extension of the role of maps requires an interactive and dynamic environment where one can create and query maps, having an extensive set of functions available to explore the geospatial data at hand.

During the visualization process cartographic methods and techniques are applied (fig. 1083). These can be considered a kind of grammar or as guidelines that allow for the optimal design, production, and use of maps, depending on the application. Charles Joseph Minard's 1869 map of Napoleon's Russian campaign in 1812 is used here as an example to illustrate the aspects of visualization. The process is guided by the phrase "How do I say what to whom and is it effective?" The phrase holds four key words: "how" refers to cartographic methods and techniques (a flow map has been chosen); "what" refers to the geospatial data (quantitative data—the number of Napoleon's soldiers); "whom" refers to the map audience and the purpose of the map (the map is
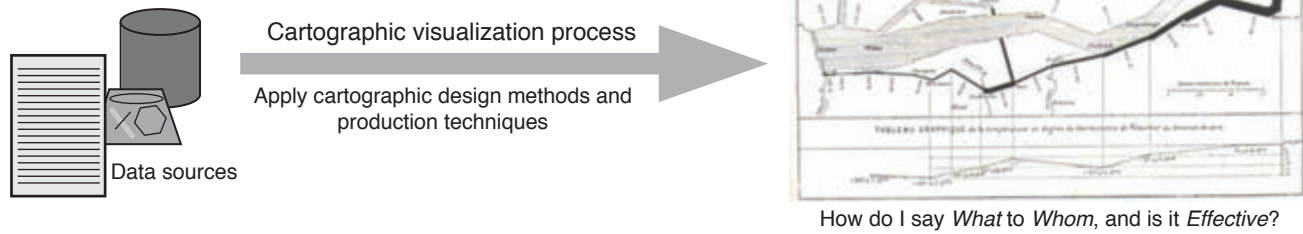
FIG. 1083. THE CARTOGRAPHIC VISUALIZATION PROCESS. Source data are converted into map-type products using cartographic methods and techniques.

How do I say *What* to *Whom*, and is it *Effective*?

Image courtesy of M. J. Kraak.

rather basic and could function in a newspaper or school atlas); "effective" reflects the usefulness of the map (do the map readers understand the message the map intends to convey, the story of Napoleon's campaign?). This last keyword is especially relevant when introducing new cartographic representations to validate their usefulness.

The cartographic visualization process described above has been and still is instrumental to cartography. Over time, visualization methods were influenced by disciplines related to cartography. In the early decades of the twentieth century, the fields of surveying and geography heavily influenced maps. Surveying contributed to the development of topographic mapping and geography to thematic mapping, and both developments were linked closely to technical methods for producing maps. These methods limited the particular design options, since most maps were complicated to produce. For instance, to create a different perspective view on a three-dimensional landscape map would not be a simple selection of the new viewing angle but a complete overhaul of the design. The revision of a topographic map sheet could take over a year to accomplish.

The introduction of the computer into map production during the 1960s reduced dramatically the time required to produce a complex map, although it took several decades to make this process interactive and in real time. Figure 1084 summarizes the developments in three trends represented by the keywords cartography, computer cartography, and geovisualization. Although technological developments drive advances in cartography and related disciplines, it is important to realize that despite the great advances in technology, challenges remain. The same technology is responsible for the tremendous increase in the amount and diversity of data to process. This increase in data for mapping has grown faster than the new computer technology can handle. At the same time, expectations of what can be done
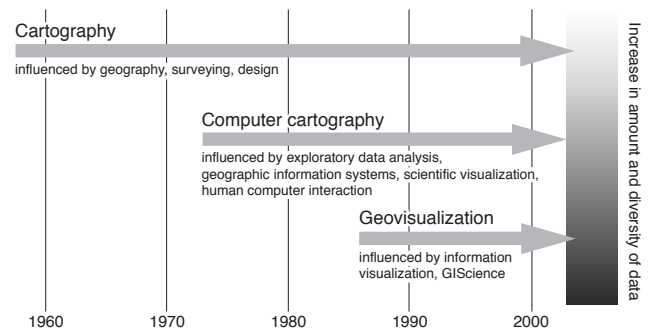

FIG. 1084. TIMELINE OF THE DEVELOPMENT OF CARTOGRAPHIC VISUALIZATION. Cartography, computer cartography, and geovisualization are shown along with the disciplines that influenced these developments in an environment that has to deal with large amounts of increasingly diverse datasets.
Image courtesy of M. J. Kraak.

and how fast it can be done have also increased over time.

The introduction of computer technology did not immediately lead to better cartographic results. Instead, the introduction of the computer into cartography initially decreased the quality of the maps produced compared to manually produced maps. Except for some high-end output instruments, most printers in the 1960s and 1970s could only handle different letter combinations to simulate gray values, and plotters worked with ball-point ink. The paper quality was poor as well. However, the quality of the map output improved quickly during the 1980s, partly because cartographers used computer-aided design (CAD) software for the production of large-scale topographic maps. This was less useful for thematic mapping because CAD software was limited in the creative design options required for these maps. In addition to paper, computer screens were used to visualize the maps. In the beginning, the software used had

limited interaction options for the map designer (Monmonier 1982).

In cartography, the computer was used first to optimize existing production processes, but soon afterward it was also used for analytical purposes. This required an interdisciplinary approach (forestry and maps, census and maps, etc.) that led in the 1970s to the development of geographic information systems (GIS) combining data integration, analysis, and visualization. The rise of GIS stimulated geographers and others to synthese, analyze, and explore their data. Maps that used to be difficult and time-consuming to produce could be quickly created in many alternative views.

The use of GIS in the following decades greatly increased the number of maps produced. As GIS software became increasingly sophisticated, it allowed interactive visualization sessions where GIS users could improve map design. This interactive visualization became an important component of what has been called the "democratization of cartography." As geographer Joel L. Morrison (1997, 17) explained, "Using electronic technology, no longer does the map user depend on what the cartographer decides to put on a map. Today, the user is a cartographer." Those users, however, were mainly professionals.

During the 1980s technological advances had a large impact on computer graphics, which led to the notion of scientific visualization first mentioned in a report by the U.S. National Science Foundation (NSF) (McCormick, DeFanti, and Brown 1987). The report, produced by a committee containing no cartographers, emphasized the role of computer display technology in prompting mental visualization and subsequent insight. Scientific visualization was defined as the use of sophisticated computing technology to create visual displays, the goal of which was to facilitate thinking and problem solving. The emphasis was not on storing knowledge but on knowledge construction. Several cartographers studied the cartographic implications of this new reliance on visual representation in science.

In particular, the NSF report stimulated David DiBiase (1990) to define a conceptual model for map-based scientific visualization, also known in the 1990s as geographical visualization (Hearnshaw and Unwin 1994; MacEachren and Taylor 1994). The model covered both the communication and visual thinking functions of the map. The model presented visualization as a four-stage process consisting of two private visual thinking stages (exploration and confirmation) and two public visual communication stages (synthesis and presentation). The intent of the model was to encourage cartographers to direct attention to the role of maps at the early private stages of scientific research where maps and map-based tools are used to facilitate data sifting and exploration of extremely large data sets.

Exploratory visualization was also stimulated by developments in statistics when the exploratory data analysis approach was introduced in 1977 by statistician John W. Tukey. Exploratory data analysis (EDA) employs a variety of mostly graphical techniques to maximize insight into a data set, to uncover underlying structure, and to detect outliers and anomalies. These objectives of EDA are also valid for geospatial data and have been extrapolated into the cartographic realm. Graphic techniques used are box plots, histograms, scatter plots, and maps.

Since 1995 the Commission on Visualization (now called GeoVisualization) of the International Cartographic Association has been active in trying to establish a research agenda for cartography that incorporates the above developments into the cartographic discipline in a more sustainable way. The commission's efforts introduced the term "geovisualization" to encompass the integration of scientific visualization, (exploratory) cartography, image analysis, information visualization, EDA, and GIS to provide theory, methods, and tools for visual exploration, analysis, synthesis, and presentation of geospatial data (MacEachren and Kraak 2001). Cartographic designers and researchers were urged to pay attention to human-computer interaction and the attendant interfaces and to focus attention on the usability of their products.

Additionally, professional cartography was seen as including both representation issues and the integration of geocomputing in the visualization process. Maps and other graphics are used to explore geospatial data, and the exploration process can generate hypotheses, develop problem solutions, and ultimately construct knowledge. In this context the traditional role of a map to "present" was recognized, but maps were also seen as flexible interfaces for geospatial data, since they offer interaction with the data behind the visual representation and are also instruments that encourage exploration.

An important characteristic of twenty-first-century geovisualizations is the ability to look at data from different perspectives using all kinds of suitable graphic representations, which were predominantly map-like but not limited to maps. Figure 1085 offers an interesting example. In the center left, Minard's map is presented again to give an idea of the path followed during the campaign as well as the effects of the number of troops. Time is inherent in the map, however; the space-time cube to the right of Minard's map, which has time mapped along the cube's vertical axis, reveals that Napoleon stayed one month in Moscow, which was not visible on the original map. The lower map is a snapshot of an animation for the campaign, and the upper map shows the path of Napoleon's troops, looking east, on top of Google Earth imagery, which gives yet another

FIG. 1085. GEOVISUALIZATION—ALTERNATIVE CARTOGRAPHIC REPRESENTATIONS OF MINARD'S MAP OF NAPOLEON'S RUSSIAN CAMPAIGN IN 1812. At the top the campaign path in Google Earth; center left shows the original map (*Carte figurative des pertes successives en hommes de l'armée française dans la campagne de Russie 1812–1813*); center right depicts the campaign in a space-time cube; and at the bottom is an animation scene of the same event. Image courtesy of M. J. Kraak.

perspective on the campaign. *Exploring Geovisualization* (Dykes, MacEachren, and Kraak 2005) describes developments in geovisualization in depth.

Throughout the twentieth century, paper was the primary medium on which maps were presented. Paper allowed for high-quality visualizations, and its only disadvantage was its static nature. Once drawn or printed very little could be modified. The computer introduced the display screen as a major presentation medium. Shortly after its introduction in the 1970s there were technical limitations in resolution and color capabilities, but these were soon resolved. The main advantage of the display screen as a medium for maps was interactivity, which is relevant for both the mapmaker and map user. Depending on the software available, the cartographer

can select and change symbology during the design process. The map user can select map content and query the map.

Interactivity was and continues to be an integral part of the exploratory visualization approach. Cartographers realized in the 1990s that maps could be combined with other non-map-based media such as text, photographs, videos, animations, and even sound. These multimedia elements were found to enrich the map content and make maps more informative and attractive (Cartwright, Peterson, and Gartner 1999). For instance, text could explain the map content, a photograph could illustrate the mapped theme, a link could be provided to a web page. The next step was to pinpoint the multimedia elements exactly on the map, resulting in a hypermap. Hypermaps were defined by Robert Laurini and Françoise Milleret-Raffort in 1990 as georeferenced multimedia. Figure 1086 is an example of Minard's map as a hypermap, enhanced with added point symbols that are clickable hotspots. Clicking the symbols results in a pop-up of a picture related to the locality. Figure 1087 shows a snapshot of an interactive animation based on Minard's map showing Napoleon's progress during the campaign. A diagram showing the number of troops is added, and the background color of the map represents the temperature diagram in the original map. The exploratory approach requires users to see and interact with different representations of the same data shown in figure 1085. To be effective, however, these views containing maps, diagrams, and tables are linked to each other so that user interaction with any of the views results in highlighting the relevant objects in all the other views. Figure 1088 shows different linked graphic representations of Napoleon crossing the Berezina River in a set of coordinated multiple views.

At the end of the twentieth century, the largest impact on the cartographic visualization process was the Internet, or more precisely the World Wide Web. Cartographers as well as map users have produced huge numbers of maps on the Internet (Peterson 2003). The visualization environment of the Internet combines most of the developments described above. This new revolution had the same initial negative effect on the quality of visualizations as the introduction of the computer in cartography. However, technical problems were solved quickly and one now finds high-quality visualizations on the Internet.

Since all data have to travel through cyberspace, map design had to be adapted to this new medium. Because a typical user surfing the Internet has a relatively short attention span, files had to be small and map information content had to be low. Yet it was possible to put all kinds of additional information behind the map image because of the interactive nature of the Internet. Clicking
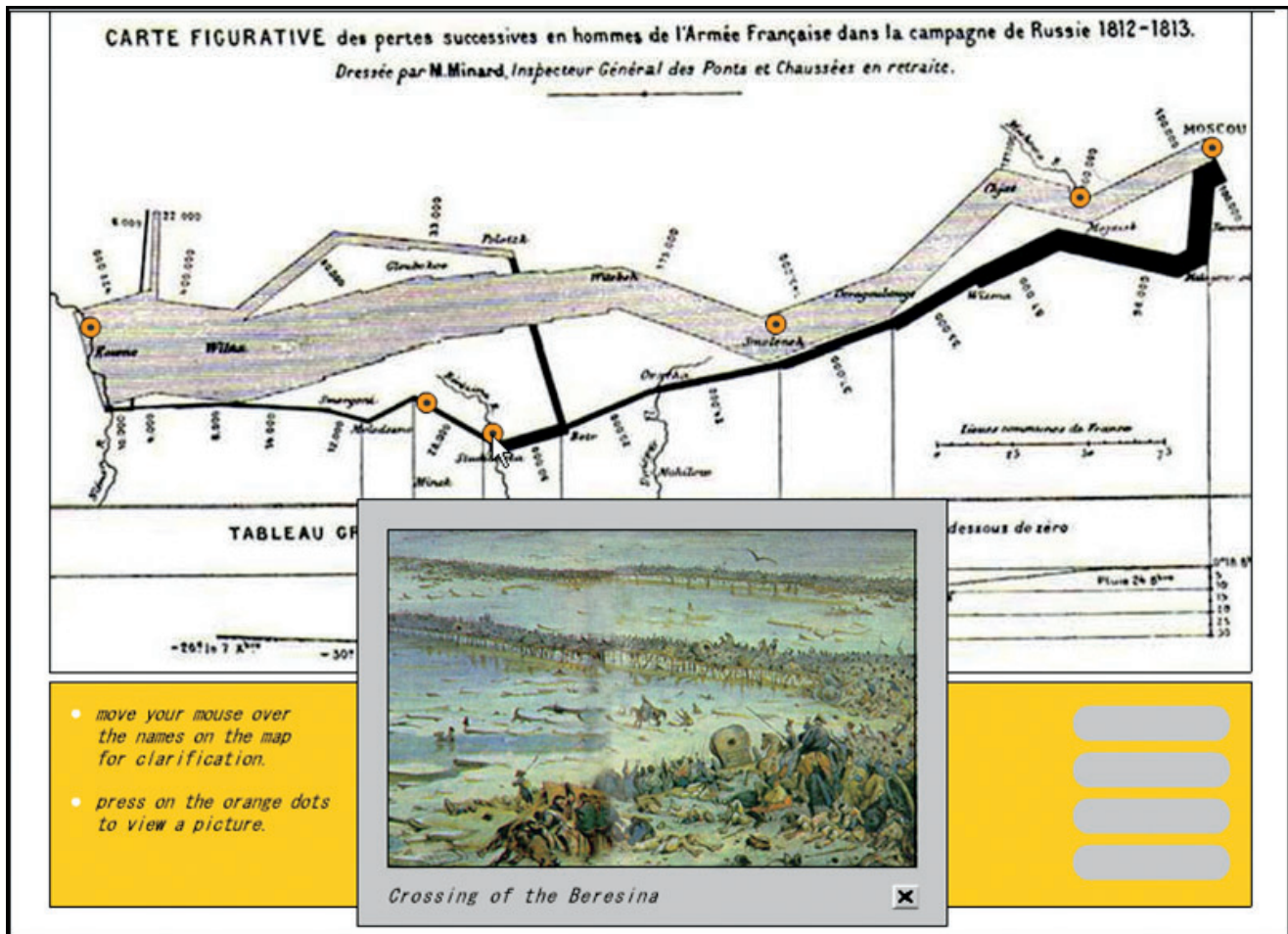
FIG. 1086. MINARD'S MAP AS A HYPERMAP. Clicking the point symbols added to the map will reveal an illustration related to that location. In this example a pop-up painting of Napoleon's troops crossing the Berezina River is shown.

Image courtesy of M. J. Kraak.

map objects or using mouse-over techniques accessed a database with additional information related to the object. For example, a user moved the cursor over the map and when the cursor hit a town symbol the name of the town was shown.

Cartographic web visualization also brought new advantageous techniques. For instance, mouse-over techniques were used to highlight geographic objects based on user interaction. The base map could be viewed in pastel tints, while moving the mouse around presented the object under the pointer in bright colors. Shading could be applied in combination with the base map tints, giving a three-dimensional look to those symbols selected. These special effects not only enhanced the map's attractiveness, but also provided additional information or help in navigating the web map and even functioned as the map's legend.

Virtual reality (VR) was another interesting development at the start of the twenty-first century that began to play a role in cartographic visualization (Fisher and Unwin 2002). VR creates a three-dimensional data environment and users become part of a digital world where they can explore and interact with the data. The experience of being within the virtual environment, called immersion, is enhanced by stereoscopic three-dimensional images, sound, and real-time interaction. With VR it would be possible to re-create Napoleon's campaign and be immersed in it.

Besides being immersed in the data, it is also now possible to let the data be immersed in our real environment. This is called augmented reality. The content of a database is projected on a special headset the user wears. Change of position or even viewing angle will result in seeing a different part of the database. An ex-
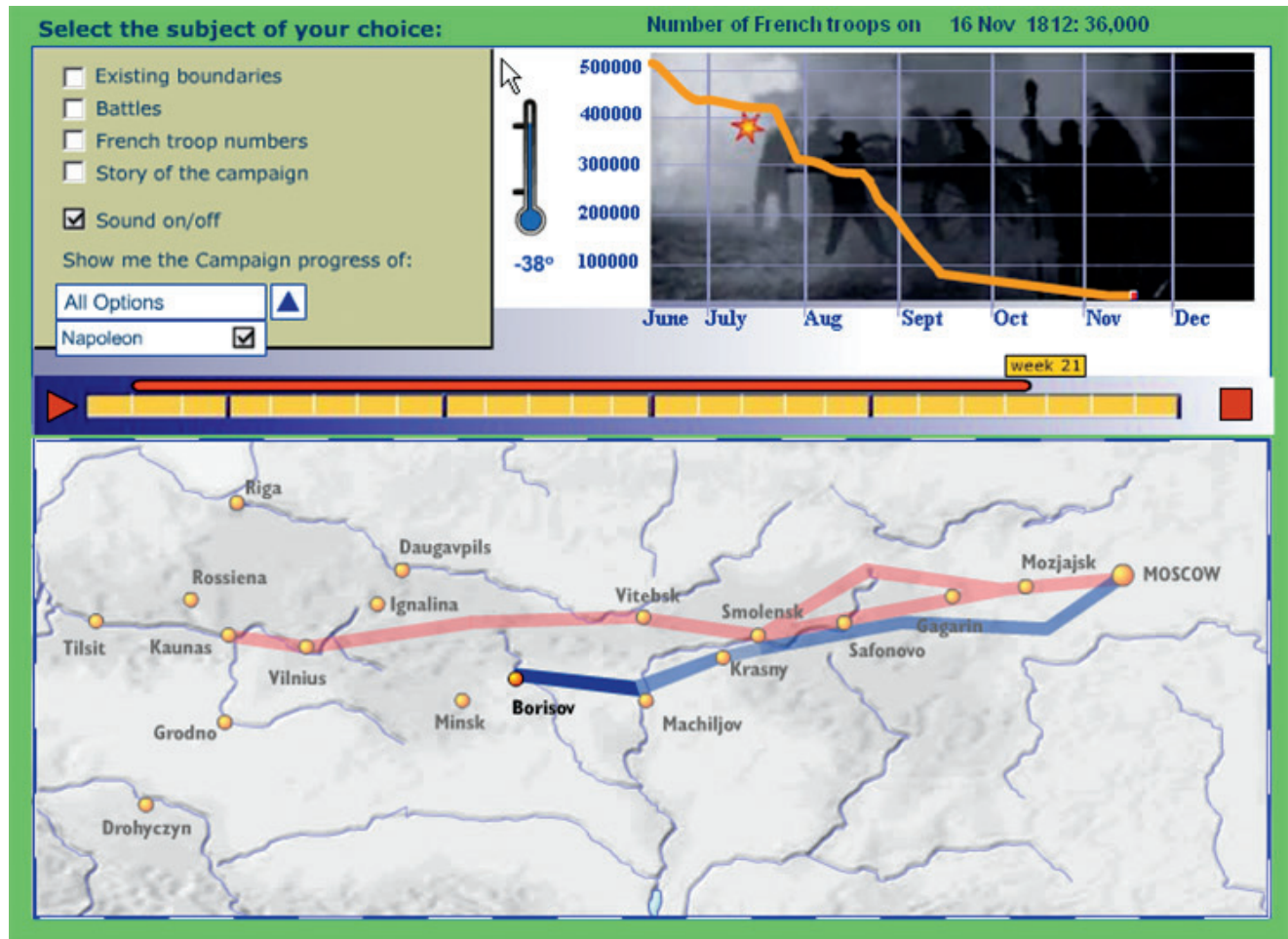
FIG. 1087. A SNAPSHOT OF AN INTERACTIVE ANIMA-
TION OF NAPOLEON'S RUSSIAN CAMPAIGN. Users can
interact by playing, pausing, and rewinding the event, as well
as opt for different representations or content.

Image courtesy of M. J. Kraak.

ample could be standing at the riverbank of the Bere-
zina and getting historical information displayed with
today's view of reality.

These twentieth-century developments in cartographic
visualization resulted in the extension of the meaning of
"map." Although the traditional role of a map to pres-
ent information is recognized and still very valuable as
the examples above show, the map is also viewed as a
flexible interface for geospatial data. Maps offer interac-
tion with the data behind the visual representation and
are instruments that encourage exploration by stimulat-
ing thinking about geospatial patterns, relationships,
and trends. The Internet expands the roles of the map
in several ways. First, the map can function as an index
to available data and guide users to other information.
It is possible, for instance, to click on a region or any
other geographic object, which in turn can lead to a list
of links. The links might refer to other maps, geospa-

tial data sets, or multimedia data. Second, the map can
be the geospatial part of a search engine. It represents
the locational component of the data while the attribute
and temporal components are often obtained by textual
search. Third, the map is used to preview available data.
The quest for spatial data can be assisted by maps that
help visualize the obtainable data. Based on the preview,
the user determines the data's suitability.

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SEE ALSO: Animated Map; Education and Cartography: Teaching with
    Maps; Exploratory Data Analysis; Hypermapping; Perception and
    Cognition of Maps; Virtual Reality

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Dykes, J., Alan M. MacEachren, and M. J. Kraak, eds. 2005. *Exploring
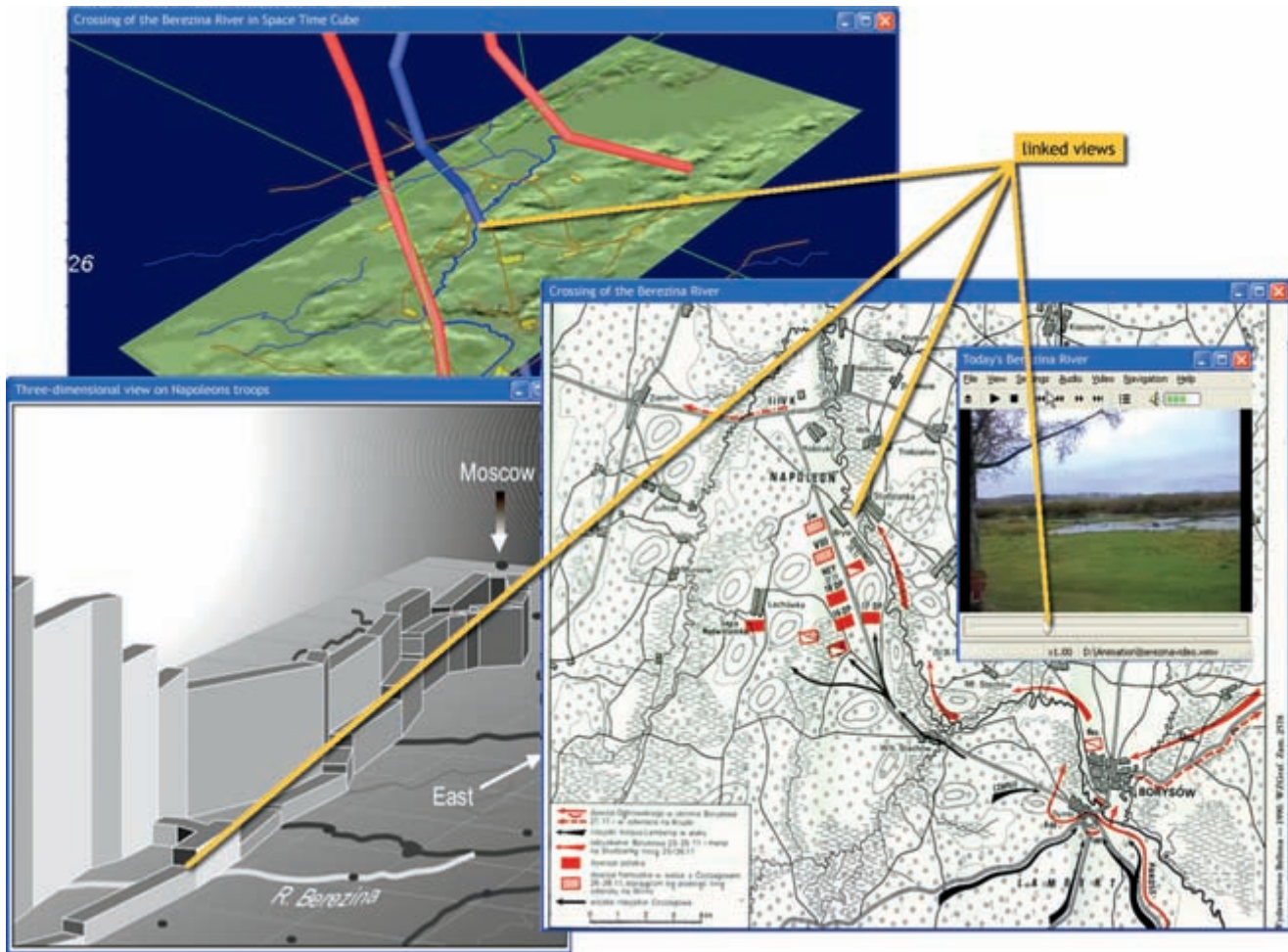   Geovisualization*. Amsterdam: Elsevier.

FIG. 1088. THE COORDINATED MULTIPLE VIEWS AS CARTOGRAPHIC VISUALIZATION ENVIRONMENT. Views are linked with a video of the location of the crossing of the Berezina River, a map, and two three-dimensional perspectives of the same event.

Image courtesy of M. J. Kraak.

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