

# 2

## *Hardware*

### 2.1 DEVICES FOR COMPUTER CARTOGRAPHY

#### 2.1.1 A Map of the Computer

In Chapter 1 we saw that the impact of the digital computer upon cartography has been revolutionary. To understand the tools of contemporary cartography, therefore, we must examine computers in depth. We shall begin by considering the nut and bolts of computing, the hardware. This will allow us to focus on the special types of devices required for computer cartography, most often unlike those required for more routine computer tasks. To conclude the chapter, the relatively recent addition of the workstation will be introduced, and its significance for both analytical and computer cartography demonstrated.

Hardware consists of a set of physical devices that perform electrical, mechanical, or other physical tasks, or state changes according to instructions given by software. Hardware is something breakable, needing mechanical assistance, repair, or maintenance, and it reflects a particular stage of technology, therefore implying eventual obsolescence. As a result, the center of a computer is of relatively minor importance for analytical cartography, although of some importance for computer cartography. Of more importance to cartography is the peripheral device, a plug-in or add-on part of the computer that gives the computer cartographic capabilities. A recent trend has seen peripheral devices with significant amounts of computing power, sometimes more than the “main” computer itself.

Figure 2.1 presents a *map of the computer*. At the heart of the computer is the central processing unit (CPU). The CPU consists of the part of the computer that actually carries out the instructions given by software, such as the addition of values in registers, places where binary operations take place. In a microcomputer, the CPU can be as small as a

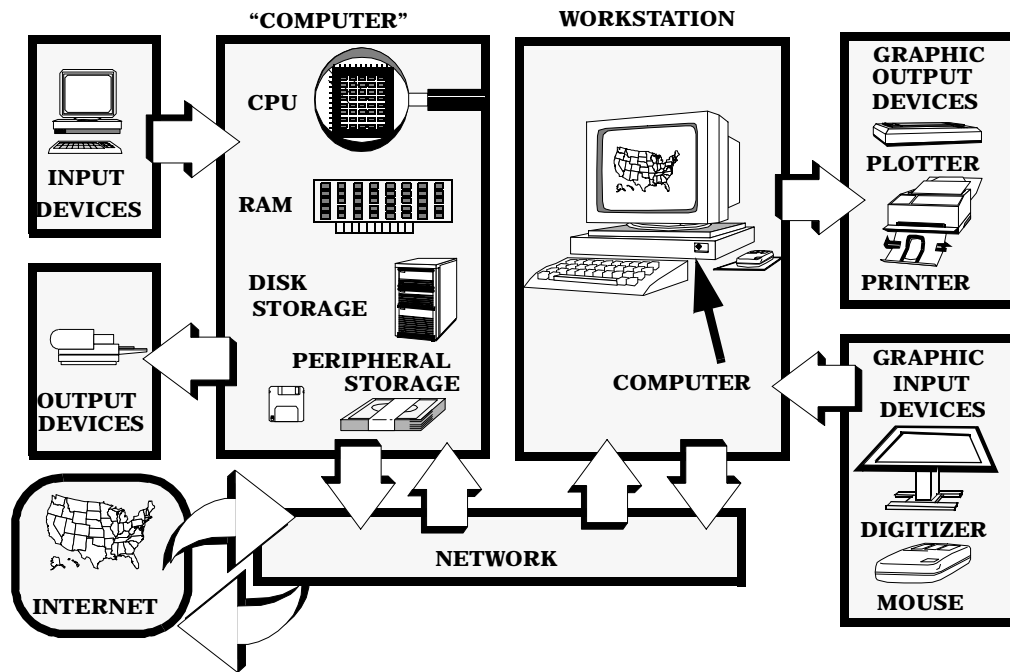


Figure 2.1 A map of the computer.

single microcircuit or “chip.” CPUs vary in power according to the size of their registers in bits and their speeds, usually measured by their clock speeds in megahertz, their basic processing rate in MIPS (millions of instructions per second), and by their ability to handle complex operations (megaflops, or millions of floating point operations per second). Many CPUs are enhanced with an accelerator, which in particular increases the speed at which the CPU can handle floating point arithmetic. Most computers can do integer arithmetic at high speeds, but slow down considerably when the use of floating point causes the registers to overflow.

The memory locations accessed by the CPU have to match the speed at which the CPU operates and therefore are limited in size. In addition, this memory must be able to store instructions, data, and parts of the operating system. Such “fast” memory must be accessible starting at any point and is therefore known as random access memory (RAM). While the first microcomputers were limited by the size of the link to the CPU (the bus) to about 28 kilobytes or less, most microcomputers now have over 640 kilobytes, with some having well over a megabyte. Workstations typically have about 8 to 32 megabytes of RAM. Because the size of the RAM is the upper limit on the address space available to computer programs, this is often a limiting factor for cartographic software.

Data and instructions awaiting the services of the RAM and the CPU reside in one of the various forms of permanent or temporary storage. In large computers, many different kinds of storage are available. Among the more temporary storage mechanisms are fixed

and removable disks. Fixed disks are installed within the computer and involve a mechanical device capable of writing information onto and retrieving it from a storage medium. Magnetic platters, optical disks, and even “bubble” memory are used to store information. Removable systems allow data and programs to be archived or added to the system. Removable systems include disk cartridges, magnetic tapes, floppy disks, and removable optical media. Most cartographic software and data are available on microdisk or magnetic tape. Among the disks, the 133 millimeter (5.25 inch) and the 90 millimeter (3.5 inch), are standard. Among magnetic tapes, the nine-track 13 millimeter (0.5 inch) at the 1600- and 6250-bit per inch densities are most common, while workstations usually use cartridge tapes. Mass storage is usually by 8-mm tape, an extremely inexpensive storage medium onto which about 5 gigabytes per tape can be written. For read-only purposes, the CD-ROM is the preferred medium, because it is robust, inexpensive, and easily produced and distributed. These media are comparatively cheap, widely available, and reliable enough to store data without error for several years.

Computer cartography involves interaction with the computer in ways that are more complex than the simple video terminal and keyboard, which microcomputers have made household features. In particular, we need to enter graphic locational information into the computer and to get output in the form of maps from the computer. This involves adding to the computer devices that are specially made for graphics. Such add-on features are called peripherals, although this term includes add-on memory, disks, keyboards, mice, and so forth. A more specific term for a peripheral is a *device*, and the devices we require for cartography are graphic input and output devices. This chapter is, therefore, largely a summary of the various graphic input and output devices that have been used for computer cartography. Historically, these devices were used in isolation, connected remotely to a large computer, and performed their functions one at a time, so that their use in cartography was much the same as when maps were produced manually. More recent developments, however, have reshaped the way devices are used. This development, in turn, has been made possible by two other developments, the development of computer networks and the development of the workstation.

Computer *networks* are groups of linked computers that can share the various devices that are connected to the network rather than to individual computers. Within a network, each CPU, with its RAM, becomes a client and is connected to the network via a cable and network software, which handles the movement of data through the network and manages the individual systems. Peripheral devices (such as disk storage, tape drives, and especially input and output devices) can then be connected to the network rather than simply to an isolated CPU. One of the CPUs on the network typically functions as the master, usually supplying most of the disk storage and services. This CPU is known as the host, and if it supplies the disk space to the network, it is known as the file server. In the case of computer cartographic software, installation is often on the file server. The software is then “released” to all of the users of the network.

Networks can be extended beyond the limits of one system by telephone and other links to other computers. Thus entire databases can be distributed, resident on different computers around the United States, or even the world, and used by clients remotely. Such networks are available even to the smallest system, including microcomputers, assuming the availability of a modem.

The second important development for cartography is the graphic workstation. In the most primitive form, a system to produce graphics contains only additional RAM connected to a graphic display card, and a monitor capable of supporting graphic display. A workstation, however, can support any number of graphic input and output devices simultaneously. As a minimum, the workstation should have both a graphics and a text display and some sort of graphic input device, such as a digitizer, mouse, or touchscreen. Many workstations incorporate more sophisticated devices. A workstation has its own operating environment and is usually connected to a network, where data and additional software are available.

### 2.1.2 Input Devices

In the preceding subsection we met the concept of a peripheral device. In computer cartography, the devices of major concern can be classified as input, those that provide data, and output, those that produce maps or other information. Within this division, we can break the devices down further into map and attribute.

Attribute input devices, although in regular use, are not particularly cartographic. Examples are the keyboard, a computer tape, or a disk from which a file can be read. Anything that can send data to a computer qualifies as an input device. Map input devices are many and varied. The most primitive, and first, was the up, down, left, and right arrow keys on a keyboard, sometimes mapped onto the *h*, *j*, *k*, and *l* keys. Continuing chronologically, the next was the joystick. Joysticks were used occasionally in computer cartography, but remain in use solely for games. Some graphics terminals included on the keyboards two wheels that moved a set of cross hairs on the screen in the *x* and *y* directions. Positioning the cross hairs and then touching a key returned the screen location to the device. This type of input has largely been replaced with the light pen, digitizing pad, touch screen, track ball, and mouse.

The light pen is favored in CAD applications, where interactive screen modification of a picture is important. The light pen is much like a pen, except that the point end emits a light signal that is detected by the screen and the other trails a wire. The digitizing pad is a small digitizing tablet, sometimes only about 200 millimeters on a side. Usually, the tablet includes, or has attached to it, a menu from which commands can be selected by pointing to the menu area indicated and either pressing a button on a cursor, or in the case of a pen cursor, pushing down on the pen tip. The graphic interaction takes place away from the screen, although when interactive graphics use the screen, the cursor position is usually continuously displayed on the screen. Many “paint” packages, the digital equivalent of a pen and paintbrush, use the digitizer pad. Figure 2.2 shows a workstation with a full set of input devices.

Another form of graphic interaction is the touch screen. On a touch screen, the screen is partitioned into menu areas, on which is displayed text or graphics describing the selection. When the user touches the screen, the touch is detected and the software reacts accordingly. Touch screens have found their way into supermarket guides, hotel and airport lobbies, and libraries, where searches are a set of hierarchically linked choices, narrowing in on a final image to be displayed. In many cases, these systems include maps.



**Figure 2.2** Workstation with multiple input capabilities.  
(Photo permission of Chromatics, Inc.)

For example, a hotel lobby screen may contain a neighborhood map with restaurants, which can be queried by the ethnicity of the food served.

The track ball is a ball mounted in a holder, which can be moved freely in any direction using the palm of the hand. Often buttons or dials allow the motion to be constrained to one direction or to proceed just one screen unit at a time. As the ball is moved, the screen cursor moves with the same relative movements as the ball. Most track balls use “wraparound”; that is, when the cursor is moved off the screen to the edge, it reappears at the opposite side.

By far the most common graphics input device is the mouse. Two types are in use: the mechanical and the optical. The mechanical mouse contains a small plastic or rubber ball that is turned by friction against the table top or a special mouse pad as the mouse is moved. The relative movements are picked up by the computer and are used to control the motion of a cursor on the screen. The optical mouse uses a reflective pad and a light beam to detect motion, which avoids the problem of dirt and dust clogging the ball as sometimes occurs with a mechanical mouse. Cordless mice allow complete freedom of movement since they need no wire connection to the keyboard.

Using a mouse involves first moving the cursor around, but also selecting features from a graphic menu. Items are selected by clicking, that is, moving the cursor into the correct location and pressing a button on the mouse. Often, double-clicking (making two clicks of the mouse button in rapid succession) makes the selection and confirms it. Holding down a button sometimes reveals another level of menu, the so-called pull-down or pull-right menus used in many graphics-based operating systems, which require more

cursor movements. Selecting a feature by holding down a button while the cursor is over a feature and then moving the feature by moving the mouse while holding down the selection button is called dragging. Dragging is an integral part of using CAD and draw-type software.

What the map input devices covered so far have in common is that although they have some graphic capabilities, the locational data they provide is too approximate for anything other than selection from menus. These devices support the graphics function of *selection*, that is, indicating approximate direction and location, and of *picking*, the choosing of a menu object. Detailed cartographic input comes from one of two sources, semiautomatic digitizing and automatic digitizing.

*Semiautomatic digitizers* are the computer equivalent of the drafting table. They contain a tablet, that can be as small as a printed page, or as large as 1.5 by 2 meters. Smaller tablets can rest on a desk top, but the larger ones require stands and include options such as power movement and back lighting. Although a number of different options are available for the cursor on a digitizer, most cursors have between 1 and 16 buttons and have options such as magnifying lenses, choices of bull's-eye and cross-hair patterns, and the ability to follow lines within the cursor window automatically. Figure 2.3 shows a typical array of tablet and cursor choices. Cursors with multiple buttons allow data such as elevations and labels to be entered along with the map information, which means that the user need not move between the keyboard and the tablet.

Generally, the tablet itself consists of wires embedded in the surface along the cartesian axes. Each wire is connected along the edges, so that when the cursor is moved to a point and the button is pressed, an electrical charge is generated by a coil in the cursor which is detected on one of the wires underneath. The unique wire that picked up the charge gives the  $x$  and  $y$  values. The signal is then converted to a string of ASCII characters corresponding to the button pressed, the  $x$  and  $y$  values of the point, and any attributes entered. These data are sent down a cable to the controlling computer, usually a workstation or a microcomputer.

Early systems often converted the signal to codes for transmission over telephone lines, because much early digitizing took place with remote connections to large computers or directly to magnetic tape off-line. This arrangement has been replaced so that the signal from the tablet now moves straight to a special purpose board inside a microcomputer or the workstation that controls the tablet. In this case, the data move directly to disk.

Electronics is not the only technology that has been used in digitizing. For a long time there were sonic digitizing tablets, still seen occasionally. Sonic tablets use a drafting table, but instead of wires set into the tablet there is a string of microphones along the top and one side. The button on the cursor simply emits a click or a beep, which is picked up by the microphones. A triangulation is then performed to figure out where the cursor is. Other tablets are simply mechanical arms like pantographs, which use the mechanical movement of the arms to compute  $x$  and  $y$ . These systems are usually inexpensive and can be mounted on an existing table.

Many digitizing tablets support voice data input in addition to the cursor. Simple commands can be spoken, and a microphone on the controlling computer matches the recorded voice against a preset list of commands. This allows much more efficient use of the tablet because the user's attention remains on the task, not on moving between menus and



**Figure 2.3** Digitizing tablet. (Photo courtesy of Numonics.)

cursor buttons. Also in use are three-dimensional digitizers, where a cursor on a cantilever is moved around an object touching the edges to record three locational dimensions. These systems have been little used in cartography.

Semiautomated digitizers are most commonly used when maps are concerned, and the larger sizes are required for digitizing sheet maps. The alternative technology, *automatic*

*digitizing*, is more recent. Automatic digitizers include scanners and line followers. At the low-cost end of the scanner market, two types of scanner exist. The first, which were designed to scan pages of text and automatically convert the pages to text files in the computer, are not suitable for cartography, with the possible exception of producing text lists for typesetting. Some of these scanners are capable of low-resolution graphics, and parts of small maps can be scanned into paint and draw software using this technology. Most of these scanners operate in pixel mode in monochrome, but some conversion to vector or object mode is now possible.

The alternative scanning technology is the video scanner. The video scanner is the digital equivalent of a television camera and is mounted on a stand. Maps, images, or air photos can be placed under the camera, and the television picture is shown on a monitor and rasterized, that is, it is turned into a grid of numbers. An identical technology exists for still cameras, which store their images on small disks and replay them through a video player as television images. Normally, what is returned is exactly what comes back from a remote sensing device, the gray tone or the intensity in a certain light frequency (a certain color) for each little square area or pixel on the image. Red, green, and blue channels for a color map can be scanned separately and re-superimposed to generate color from three gray-scale images.

Geocoding on these images is usually established using reference or control points and rubber sheeting, topics covered in later chapters. Only small areas of maps can be scanned with these low-cost systems with true cartographic fidelity, although the resolution capabilities of these systems are improving rapidly.

The top-end scanners are of very high resolution and as a result are expensive, although their price has fallen considerably recently. High-precision scanning devices use what is called a flying spot technique, which involves moving a light or laser beam very quickly across the surface and detecting either absorption or reflectance at every point on the surface. Precision scanners often rotate the map on a drum, moving the laser in very small increments across the map surface. Because paper maps can fold, fade, or tear, the source map is usually the film separation from which the map was printed. Monochrome scanners can be used to scan each ink-color separation separately for any map. Increasingly, however, color scanners are capable of extracting colored features directly.

One of the problems with scanning maps is that most maps have a great deal of redundancy. Polygon maps contain information only at the boundaries. Also, text is not easily processed from scanned data. Other problems mean that much postprocessing must be conducted on scanned maps. For example, the map separation containing contour lines can be scanned simply, yet the breaks in the lines for contour labels must be joined together after scanning to give continuity and the labels must be deleted and turned into an accompanying attribute file. Also, scanners often have resolutions that supply an immense amount of data for very small pixels. As seen in Part II, geocoding maps involves far more than simply converting a map into sets of numbers.

Scanners are in widespread use for computer cartography. Many of the earlier problems with scanning have been eliminated. An important breakthrough was the development of hardware for the automatic conversion of the scanned data to strings of  $(x, y)$  pairs, known as vector data. These special purpose vectorizers have made scanning a valid alternative for digitizing in bulk. Scanning is widely used in high-quality production



cartography. As the costs and capabilities of scanning evolve, it is highly likely that scanners will assume most, if not all, of the map input process in computer cartography.

### 2.1.3 Output Devices

As before, we can divide output devices into map and attribute. Good examples of the latter are such things as the line printer, disk, tape, and any other nongraphic medium. The line printer was used as an output device by the very first generation of automated mapping systems. The limited capabilities of the line printer were augmented by overstriking characters to get gray tones, by printing symbols, and by retouching the final output.

Contemporary map output devices fall into several types. The first type are plotters. Plotters are an example of how computer cartography tried to replicate the previous technology. Plotters do this by drawing a map on paper. If digitizing can be thought of as an analog-to-digital conversion, then plotters convert the digital back to analog information. Analog (especially paper) maps have some advantages for storage and are convenient to carry, especially into the field.

Pen plotters fall into two different types, flatbed and drum. For many years flatbed plotters were cheap, and readily available but not really of high cartographic quality. Drum plotters were expensive, and difficult to operate, but produced much higher precision, better-quality output. Now, however, some extremely inexpensive drum plotters are available, while some of the very highest quality cartographic output is now plotted, or more usually scribed, by flatbed plotters. Both flatbed and drum plotters are vector devices. Flatbed plotters take a sheet of paper, film, or scribecoat and attach it to a flat surface. The pen then moves over the paper, which is held in place with tape or more frequently by an electrostatic field that holds the paper perfectly flat. The plotter then simply moves a pen along two axes.

Different technologies determine the actual drawing. The pens can move on an arm, which itself moves along an axis; the “bed” can move in one direction and the pen in the other; or any combination of these movements is possible. All plotters have only two fundamental basic operations: move with the pen down or move with the pen up. If you move around with the pen down, it draws.

With a flatbed plotter you typically have to load each sheet of paper or film yourself and take it out again when it is finished. You also have to load the pens yourself, although even the least expensive plotters are capable of changing pens automatically. More sophisticated plotters can recap pens and change ink without operator assistance. Also available are automatic paper feed and the cutting of plots when the drawing is complete. This allows the use of rolled paper and the queuing of multiple plots for plotting when the operator is absent.

The drum plotter (Figure 2.4) has a rotating drum with prongs that feed holed paper from a roll. Drum plotters have hoppers that hold one or more pens to support different colors. Motion in the  $x$  direction is achieved by moving the paper with the drum past the pens. Motion in the  $y$  direction is by moving the hopper across the drum (Figure 2.5). Most drum plotters can use a large variety of pens and plot media. Pencil point, fiber



**Figure 2.4** A drum plotter. (Photo permission of Houston Instruments, Austin, TX.)

point, rollerball, and refillable ink pens can be used to plot onto paper, film, Mylar, or acetate. Some very high quality maps can result. Both flatbed and drum plotters, however, are poor at filling areas on maps with continuous color, because the pen has to be dragged backwards and forwards until the area is filled. When all that is required is text and linework, the quality is of cartographic standard.

Another type of plotter is the electrostatic plotter. Probably the major uses of electrostatic plotters are in the electronics industry, where they are used for printing multicolor circuit boards because they can print a large area of coverage with a great deal of detail.



**Figure 2.5** Pen hopper on a drum plotter. (By permission of Numonics Corp., Montgomery, PA.)

Electrostatic plotters use electrical charges to attract ink to the surface of treated paper. Although electrostatic plotters are bulky, expensive, difficult to maintain, and often support only a few colors, they are better than pen plotters at areal coverage.

Moderately related to the electrostatic plotters are printing technologies. Printers use impact through an ink source onto the surface to produce a plot as in a typewriter. The first printers of near-cartographic quality were dot matrix printers. More recently, laser-jet printers have taken over completely. Laser-jet printers have high definition, usually as simply black on white, and have revolutionized desktop publishing and word processing. The resolutions of low-end laser-jets is several hundred dots per inch, but these printers are fully consistent with typesetting-quality printers with over 1,000 dots per inch.

Many pieces of cartographic software use the laser-jet printer as the primary, or even the only, graphic output device. The PostScript industry standard, widely used by laser-jet printers, has allowed a great deal of device independence, and many drivers for graphics allow maps to be sent to laser-jet printers. The laser-jet printer is a refinement of the xerographic process. The link between publishing, cartography, and typography that this technology offers is another opportunity for cartographers to make superior maps.

Impact printers are capable of low-quality color. Better-quality color is available, however, without photography using a hybrid technology halfway between dot matrix and laser-jet plotters. Ink-jet plotters are a hybrid because they are not printers and they

are not plotters. They use a method where ink is sprayed directly onto the surface. They normally have four ink guns with four different inks for the production primary colors of magenta, cyan, and yellow. The fourth gun contains black. Mixtures of these four inks give a very large number of different color possibilities. High-end ink-jet plotters produce almost photographic quality images and are getting better all the time. Low-end ink-jet plotters, however, produce rather garish color, can print only fairly narrow strips of paper, and are of low resolution.

Two new technologies have led to significant cost reductions in high-quality printing. The first is the bubble-jet printer, a technology in which inks are sprayed onto the paper in much the same way as in ink-jet printing, but the final propulsion onto the paper is accomplished by the rapid intense heating of the ink in a narrow jet. Bubble-jet printers can produce large formats and color and are comparable in quality but are generally less expensive than laser-jet printers.

Another significant development is the development of dye-sublimation printing, in which dyes are placed onto prepared paper under natural light. Dye-sublimation printers can give extremely high-quality, photograph-like output on glossy photographic-type paper for a very reasonable price. Although these printers still cost thousands of dollars to purchase, many slide and copy services now have this technology and can produce output in this form.

The last major category of map output devices are those involving photography. At the high end of film technology is the film writer, which typically writes onto a very large piece of film and thus is favored for the hard-copy of remotely sensed images. At the middle of the range is the graphics camera. Graphics cameras are separate devices connected to the red, green, and blue color channels normally sent from a graphics system to a color monitor. The color image is then reconstructed on a flat display at the end of a box, in the focal plane of a bolt-on camera back.

Typically, the exposure is controlled completely by a microprocessor, including the aperture, the light intensities, and the exposure time. Each of the red, green, and blue channels is exposed separately, making the color image additive. Graphics cameras usually support most photographic media, including 35-mm film, the various instant picture formats, and various sizes of sheet film. The attraction of this method of hard-copy is the price, which can be very reasonable per image, and that the images are virtually distortion free. Service bureaus now also offer extremely low cost conversion of digital files from raster formats to 35-mm slides or to photo-style prints. This is often far cheaper than purchasing even the lower-end graphics film copiers and recorders.

At the low end of the camera market are screen copiers, some of which are very inexpensive. These devices mount onto a black screened box that fits over a monitor. The mount supports usually an instant camera type of camera back, although some support 35-mm film. A number of different processes can be used, including one type of slide film that can be developed in only a few minutes with a stand-alone slide developer. The quality of this type of output is sometime very good, although care must be taken to avoid the “barrel effect” of cameras that are focused too closely onto a surface that is actually curved and not flat.

True flat screens, at first only as liquid crystal displays (LCDs) but now in color and as back-lit plasma screens, offer distinct advantages to cartography. Last but not least, an

inexpensive way to photograph computer maps is to focus a 35-mm camera with a telephoto lens and a tripod onto the screen from a distance of about 2 meters in a darkened room. An  $f/4$  and about 1 second for ASA 64 film is required because the scan lines are caught in the image at speeds greater than about  $\frac{1}{15}$  of a second. Any reflections or screen edges in the image can be masked out on the slide with tape.

As a final example, some plotters now plot directly onto microfiche and microfilm. This may be one of the major ways that analog maps will be distributed in the future, especially if a hand-held viewer is used. The international report to the ICA, published in the *American Cartographer* for 1987, includes two microfiche maps submitted as the best examples of American cartography in the previous year. Digital maps can be produced directly from plotting devices onto microfiche or microfilm with no paper involved. These media take up little storage space, and can be mailed in a single envelope instead of a map tube, eliminating rolling and folding.

## 2.2 RASTER AND VECTOR DISPLAY TECHNOLOGIES

A major historical distinction between different computer devices for computer cartography is that between raster and vector technology. These two different display technologies have had a particular influence on much of the theory and data structures involved in analytical and computer cartography. It is worth describing the alternative technologies in a developmental context so as to introduce the newer technology, which has eliminated many of the inconsistencies between the two technologies.

In raster technology, the screen or the input device is divided into discrete pieces called pixels, which have a finite size. For an orbiting scanner on a spacecraft these would be single areas on the earth's surface for which we can resolve data. On a map they could be latitude and longitude cells or meters marked off on a Universal Transverse Mercator (UTM) grid. Each square or rectangular pixel has an attribute associated with it, which could be a color, a light intensity, a gray tone, or a red, green, blue value for that pixel. For input they would be associated with readings or measurements. In terms of output, the data could be displayed as is, each pixel mapped onto a piece of the screen.

The alternative is vector technology, in which control of the output device comes from software, which moves a point light or pen across the screen or paper, leaving a mark. Vector input is particularly suited to maps that have lines on them, such as coastlines or rivers, political districts, contours, and so forth. Raster input is particularly suited for maps that have attributes with extensive areal characteristics such as land use, land cover, surface moisture or ocean temperature: an attribute measured over a large area. Vector and raster, therefore, are two different structures, two different technologies for both input and output.

Vector graphics dominated the computer graphics market very early on, with storage tube-technology terminals. A storage tube contained an electron gun that sent a stream of electrons toward a screen treated with different phosphors that glow when struck with electrons. Control over movement of the beam was achieved using a series of magnets which allowed the beam to be deflected and moved continuously. Because the phosphors stored the charge when struck by electrons, the screen stayed glowing when hit, and lines, points, and areas could be traced out with the electron beam. When complete, the entire



**Figure 2.6** Special purpose raster-to-vector converter. (Photo courtesy of LaserScan Laboratories Ltd., Cambridge, England.)

screen had to be cleared at once, usually by depressing a button on the keyboard. Storage tubes allowed straight and curved lines to be traced out, although they were poor at filling in areas. In addition, virtually all storage tubes were monochrome, usually a light green glow on a dark green background.

The advantage of vector displays is that we can draw a line in any direction with any length and have it appear exactly the way it would on a paper map. The finite limit on resolution is the size of the grid of phosphors, a very small spot on the screen surface. The disadvantages are several. First, the devices have to be fairly large. My first graphics terminal, a storage tube device, was so large that it had to have its own stand. The display tube on the terminal had to be quite deep, and the screen area, although flat, was very small. In addition, the phosphors eventually decayed, leaving images “burned” into the screen. Storage tubes also could be quite slow in drawing a map, although plotting time was a function of the power of the computer behind the terminal. Because selected update was not possible, waiting for redraws could be tedious. Raster technology now completely dominates the computer graphics industry to such an extent that software when required usually simulates a vector display device using a raster display. Raster technology evolved out of television technology. In this case the screen phosphors respond differentially to electrons by changing red, green, or blue in different intensities. A major difference is that the phosphors are arrayed in a grid as pixels. A look at a color television

screen using a magnifying glass will reveal the cells that can illuminate in different colors. With a very large number of pixels, they appear to give a continuous image, although in fact it is a discrete image. In raster displays, the electron beam scans the screen with about one full scan every  $\frac{1}{60}$  of a second, refreshing or temporarily illuminating each in turn. To actually see the screen redrawing we have to use something that is fast enough that it sees it only for a very short space of time. A good way to do that is to use your 35-mm camera and take a screen photograph. At  $\frac{1}{30}$  of a second, bands are visible in screen photographs across the picture or the TV screen because while the shutter was open, the screen refreshed once and got part way through refreshing a second time before the shutter closed.

The conversion from raster data (preferable for scanning) to vector data (often preferable for plotting) is often performed by hardware rather than by software. In Chapter 11 the vector-to-raster (and vice versa) transformations are considered as a software problem. The same task, however, is commonly performed by special purpose devices. One such system is shown in Figure 2.6. Because the vectorization often introduces ambiguities, especially in the topology of line and polygon maps, these devices must support extensive operator control over editing. It seems likely that human interaction will be used in this editing and matching process for some time to come.

## 2.3 REAL AND VIRTUAL MAPS

With so many different pieces of hardware, capable of producing so many different types of digital map products, it is not inappropriate to ask “What is a map?” To answer part of the question, Moellering (1980) introduced the concept of real and virtual maps. A real map is one that has gone through the symbolization transformation and has found a realization as a tangible object. This implies that the cartographer selected a scale and plotted a specific map type, legend, and text. A virtual map is like a possible map; for example, if we have a digital outline map of the United States and access to state statistical data, then any variable can be mapped, using a number of different methods, classifications, and so forth. The set of possible maps is finite and even directly accessible using an interactive mapping package. A virtual map, therefore, is both a nonpermanent map in itself and also a digital equivalent of a “proof” map, made to reveal the effects of a particular color combination or cartographic technique.

In producing a virtual map we need not be concerned with the specifics of the technology with which the real map will be produced; it need not even have been invented yet. A similar idea is the distinction between hard-copy and soft-copy. First, a hard-copy map means one that we have produced that is actually going to last, using a stable medium in a form designed for viewing and use. Soft-copy maps came about with computer cartography. A soft-copy map corresponds to the work sheet in manual cartography. It is a map we can look at quickly to see if we like it, if we want to produce a hard-copy at all. With many geographic queries, a soft-copy map can answer our cartographic questions completely, meaning that we never need to produce a hard-copy map.

Soft-copy and virtual maps have given computer cartographers the option of using a design loop, a revolutionary tool for improving maps. The design loop is a system by which a map design is improved by interactive trial and error rather than by textbook

learning. In manual cartography, map data are compiled, scales and projections are chosen, and a set of map types and symbolization techniques are selected. Finally, the cartographer invests the necessary hours in actually producing the map. With so much time invested, one is less likely to see flaws in the map design. If somebody then said “The title is too large and should be moved over 10 millimeters,” there is nothing to be done, except to take note for the next time. If the map were a soft-copy, the cartographer could probably make the change in a matter of seconds and then ask the critic for any additional feedback. The ability to change design interactively in this way is the design loop. The design loop also frees the cartographer to learn from deliberate mistakes and allows experimentation with nontraditional designs.

Some soft-copy is indeed soft in that it is actually a temporary image, like a fax. Thermal printers have been used to produce map images, but are usually used only as a cheap intermediate stage before another form of hard-copy is generated. Most paper maps are in reality only longer-lasting versions of thermal prints. Paper tears, expands and shrinks, creases, fades, stains, and is combustible. Virtual maps, because they are technology independent, are virtually indestructible. Unfortunately, they are not yet practical enough to take hiking in the rain.

## 2.4 WORKSTATIONS FOR CARTOGRAPHY

The most important hardware revolution for cartography in recent years has been the incorporation of microprocessors directly into the display device. In the early days of computer cartography, only large computers did computer cartography, and users of the large computers were remotely connected via dial-in lines and stand-alone “dumb” graphics terminals. Special-purpose hardware devices such as digitizers and plotters were remotely connected at different locations and were often not available for hands-on use. Microprocessor technology has radically changed this state of affairs. Microprocessors took most of the capability coming from the large computer and put it into the terminal itself.

Over time, more and more functions and capabilities have been moved from the mainframe computer to the graphics terminal. The next logical step was to disconnect the graphics terminal from the mainframe, and move to a self-contained graphics device called a *workstation*. A graphics workstation can support multiple input and output capabilities and may have its own RAM, own disk, and usually even its own operating system. To gain access to mass storage, and to communicate with other workstations, the workstation is usually networked.

A typical workstation for cartography (Figure 2.7) may include a digitizing tablet, a mouse and a keyboard for input, a color and text graphic screen for output, and could be networked to plotters, laser-jet and ink-jet printers, and color-graphics cameras. The workstation concept is at the heart of the international graphics programming standard, GKS. In a workstation, any number of input and output devices can be supported as peripherals to the workstation. Graphics input devices can be locators, in which case they can point to locations on a map, or valuator, in which case they can simply indicate a value such as a dial or a joystick (Figure 2.8).

For menus, input can be choice, in which case the user selects from a set of options, or pick, in which case the user can select by pointing to a segment of the drawing on the screen, such as a box or an object. Graphics output devices are literally almost anything



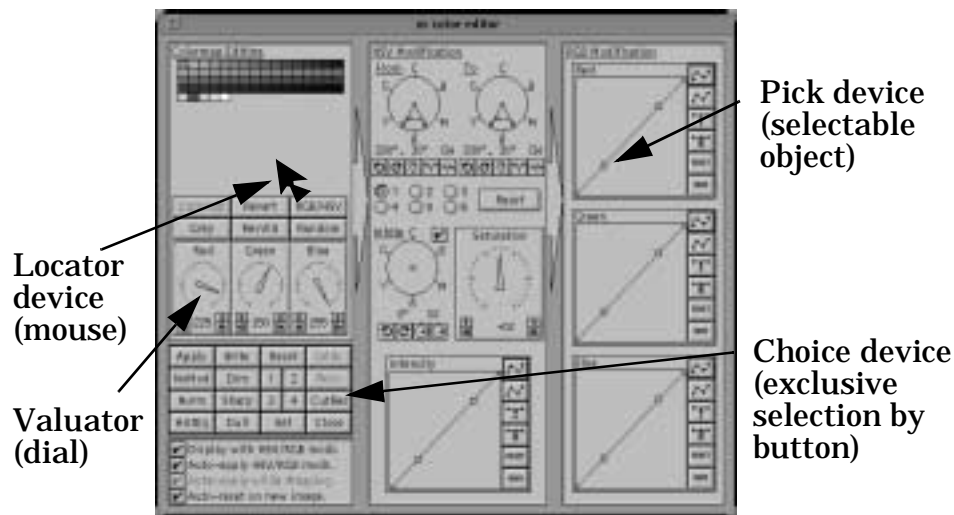


**Figure 2.7** A typical workstation. (Photo courtesy of Intergraph Corporation)

capable of producing a map. Using GKS, the concept of real and virtual maps finds expression in the terminology of the workstation, because a real map is simply a virtual map that has gone through the correct workstation transformations.

No discussion of hardware can be complete without a glance at the future and the new display technologies it holds. The one projection that will survive all the new technologies, however, is the workstation concept, which is versatile enough to incorporate any new hardware technology. Even portable workstations are now available, and breakthroughs in microprocessor technology have made the high-end microcomputer a workstation in all but name.

Some devices do, however, appear to have a cartographic future. First, a color screen shutter which can be coupled with polarized glasses to generate stereo screen images is available. Recent versions do not even require the glasses, but generate stereo nevertheless. In photogrammetry, remote sensing, and terrain analysis, this seems to be a device with some interesting prospects, as yet fully exploited. Second, the field of virtual imaging has also given us the helmet as an output device, in which the screen inside the helmet uses the entire field of vision of the viewer, and a glove or even a bodysuit as an input device. Maps that can be “virtually” explored (rather than virtual maps) offer an exciting future for cartographers. One vendor has introduced a head-worn display small enough to be worn while driving, flying, or performing other tasks. The ability to generate maps in real time so that they can be seen in peripheral vision is an exciting development and



**Figure 2.8** Different workstation Input devices supported by GKS.  
(Example using xv by John Bradley. Used with permission.)

may rival the success of dashboard displays for vehicle navigation systems. Third, the linking of display technology with the real time capabilities of satellite-based navigation systems has great potential for cartography. While none of these technologies will influence how maps are made, the potential for influencing map use is extraordinary.

## 2.5 REFERENCES

- Moellering, H. (1980). "Strategies for Real Time Cartography." *Cartographic Journal*, vol. 17, no. 1, pp. 12–15.