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ABSTRACT

This paper discusses the factors involved in making decisions about a multimedia display system. Theoretical factors, including gaining and holding learner attention, specific attention-getting devices, encoding and retrieval of information by learners, and presentation of information are considered. Ways that video is associated with computer displays are then reviewed, including managed versus integrated video and digital versus analog video. Two prototypical trade-offs in multimedia design--information versus time and convenience versus quality--are described in order to provide a framework for the kinds of choices necessary when developing multimedia courseware. Constraints in several specific areas are addressed, including resolution, image size, color depth, speed, and data rate and bandwidth. Practical considerations that determine the actual configuration of a workstation or a group of workstations are also discussed, with emphasis on the choice between single screen and two-screen systems. The final section presents a case study which outlines the decision-making process in designing a multimedia workstation for a plant biology laboratory; prioritized system requirements and the system configuration are described. (43 references) (MES)

Title:

Choosing a Display Format for Instructional Multimedia: Two Screens vs. One

Author:

C. David Taylor

Choosing a Display Format for InstructionalMultimedia
Two Screens vs. One

The technology for capturing, storing and displaying multiple media with the computer has made revolutionary strides within the past few years. Given the wealth of choices now available to the designer of multimedia courseware—which must be balanced against the technological constraints of a given computer system—the decision about presenting media in an instructional situation is more problematic than ever. Of the many available alternatives for displaying information to the learner, what does the designer need to know in order to make a decision that will further the project goals? This presentation will first give a brief review of multimedia display technology. The second section will describe the technical, theoretical and practical factors that should be considered in making a decision about a display system. Technical decisions involve consideration of the *trade-offs* among the resources of a particular computing system. Theoretical factors draw on research and guidelines from a wide variety of fields that include learning theory and instructional design, human-computer interface design (human factors research), visual learning and media selection. The third section will present a brief description of the decision-making process that went into the design of a multimedia workstation for a plant biology laboratory.

Factors in Decision-making

How do we make decisions about when to use the various media within a single courseware program? A traditional area of instructional design and development concerns *media selection*, and a number of useful models have been developed to aid in choosing the appropriate media to deliver an instructional message (Reiser & Gagne, 1982). The issues raised and discussed in the rationale for these models are highly relevant in the choices of the individual media used within a multimedia system. However, almost all of the relevant research—and the resulting established and tested models—concerns single media used in isolation, and the models were developed well before the advent of multimedia. The question for multimedia, on the other hand, is of a different nature: in the face of the incredibly rich variety of choices, how does a developer or designer choose and *mix* different media to achieve the best effect? This is a different sort of question, and it is the central issue in this article. There are three perspectives on this problem: one based on theoretical principles of learning and instructional design, the second dealing with technical trade-offs within a computer system, and the third purely practical.

Theoretical Factors

Due to its recent emergence, there are no well-demarcated boundaries to multimedia as a field of research. Some authors (cf. DeBloois, 1989) have wisely recommended that we should refrain from spelling out strict guidelines for usage, because it may hinder experimentation in the field. However, several areas of past research are relevant in making decisions about the display of multimedia, although it may require effort and imagination in order to transfer results to this new field. These areas include learning theory and instructional design, media selection, visual learning, and human-computer interface design (from human factors).

Instructional design and learning theory are closely interwoven (cf. Gagne, 1985; Gagne & Briggs, 1979)), and have had a seminal influence on the development of computer-assisted instruction and interactive video (Jonassen, 1988; Hannafin & Rieber, 1989; Hannafin & Phillips, 1987), from which the current conception of multimedia is derived and closely allied. Although multimedia and CAI can make a useful contribution during each part of the instructional process, the method of display is more consequential in some than others. The framework provided by ROPES+ (Hannafin & Rieber, 1989; Hooper & Hannafin, 1988), a technology-oriented "meta-model" for instructional design based on applied cognitivism and information processing theory, is especially useful for application of design principles in the decisions involving display technology. The following discussion of attention, encoding and retrieval and presentation will identify key areas of the instructional-learning process in which the mode of display has the most salient areas of influence.

Attention as a Learner Resource

Attention is a key construct in learning and instruction (Klatzky, 1980; Gagne, 1985) and, for that matter, in any form of communication. Workers in the communications industry, especially in the advertising sector of broadcast media, wage a constant battle to capture the public's attention and direct it favorably toward their product and message. Cognitive learning theorists have demonstrated that attention is a resource with limited capacity that can be allocated to only a few processes at one time (Kahneman, 1973; Norman, 1976; Klatzky, 1980). In addition, more attention is required for unfamiliar material, such as normally occurs in an instructional situation. As such, the designers of multimedia must be constantly aware that they are also working to gain, hold, control and direct—and even provide relief for—the learner's attention. This power should not be taken lightly, and, indeed, it implies a serious responsibility for the cognitive status of the learner.

In the events of instruction model (Gagne, 1985), *gaining attention* serves as the "wake-up" call for learning: it prepares the stage for learning and can be coordinated with orienting devices, such as advance organizers (Ausubel, 1963) and stimulating the recall of previously-learned information. Multimedia, because of its novelty, is currently a premier device for attention-getting. However, attention-getting should be used cautiously (getting does not guarantee holding attention). For example, it would not be prudent to waste a large part of the system resources on a flashy opening sequence, and then use a text-only presentation during the remainder of the instructional program. It is easy to irritate users and lose their attention if high expectations are not fulfilled; the designer should be careful to deliver on all promises, or the result could easily be a net negative effect.

Creative uses of multimedia can facilitate the gaining, directing and holding of learner attention. For example, orienting activities (such as advance organizers or presentation of objectives prior to instruction) are "mediators through which new information is presented" (Hannafin & Phillips, 1987) and prepare the learner for forthcoming instruction. Advance organizers (Ausubel, 1963) have mixed claims of success, it is often asserted, because they are not applied according to prescription (Ausubel, 1977; Mayer, 1979), which is at a "higher level of abstraction, generality and inclusiveness" than the subsequent content (Ausubel, 1963). It has been recognized that video is not an ideal medium for presenting detailed material, but is better used for broader, abstract material, possibly with an emotional appeal. Therefore, a short, abstract video segment may serve well as the medium for an advance organizer, and, similarly, for a lesson summarizer. On the other hand, AIME research (Salomon, 1984; Cennamo, Savenye, & Smith, 1991) has shown that television, because it is usually perceived as easy to understand and places few demands on viewers, can cue learners to invest less mental effort in learning program content. Consequently, multimedia designers would be well advised to avoid the look and feel of "television" in the design of their programs; for one thing, this would seem to imply that they should avoid long, linear video sequences and should increase interactivity whenever possible.

The use of multiple media can be useful in providing the variety within a presentation that is important for maintaining and holding attention. Use of the different media can strengthen the power of CAI to vary viewpoints, the pace of a presentation and provide numerous opportunities for interaction and practice. It has also long been recognized that each medium has its own attributes and symbol system that directly or indirectly impacts learners, which renders it more or less suitable for different instructional outcomes and content (Salomon, 1979; Salomon & Gardner, 1986). In addition, different media assume and develop different skills (McCluhan, 1965) at the same time that their messages converge as to the knowledge that they convey (Bruner & Olson, 1973). For this reason, *media selection* has evolved into a well-established decision-making process, and a number of selection models exist that have a variety of formats and take different learner, task, and instructional variables into account. However, almost without exception, these models were developed with the assumption that individual media were to be used in isolation. The advent of multimedia changes the basic ground rules of media selection and usage, and the changes currently underway point toward re-opening this important field of research (Locatis, Charuhas & Banvard, 1990). Kozma (1991) notes that choices about media selection were formerly macrolevel decisions, but with multimedia such decisions can be made more frequently and selectively at the microlevel, which opens up the possibility of selecting media based on individual learner needs and preferences.

A basic premise of this article is that the multimedia devices that are the most powerful in terms of gaining attention also tend to be the most expensive in terms of system resources. Digital motion video and 24-bit color animation, it has already been noted, require extremely large file sizes and extensive CPU loading. These formats cannot be used too freely on most systems available today. The list of presentation formats below represent an assertion by the author—based on intuition, experience and available research—of a range of presentation devices scaled from least attention-holding (1) to most attention-holding (6). It is a relative scale, in that if a screen contained two items with different formats that competed for attention, the item that was higher on the scale would tend to hold the viewer/user's attention more effectively. This list represents testable hypotheses; results could be used in a quantitative trade-off analysis (Norman, 1987).

Attention-getting/holding devices from least to most attention-holding

1. text only
2. Static visual/graphic (varying by color and size)
3. Animated visual/graphic (silent)
4. Sound alone
5. Sound + Movement

An additional assertion is the following list, which represents items that tend to create an unpleasant discord in the user's multimedia experience, and therefore have a net negative effect in attention and, therefore, learning. These are presented in no particular order.

0. Sound vs. movement
0. Incomprehensible, badly-designed static or moving visual
0. Obnoxious sounds
0. Repetitive image, sound, etc.
0. Very slow movement (or response to input) that forces the user to wait before progressing

Research in the relative importance of television production factors is useful for the video and audio aspects of multimedia (Wright & Huston, 1983). For example, it has been found that most learning occurs when audio and video are redundant, that is, are synchronized and repeat and reinforce the same content; when audio and video interfere with each other, learners consistently shift their attention to the video at the expense of the audio track (Hanson, 1989).

Encoding and retrieval are crucial events in instruction; they might even be described as the defining operations of the learning process. Information must be encoded in long-term memory in such a way that it can be retrieved when needed; otherwise, the information is inaccessible and therefore useless, a situation that has been described as *inert knowledge* (Whitehead, 1929). For example, Paivio's (1979) dual-coding hypothesis suggests that encoding can take place in two channels, one visual and the other verbal. Research in this area shows that the more concretely information is presented, the easier it is to picture and remember; the more abstract, the harder it is to picture and remember. One of the strengths of multimedia, obviously, is its wealth of techniques for presenting information in concrete form.

A key principle asserted by the ROPES+ model is that *distinctiveness* at encoding (which should to be distinguished from image clarity) will be related to importance, which will facilitate the retrieval of knowledge. An important conclusion to be drawn from this principle is that designers should save their most distinctive presentation power for key concepts and ideas. A related principle is *spread of activation*, in which superordinate concepts set the stage for learning related, subordinate concepts. This is the same pattern as is used with orienting activities: after attention is directed to the key concept, subsequent subordinate concepts will be associated with the superordinate. A conclusion to be drawn here is that expensive system resources (e.g., high-attention devices, such as animation drawn in 24-bit color, or full motion video) should be reserved for cuing learners as to the importance of superordinate concepts; simpler displays will then suffice in the presentation of related but subordinate concepts. In addition, the association of knowledge with the context in which it is to be used is important in the encoding process, which then can lead to its appropriate retrieval; although text can describe context, the realism with which video can demonstrate context is one of its most powerful features (Hamilton & Taylor, in press).

The presentation of information has been given the greatest amount of attention in media and CAI design, although, as we have seen here, it is but one stage in the instructional process. A great deal of research has been done in this area, such as the extensive work in visual learning (Dwyer, 1972), text and screen design (e.g., Morrison, Ross, Schultz, & O'Dell, 1989), and human factors interface design (Rubinstein & Hersh, 1984; Hancock, 1987; Laurel & Mountford, 1990), which has resulted in useful guidelines. Due to the recent, rapid advancements in multimedia, however, most of this work provides little specific help to the multimedia designer/developer, although some principles do transfer to presentations of mixed media. For example, research in visual learning shows that the addition of visuals often helps comprehension of many different types of information. However, an increase in visual complexity (e.g., greater realism—photographs) in visual illustrations rarely helps in comprehension, especially in higher-order learning (Dwyer, 1972). This research can help in d cisions about presenting high-end graphics using 24-bit color, which are costly in terms of system resources. These effects can vary according to learner characteristics (e.g., Canelos, Taylor & Gates, 1980). Of course, when deciphering visual complexity is an instructional objective—such as when biology students must identify details on a photomicrograph of plant tissue—the capability to display high image quality becomes a high priority.

Summary: Obviously, a great deal of existing research can inform the decisions regarding display devices in multimedia. As yet, however, there is very little research that applies specifically to key attributes of multimedia, such as the effects of mixing media, efforts at directing attention within the screen or screens, use of multiple versus combined screens, or other factors discussed here. This is primarily due to the fact that the field itself has only very recently come into existence; not only have researchers had little time to do research, but the rapid fluctuations of the field have made it difficult to set research priorities. Until relevant, specific research is performed and results in viable, useful guidelines, practitioners must rely on related research findings, experimentation and intuition.

Technological Factors

A Brief Technology Review

The increase in capability of the personal computer has been a story of sure and steady—albeit extremely rapid—progress in processing power, clock speed, bandwidth, etc., and computer users have watched on-screen displays change from all text with very simple monochrome graphics to photorealistic images and sophisticated audio-enhanced animation. The fundamental, ground-breaking changes, however, are most evident when we review the way that video has been associated with the computer display.

Managed Video vs. Integrated Video

In the early days of microcomputer-based interactive videodisc (circa 1980), an interactive video presentation was limited to two screens: a computer monitor for digital information (text and computer graphics), and a video monitor for a television signal, which was played back from a videodisc or videotape (Romiszowski, 1986, p. 384). Insofar as the video was concerned, the computer functioned as a primarily control device for finding and displaying either single video frames (as still images) or sequences of frames (as motion video) on the video monitor. From the beginning, there has always been an strong movement toward combining the two displays, but the fundamental differences between the computer and television signals—different scan rates, retrace and blanking speeds, bandwidths, overscan/underscan, etc.—made the marriage difficult. These technical differences are many and complex, and it is impossible to cover them here. Two solutions to this fundamental incompatibility of the two signals—either overlay boards or special monitors—allowed the computer signal to be superimposed over (but not actually mixed with) the television image. The epitome of this solution was the original IBM InfoWindow display system, which was actually a television and computer monitor combined within a single box and screen. As might be expected, such elaborate solutions added considerable cost to a microcomputer system, and the most affordable applications of interactive video continued to use the two screen system.

In the last few years, a number of engineering advancements, in the form of sophisticated yet affordable add-on boards, have advanced the merger of video with the computer system (Wells, 1989). These "desktop video" boards (ColorSpace IIi/FX, Targa boards, NuVista, etc.) offered several useful features, which could be grouped into three functional areas. They could digitize a single video frame (at various resolutions and color depths), which could then be stored and used in the same manner as a standard graphics file. Second, they could convert the computer signal—such as computer graphics and animation—into a television signal (NTSC) for output to videotape. Finally, some boards could superimpose the computer signal over a television image (by synchronizing or genlocking the two signals), and output an RGB or composite television signal, which could be recorded on videotape. These devices are intended to provide sophisticated television production capabilities to a video non-professional (thus their output of a television signal, and the term "desktop video"), as well as some limited incorporation of television images into a computer/digital format (Wells, 1989). The most sophisticated systems (such as Newtek's Video Toaster) provide the same capabilities (albeit of lower quality) of several separate, dedicated machines normally found only in broadcast-quality video editing facilities. To the extent that these boards produce a television signal as output, they run counter to the prevailing trend of multimedia , which is to incorporate all media into a single, digital format for display on a single monitor.

In all of these previously described technologies, the video signal must come from a conventional analog source (such as a VCR or a videodisc player) and tends to retain its fundamental identity as a separate, analog signal during its display or playback. This approach can be described as *managed* video (Arnett, 1990a & 1990b), in which the computer serves as a control device for a conventional external video source. The next step is *integrated* video, in which motion video is converted to digital form and then is treated as just another window on the screen, and managed in the same way as any other file type, like a graphics or text file. Such video can be manipulated (e.g., re-sized, re-edited, combined with other file formats) with software controls. There are currently two approaches to integrating (digitized) video in computer systems. Intel's DVI, which has been under development for the last few years, requires special hardware in the form of add-on boards to process and display video. On the other hand, software-only solutions, such as Apple's QuickTime offer greater simplicity of use and would seem to be the more highly integrated. Although a digitizing board is required to create QuickTime "movies" (video files), they can be played back on any Macintosh, without special hardware. At this writing, however, DVI provides the better image quality, as might be expected of a product with special hardware and a two to three year head start.

Problems and Pressures of Integration: Digital vs. Analog Video

The problem in integrating video into the computer system (in addition to the signal/display incompatibility mentioned previously) is the large amount of information in a television signal, combined with the relative slowness of the computer's data bus (its "bandwidth"). A single frame of raw, uncompressed video can requires as much as one megabyte of storage space, depending on the computer system. This file size has made it virtually impossible to store or play back motion video at a rate approaching "real time"—that is, at thirty frames per second. Even the fastest and largest hard drives cannot access and write such large files to the screen at this rate. For this reason, many developers are working on various forms of video compression, so that video frames can be stored in units much smaller than 1 MB. Complex algorithms are required to accomplish video compression, but fortunately two standards have already emerged. JPEG (Joint Photographic Expert's Group) is a high quality standard for compressing and storing single frames of video and is excellent for photorealistic stills such as slide images, but it requires too much disk space and bandwidth for motion video on personal computers. On the other hand, the algorithms used by MPEG (Motion Photographers Expert's Group), for motion video, compares information between successive frames so that similar information is not repeated. Although MPEG is not yet an official standard, many companies are working feverishly to incorporate these standards into their products (Arnett, 1990a & 1990b). For example, the first release of Quicktime uses JPEG for its still-frame capture, but does not yet achieve the MPEG standard for motion. On the other hand, DVI will support MPEG by late 1992.

Why is there pressure to convert all information into digital form? The answer is that digital data is the common denominator for all computer systems, and therefore vastly simplifies problems of storage, playback, transmission (over networks) and display. Similar tools can be used used to create, edit and display video as are currently used to create computer graphics or to edit text documents. When video, graphics, text and sound are simply different computer file types, development, delivery and display becomes vastly simplified. Storage and retrieval of all media in digital form, in addition to a technical simplification, promises integration of many different media into a single new medium: multimedia. Furthermore, only by conversion of video to digital form can it be made available over computer networks.

Technical Factors: A Matter of Trade-Offs

A fundamental premise in the world of computer interface design is that "There are no simple answers, only trade-offs" (Norman, 1987). Trade-offs can be defined as interrelated computer attributes that tend to draw on the same limited resources within a computer system: memory size, disk space, processing speed, transmission bandwidth, etc. For the multimedia designer, therefore, it is in fact impossible to freely mix media in courseware due to the inevitable limits on processing power and memory of the computer. A premise of this article is that developers must learn the limits imposed by the technical constraints of their hardware and software, so that they can best mix and match media to fit the instructional design while also following the most economic path within the technical constraints.

Norman (1987) has developed a quantitative comparison method, called trade-off analysis, which adopts the power function from psychological research. Briefly, this method computes User Satisfaction values for various attributes of the computer interface (i.e., disk access speed, image size, image quality, etc.), and then compares two interface variables graphically so that an appropriate compromise, or trade-off. can be selected. For example, user satisfaction with *image size* could be compared with user satisfaction with *time required to display an image* in order to obtain the most appropriate compromise, because improving either one requires substantial system power. In addition to giving confidence and justification for the necessary compromises in design decisions, this technique may show that a satisfactory compromise is not possible for different classes of users, such as experts and novices who must use the same system. The major criticism of this method, as Norman (1987) notes, is that there is currently little or no quantitative data available for user satisfaction, especially for variables in the brave new world of multimedia usage (e.g., what are the acceptable ranges for motion video frame rate, image size or resolution?). It would seem that acquiring measures of user satisfaction with various trade-off parameters for multimedia would be a useful and fruitful area of research. For the purposes of this article (and in keeping with the philosophy of the tradeoff analysis), it would seem sufficient to identify and isolate the key factors involved so that we may be aware of them. In so doing, we must realize that the usefulness and satisfaction with the entire courseware program/computer system will be due to the sum of its parts (Norman, 1987).

Prototypical Trade-Offs for Decision-making

Before considering specific technical factors that fit into the trade-off formula, it will be advantageous to consider two protoypical trade-offs that have recurred throughout the history of computing and are even more evident as multimedia becomes more prevalent. These can be described as *information versus time* and *convenience versus quality*. These two trade-offs can provide a framework for the kinds of choices that must be made when designing and developing multimedia courseware.

One of the more onerous aspects of working with computers is how systems slow down as a greater informational burden is placed upon them. A simple example concerns the integration of user-friendly devices such as menus, windows, and plentiful help screens. Although the progressive increase in computing power has made such devices a standard feature of personal computers, it was not so long ago that their use could be counted on to slow down systems considerably. It is ironic that the more user-friendly a computer system becomes, the slower it can be expected to operate; experts eschewed such programmatic helps in favor of lightning-fast responses, which required memorizing and inputting obscure, abbreviated keyboard commands. Such a trade-off is most noticeable in the display of increasingly realistic images. Only a few years ago, a monochrome diagram, composed of jagged squares, was the most we could expect in the way of graphics on a computer screen; today, near-photographic reproduction quality for still images, and television-quality motion video, are becoming the standards of multimedia. Displaying these kinds of graphics, however, has required the kind of storage space and horsepower that was available only on mainframes a decade ago.

Kay (1990) takes this notion one step further in describing a trade-off between speed-and-power vs. exposition-and-thoughtfulness, which relates to the use of artificial intelligence in interface design. Briefly, it may be preferable—yet more expensive in terms of system resources—to have a system that can adapt to the user's needs and can filter incoming data in order to supply more suitable information, rather than simply supply more information at a higher rate. The question is whether we want to build machines that are modeled more as intelligent personal servants, or as more powerful, faster engines. Again, there are no right or wrong answers; the correct soution depends on the needs of the specific situation. In the example at hand, multi-media will obviously require more system resources than a single medium. Yet, as Bruner and Olsen (1973) have noted, multiple media may be necessary in order to provide the variety of perspectives that different learners, with different skills and abilities, require to achieve a complete understanding of the underlying knowledge.

The great boon of media—especially multimedia—is its convenience. As every schoolchild knows by now, a videodisc is capable of storing 54,000 single images (which can be played back at 30 images per second to serve up 30 minutes of motion video), which is the equivalent of 675 slide trays, each holding eighty 35mm slides. This is a staggering statistic, but as anyone who has compared the image quality of a 35mm slide and a videodisc image (even displayed on the very best monitor) knows, the two are not the same. Much detail, sharpness, and subtleties of color are lost due to the limitations of the video signal. If we extend this line of thought, we can consider that the slide itself is a copy of a real scene (or a work of art, or a real object), then we are several times removed from the direct experience of the original. We may be able to store reproductions of reproductions of 54,000 works of art on a single piece of plastic, but what else have we lost by merely asking students to recognize reality rather than experience that reality? The result of this trade-off, which is most prevalent in computer-based multimedia, is to substitute representation for direct experience. The trap for which developers must constantly be aware, therefore, is not merely to use the power of multimedia to present more opportunities for representing reality—which is easy—but to give students more opportunities to experience reality in different ways. Simulations are a step toward this direction, but the challenge is use multimedia to create ever more powerful and realistic simulations. In order to counteract this tendency, instructional developers might use the computer as an auxiliary tool—for example, to interface with and analyze reality—and not always as the centerpiece of a presentation (Kay, 1991).

Current Technical Trade-offs

With these general trade-offs in mind, let us now look at the current state of constraints and see where we are and where we are heading. In general, a set of trade-offs within a given system means that a gain in one of these areas will result in a loss in another area, if all other system resources are held constant. Remember, these trade-offs are being discussed primarily from the viewpoint of the storage, processing and display of computer (digital) images. Analog video devices (such as laser videodisc and videotape) have similar/analogous constraints, but the technical specifications for analog video images are fixed by international standards and are much less variable than digital (e.g., 30 frames per second, 512 horizontal lines; vertical lines depend on the quality of the recording medium and the capture, transmission and display devices).

- **Resolution** is the apparent sharpness of the image as it appears on the screen. Images with high resolution appear sharper and crisper, with the result that details are more visible and easily inspected. Resolution is affected dramatically at each stage of the recording process, starting with the lens quality of the camera, through the quality of film or the tape format used for recording (Betacam vs. VHS), the type of transfer process from film to tape, and ending with the final display medium. In terms of program content, resolution can be relatively unimportant (a talking head), or extremely important (a microscope slide of plant cells or an x-ray radiograph).

Resolution is a more subjective quality than it might seem. Experience shows that audiences will accept lower levels of image resolution unless there is a a side-by-side comparison with an image of higher resolution. For example, we know that VHS tape has the worst image resolution of any video medium, and is several orders of magnitude worse than projected 35mm motion picture film, yet audiences willingly embrace it because of the great convenience it offers (remember the convenience versus quality trade-off). The lesson to be learned here is to be careful about mixing similar image types with different resolutions on the same screen. However, side-by-side screens—one displaying video and the other digital data—could most likely have different resolutions if the audience has been conditioned and habituated to viewing specific types of information on each screen. This issue of "frame protocol" (Hannafin & Rieber, 1989), will be discussed later.

- **Image size** is a constraint in digitized images. Larger image size translates directly to more pixels, meaning larger file sizes and CPU processing requirements. This means, for motion video, that larger files must be retrieved, processed and displayed at a high rate. Some early versions of digitized motion video (such as Quicktime, as of this writing) look their best at only 1/16 normal screen size. However, this postage-stamp size results in an acceptable *apparent* sharpness, although this same image, if enlarged, would be seen to have very low resolution. Again, image size trade-offs do not affect analog video displays, since they are limited only by the display device (the size of the monitor screen or the power of the video projector).

Image size constraints will drive the choice and design of images displayed on the computer screen. If a small image is acceptable, then it should be used in the interest of conserving system resources. For example, a talking head or a close-up of some type of action (such as hands assembling a machine) will probably work well; however, a landscape or a large photomicrograph with significant detailed areas will not be acceptable in a thumbnail size. Videographers who record scenes for use in a window on a computer screen should keep the small size constantly in mind, just as motion picture cinematographers who made the transition to television many years ago were forced to change their habits of screen composition.

• **Color depth** refers to the number of colors that can be shown simultaneously on the screen at one time. The usual parlance refers to the size of the digital encoding unit for each pixel on the screen: 2-bit color allows 16 simultaneous colors, 8-bit color = 64 simultaneous colors, 16-bit = 64,000 colors, 24-bit = 16 million colors; 32-bit images allow the same color depth as 24-bit with the extra 8 bits providing accessory information. The trade-off, as in image size and resolution, is simple: more colors equals more data and a larger file size. Therefore, designers should use the smallest color depth (fewest number of colors) that is workable. For example, a talking head should not require 24-bit color, unless facial details are important. However, an art history expert may find even 24-bit color somewhat constraining, depending on the resolution of the monitor.

• **Speed** refers to the rate at which new frames can be displayed on the screen, that is, the refresh rate and the frame rate. Once again, speed is not an issue with analog devices, such as videodisc or videotape. True motion video requires thirty new frames to be written on the screen every second (NTSC standard). Standard QuickTime, for comparison purposes, can only manage about twelve frames per second, and with other trade-offs, the range can go as high a 15 or as low as eight or nine per second. DVI, on the other hand, normally plays at a full 30 frames per second, as befits a hardware-based system.

When video is recorded at 30 fps and must be played back at a reduced rate due to system constraints, two things can happen. If all frames are displayed, the action appears in slow motion and the result is not "real time"; or the computer skips frames in order to maintain "real time", the results appear jerky, especially if the frames are skipped intermittently. How does this choice affect design decisions? A talking head must be played back in real time in order to match the audio, but watching someone talk jerkily at 10 fps is rather disturbing. A designer would probably put speed of playback as a top priority for a talking head and sacrifice image quality and size. On the other hand, most graphic animations do not require playback at 30 fps. For purely economic reasons, many broadcast animated cartoons are in fact recorded as two (or three) frames of video or film for each graphic frame, which gives them an effective speed of 15 (or 10) frames for every second. Because these cartoons are so packed with action, our eyes tend to fill in the blanks. In this case, a slow speed is acceptable and resources can be re-allocated to increase color and resolution.

- **Data Rate and Bandwidth**—Data rate refers to the speed at which data is read from the storage medium, while bandwidth is a related factor that refers to the carrying capacity of the transmission channel used to transfer the data. Both parameters are therefore related to, but different from, the speed factor just described. For example, CD-ROM's are notoriously slow at reading data, and for this reason cannot currently be used for direct playback of uncompressedvideo, despite their tremendous storage capabilities. Networks also tend to be bottlenecks for transmission of large files, such as video, at a fast enough rate for suitable display of motion.

Summary

When choosing a display format for interactive multimedia, the decision about how and whether to mix analog and digital images is fundamental, as is the decision about whether to use managed or integrated video. Managed video is the current norm, and the simplest method is to keep the analog display separate from the digital display. An added level of complexity and cost is required to overlay the computer signal on the video display. True integrated video requires conversion of the analog source to digital, and adequate storage and processing power for retrieval and display. Once the important technical constraints of any computer-based multimedia system are understood and delineated as interrelated trade-offs, it will be easier to make decisions regarding the components of computer system. It may be helpful to remind ourselves that most system constraints tend to level off as the technology advances (e.g., storage capacities, processing power, transmission bandwidth). All trade-offs, except for the prototypical trade-offs that tend to be endemic to computer systems in general, tend to become less constrictive as time goes on.

Practical Considerations

System requirements and constraints, and the theoretical factors that affect learning, are important matters that should concern anyone who has the responsibility for designing and developing a multimedia display system. The following section is intended to address the more practical matters that will determine the actual configuration of a workstation or a group of workstations in a particular context

. Some of these considerations are direct implications of previously-described technical and theoretical factors.

1. An single screen system that incorporates analog video with computer overlay is typically more technically complex (and therefore more expensive) than a two-screen system, despite the requirement for an extra, video-only monitor. However, single-screen systems that use integrated (digital) video can be much simpler, except that they now require more powerful computers and very large storage capacities (i.e., hard disks in the gigabyte range, CD-ROM drives, high-capacity tape drives), or networks with high-bandwidth capabilities (e.g., Ethernet).

2. Two-screen systems are simpler to control from a programming standpoint than single-screen managed-video systems. For example, a Macintosh two-screen system requires only a single cable and minimal software (e.g., Hypercard) in order to provide complete control of a videodisc player. However, integrated systems show promise of also being very easy to control; for example, Hypercard can be used to control Quicktime movies with a minimum of complexity.

3. Altering single screen, managed-video courseware programs (computer graphics overlaid on video) will probably be more problematic than altering programs that have kept the two media separate (dual screen). However, single screen integrated-video designs will ultimately offer greater flexibility for modification.

4. Two-screen systems will require more physical space (for the second monitor, as well as for the video source device, probably a videodisc player).

5. Two screen systems have twice as much physical display (screen) space for presenting information. They can present different levels of image quality without disturbing the viewer, as would be the case if different quality levels are mixed on a single screen.

6. Two-screen systems require observing a more complex and uniquely defined *frame protocol*, which is defined as the "systematic use of available screen space for defined purposes" (Hannafin & Rieber, 1989). Also, a cardinal principle of

interface design is consistency (Rubinstein & Hersh, 1984), and a second screen compounds the problem of consistency of use.

7. Two screen systems may require stronger and more frequent and elaborate cuing, so that students will know when and where to direct their attention to the second screen.

8. Two screen systems will offer new opportunities and greater flexibility for varied or learner-control system uses. For example, the video screen could be used as a television monitor, or as a stand-alone monitor for a hand-controlled (or bar-code controlled) videodisc player. Likewise, depending on the capabilities of the computer system, the computer could be used alone with the same capabilities as a single-screen, all-digital multimedia platform.

The decision about which hardware configuration to purchase will depend on a combination of factors, based upon theoretical, technical and practical considerations. It is to be expected that no system will be a perfect match, and that compromises must be made. Remember that "there are no simple answers, only trade-offs" (Norman, 1987).

Decisions Affecting the Plant Biology Multimedia Workstation: A Case Study Outline

Recently, the author and his colleagues were required to make decisions about the hardware for multimedia student workstations to be used in a sophomore-level plant biology laboratory. The following is an outline of the requirements prioritized into two categories, based on course objectives.

Important requirements:

• Highest possible resolution, color rendition, and image size for graphic and photographic images

• Storage for a large number of images (photographs, animations, still pictures, etc.)

• Create and maintain a database of images that could be accessed apart from the computer system (i.e., with hand controller or bar code, as a classroom display or for individual use in a media carrel)

• Moderate need for real-time motion video
• Fairly low-cost system
• User-friendly, easy-to-learn system
• High system speed (no long waits for system to write a graphic to screen or respond to user input)
• Variety of software: simple database of images; classic self-instructional tutorials; several simulations; some computer-based tools, such as cladistic programs, word processors, etc.
• Flexibility to use a variety of different courseware at various levels of interactivity, some of which has not been identified (e.g., Level 1 and 2 videodiscs; computer tools, such as word processors and various scientific programs)

Less important requirements:
• User manipulation of realistic (video) images
• Complete integration of text and images (i.e., images can be satisfactorially used as illustrations of text)
• Conservation of physical space (i.e., extra equipment is not a problem)
• Maintaining of all information in digital format
• Frequent updates of visual image bank

System Configuration

The final decision favored a classic two-screen system, in which the computer (Macintosh IIsi with a high-resolution monitor)controls the videodisc player (Pioneer 2200 with a high-resolution video monitor). Although there is a relatively high cost involved with updating a visual database that is stored on videodisc, image quality requirements, system flexibility and the current flux and uncertainty in digital video presentation and storage dictated the choice of this design.

Coincidentally, this dual screen arrangement matched certain skill patterns that students of biology must develop: finding and matching details on diagrams to realia, or real-life objects (i.e., matching parts of a diagram of a tissue to a section of tissue on a microscope slide or a photomicrograph). This carry-over of skill patterns helped us to specify a consistent design feature, or screen protocol, that we tried to maintain throughout the program: restrict the computer screen to symbolic information (text, diagrams, etc.) and the video monitor to realistic images and highly detailed graphics.

On the surface, the decision in favor of a two-screen system may seem to run counter to the trend toward single integrated systems; yet it maintained the required system flexibility and freed the computer to perform those things that a computer does well. It also maintained an acceptable system speed for a relatively low-cost system (Macintosh IIsi) with a user-friendly interface, and yet allowed for a high degree of interactivity.

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