Abstracting Craft

The Practiced Digital Hand

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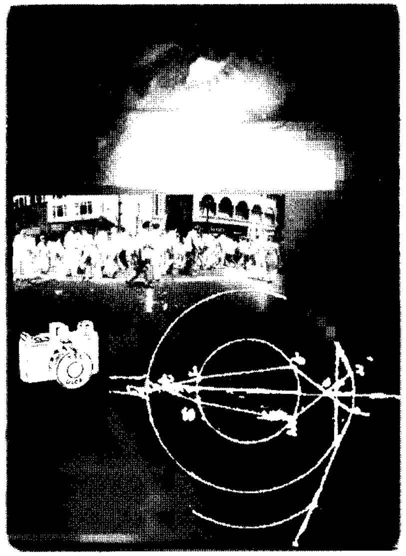


2 Eyes

Eyes are in charge. What you see is what you get. Seeing objectifies the world, and for this reason no other act of perception is so closely connected to working and thinking. Eyes guide tools, read notations, appraise designs. Whereas hands feel their way one piece at a time, eyes see wholes, and compare many objects simultaneously. They recognize images and understand pictures. Signs and symbols *appear* more than they taste, feel, smell, or sound. Even in spoken language, we often say "I see" to mean "I understand." We have "insights." Seeing is believing. No wonder the eyes have been called "the great monopolists of the senses."[1]

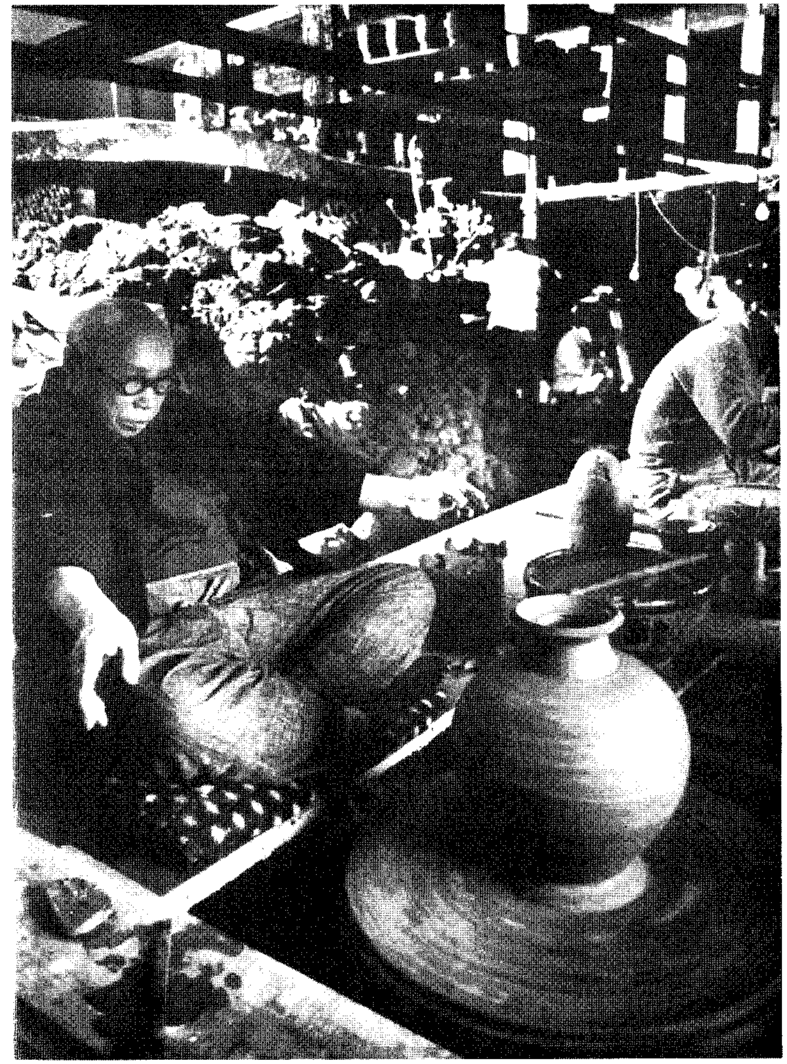
Biologically, our paired eyes are made for searching through the depth of the natural field for anything we must catch (or avoid) to survive. We see far beyond the grasp of the hands or the range of our strides; we gaze upon a lot that we cannot or need not act upon. Contrast the sense of touch, which always elicits a response.

At close range our powers of focus improve. Eyes activate the hands, and hands direct the eyes. To examine something, we prefer to have it within reach. We walk over to it; where possible, we pick it up. Held in our hand, scrutinized by our eyes, the object comes to life. We not only study it, we modify it. We envision variations and alternatives, and we then proceed to give those form.

Hand-eye coordination distinguishes humanity as the maker of things: *homo faber*. It is our talent to bring a mass of raw material into conformity with a vision. We fashion tools and coax materials. Under visual guidance, what would otherwise be brute grasp grows into specialized skill. Hands acquire some independence through training, but they still turn to the eyes for purposes. When in action, a skillful touch remains subsidiary to focal vision. Because this kind of coordination satisfies, we pursue it in play, too: sports, musical performance, building projects, and traditional handicrafts give pleasure though coordination. Reflection finds harmony in the steady flow of hand, eye, tool, and material.

The craft artifact, always the traditional object of coordinated efforts, is therefore as much a product of the eye as of the hand. Vision appreciates its qualities of proportion, material economy, and workmanship—recorded harmony. In the process of production, the artisan's eye for detail continually assesses the artifact's condition. For example, the eye can watch for material stress through visual cues such as dents or deformations. The eye can follow the imperfections and eccentricities of the material, such as the cracks in fine leather, and make those into assets. The eye can find quality in such workmanship by others, and this is an important basis for appreciation. Vision finds cultural identity, too, as form and ornamentation bear tradition. Much that we appreciate in craft, the eyes understand.

Literate notation is different. In a way it is more visual still—indeed it lets the eyes take over. In doing so it opens abstractions, invites organization, and administers invention. But visual literacy requires education, whereas handicraft can be learned doing or simple training, and this has separated professions from trades. Moreover, the literacy needed for scripted notations such as writing or programming often comes at the expense of a more general visual literacy practiced in reading images. It

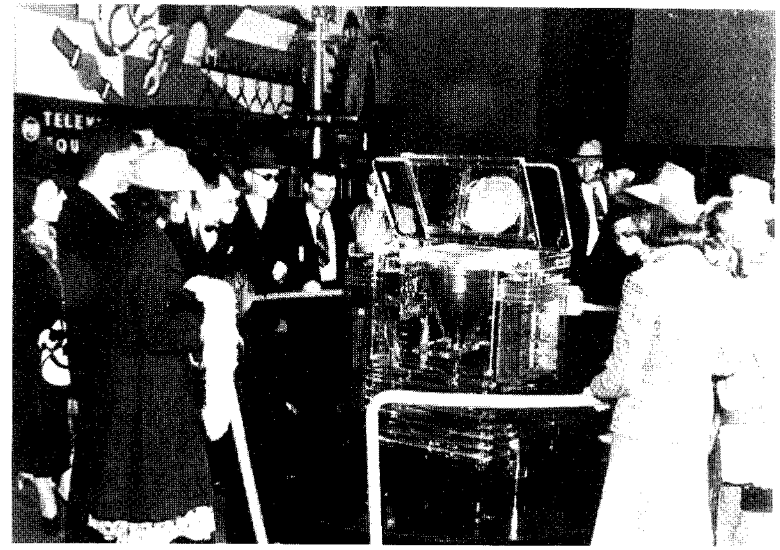


2.1 **Holistic vision is integral to traditional craft** has also overspecialized the hand. Although manual control of position is sometimes refined in writing, the hand's role is diminished overall: exertions of force become quite monotonous, and the capacity to probe goes almost entirely unused. And although for some people the writing pen, or particularly the drawing instrument, remains an object of considerable skill, for most others the act of writing, or just simply reading, does not entail much physical ability.

Today we no longer even need hold much of our reading matter, for instead we stare at screens. The two-dimensional object of vision has become cinema, television, or especially the computer, which has become a visual medium itself and has permeated many older visual technologies as well. Computer graphics now mediate enough activities to suggest that computing's preeminence and visuality are somehow related. Even text production becomes more visual: most developed writing is now done on a screen rather than on paper, at least when authors have a choice. Similarly, drafting now is almost universally computer-assisted line processing, at least in professional settings. Photography is going digital quite rapidly. Manufacturing increasingly relies on computer-aided design and manufacturing (CAD/CAM) and related process control systems. Entertainment promises to unite television and computing. Each of these technologies contributes to an image culture, which we may expect to generate still further forms of visual production.

The onscreen image moves. In comparison to paper, screens can not only mix writing and images more easily, but also can change their contents more rapidly. In comparison to objects or texts, photographs reach a much wider audience, and moving images get more attention. With as few as a dozen images per second we can construct depth and movement as if peering through the screen into a natural space, and we can assume that just about everyone will be able to read this as a movie.

The screen, however, is hardly the ultimate condition. As has been the focus of much recent hype, appropriately engineered stereo images—for example, those achieved with headsets or goggles—can let us read "through the looking glass" into an immersive representation of artificial



2.2 Eyes take command: the introduction of television, 1939 New York World's Fair

worlds.[2] That this optical artifice is so commonly referred to as virtual "reality" demonstrates our willingness to give the eyes a monopoly.

Under present conditions of computer usage, hand-eye coordination changes. Traditionally, hand, eye, and tool converged in one place: when the hand worked a material, the eye followed it continuously; or the hand held a paper, while the eye read. Now the hand moves a mouse while the eyes look at a screen. Hand-eye separation may be normal among some sorts of processes, such as playing from a musical score, drawing from the human figure, catching a baseball, and driving a car. But for processes that work a material, hand-eye union has always been essential.

Without the guiding eye, the hand performs fewer continuous strokes, like drawing a bead of watercolor across a sheet of fine paper, and more quick, discontinuous actions, like clicking on lots of boxes. For most people, this reduction of hand-eye coordination is a source of regret. The hand was not made to twitch—or to click boxes all day. Yet for some people, especially those who never had the traditional skills, computing is a source of new opportunities for coordinated action. This is particularly true where direct manipulation software makes the repetitious work more tolerable. Recall that direct manipulation is defined by the continuous *visibility* of the object being modified. Many people understand only those computer operations that produce a visible result—whereas working on an abstract mental model without visual identity or graphical acknowledgment is much more difficult. Nevertheless, relatively few graphical operations are truly direct manipulations: pointing at commands on menus, and filling in forms in dialogue boxes, do not satisfy our instinct for tools.

But mechanical actions like pointing are easily improved. Recent technologies such as digital notepads and video-conference whiteboards may restore a more normal hand-eye union. In general, more computing power means more continuous representation, and more complex objects and worlds. Maturing software frameworks support more psychologically coherent operations. Better hardware support allows for bettor sensory coordination. This need not mimic traditional actions, but may invent new techniques. As an example of how engaging some of these may become, note that gaming enthusiasts (who tend to be the first to gain access to emerging human-computer interaction technologies) already find some new forms of coordination outright addictive.

Better sensory frameworks, not limited to vision, make for better computing. Better software to orchestrate our skills and senses, and to structure our mental models, makes for more satisfactory work. In this regard, provision for richer hand-eye coordination is only the beginning—the ultimate goal might be described as a multisensory grasp of sophisticated intellectual structures. Whole-body expression and kinetic memory could perhaps find a role. Audio dimensions, too, can and should be considered. Nevertheless, principles of abstraction, literacy, and symbolic communication—as well as artisanry and other ways of form giving—have traditionally been the province of the eye.

Thoughts on Visual Thinking

Vision abstracts. In his influential work on visual thinking, Rudolf Arnheim observed:

> We need and want to rebuild the bridge between perception and thinking. I have tried to show that perception consists in the grasping of relevant generic features of the object. Inversely, thinking, in order to have something to think about, must be based on images of the world in which we live. The thought elements in perception and perceptual elements in thought are complementary. They make human cognition a unitary process, which leads without break from the elementary acquisition of sensory information to the most generic theoretical ideas. The essential trait of this unitary cognitive process is that at every level it involves abstraction. Therefore the nature and meaning of abstraction must be examined with care.
>
> There is no getting around the fact that an abstractive grasp of structural features is the very basis of perception and the beginning of all cognition.[3]

Abstraction means that vision is not just sight. Vision goes beyond simply recording arbitrary samples to formulate identities and recognize patterns. Yet this abstraction is not the opposite of concreteness, or unrelated to tangible things, but may have its origins in those very phenomena. Nor is abstraction just a token by which one thing, image, or symbol represents others, but rather it is a higher-level schematization. It is more than a classification, too, or more than generalization by induction, by either of which methods a higher order is inferred from what is perceived.[4] The difference is that visual abstraction is active, imaginative, adaptable—and above all else, *generative.*

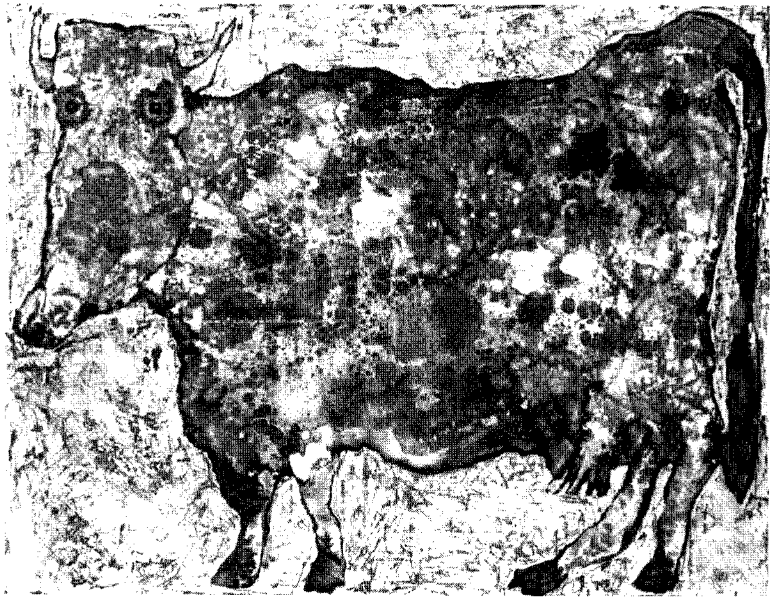
This impetus toward abstraction is of course most pronounced among great artists, but it is something that all of us do, even when we are just walking around. Perhaps nobody can equal the visual drive and agility of Picasso, whose particular three-year body of work shown together at Antibes, for example, supremely demonstrates the abstractive visual impetus. But each of us has an abstractive imagination: we can identify essential similarities amid superficial differences, and we have a tendency for what we have been looking at to shape what we are inclined to notice next. For most anyone, generative vision is evident in evolving visual preferences, sensibilities, or fashions. And for creative people visual speculations assist inventions, and visual tokens most effectively represent ideas.

Normally these tokens are images. We might then define visual thinking as the use of images to generate ideas and knowledge, plus the use of abstractive grasp to detect patterns and identities in images. Note, however, that images may be perceptual or conceptual, pictorial or topological (spatial). Note also that images are not very formal. Visual thinking occurs in enough contexts to suggest that it is largely independent of formal symbolic reasoning. Like text, mathematics, or software code, but independent of them, images produce ideas too. Visual thinking creates recollections, recognitions, correlations, comparisons—especially when the mind works with a stream of fleeting, freely associated images.[5]

Not everyone agrees with this principle. Psychologists, art critics, cognitive scientists, computer scientists, and software designers have debated about visual thought for decades. The intellectual context for these inquiries encompasses the most general findings of the last half-century. For example, postmodern physics has established that the observer influences the observed. Literary criticism holds that any piece of authorship is selective and rhetorical, as is any reading. Vision becomes relative, and aesthetic theorists contend that any form may represent anything. Unconscious imagery gains respect, and psychologists suggest that we pay a high cost for keeping a schism between this latent imaginative power and the greater focus of symbolic reasoning.[6] Many educators observe that, for better or worse, images compete powerfully against text. Traditions based on *logos,* or the authority of the word, are challenged by the *tekne,* or masterful manipulation, of the image. If television has numbed many minds, perhaps interactive simulations have opened at least a few others. In some cases, visual computing has provided a few children with a newer window on knowledge.[7]

This debate may continue perpetually because vision takes so many forms, some difficult to document. A behavioralist might study external stimuli, a semioticist might observe cultural contexts, and a cognitive scientist might focus on the physio-neurological basis for syntactic structures. An artist, however, might simply seek a receptive condition, and a philosopher could posit a platonic mind's eye not measurable by scientific instruments. In any case, we should be comfortable in saying that vision is many things: part sight, part significance, part structure, part state, and part intent. Anthropologist Ken Wilber has formulated a useful classification whereby men and women possess at least three modes of knowing: the eye of the flesh, which discloses the material, concrete, and sensual world—the world of sensibilia; the eye of mind, which discloses the symbolic, conceptual, and linguistic world—the world of intelligibilia; and the eye of contemplation, which discloses the spiritual, transcendent, and transpersonal world—the world of transcendelia.[8]

A substantive work of art may encompass all of these forms of vision, and of course the fine arts are particularly rich in theories of the image. Consider one standard: the work of art historian Ernst Gombrich. Gombrich regularly argued that seeing and representation are anything but literal, unfeeling acts. "The eye is not a camera," he wrote. "One thing can be taken as established. There is no fixed correlation between the optical world and the world of our visual experience." Subjective visuality pivots between recognition and recall, for while the former depends on what we have previously learned to see as well as what we have presently chosen to focus upon, the latter depends on our ability to associate the many things we have seen. As evidence that these two processes mix, Gombrich notes that otherwise, "oculists who wish to test our eyesight would not have to use random letters rather than coherent texts." Moreover, not only symbolic systems such as text, but many more general aspects of the visual world are significantly coded and afford each of us a visual disposition.[9]



2.3 Gombrich's example of subjective vision: Jean Dubuffet, *Cow with Subtile Nose*

Practical graphic design employs more or less the same principles. Visual communication must establish context for its content and appeal to the disposition of its intended audience. It presents rhetorically, and is read by cues, such as hierarchy, differentiation, or identification. Effective graphic design therefore uses structure and selection not only to transmit but also to reinforce and explain content. In this way, mere data can become useful information. Nobody has demonstrated this better than Edward Tufte, whose books *The Visual Display of Quantitative Information* (1983) and *Envisioning Information* (1990) have become standard references among graphic designers. Tufte insisted that format could reinforce content, that all data reporting was selective if only by format, and that most formatting was negligent. That Tufte was turned away by publishers and had to resort to his own production indicates the degree to which the communication of "hard data" had been misunderstood. The need for a visual, digital form of rhetoric had been unrecognized. Thus for those designers who do appreciate the distinction between raw data and effective communication, these books stand as landmarks at the arrival of visual computing.

Naturally the role of visual thinking varies by discipline: design is certainly more visual than law. Not only graphic designers but also architects, engineering designers, and even many eminent theoretical scientists have been documented to rely on visual thinking.[10] For example, atmospheric scientists benefit by visualizing trends that are neither especially perceptible first-hand nor very intelligible in complex systems of equations.

Software designers are influenced by all of these considerations. Their quest might sound like this: Can the visual representation of tools, media, and artifacts become sufficiently intuitive to allow us to use the full spectrum of our abilities and imagination? Can the visual codes and metaphors themselves become objects of craft? Can they become three-dimensional, dynamic, expressive, full of workmanship? Just as important, can the overwhelmingly visual world of the computer accommodate nonvisual actions and perceptions? The answers to these questions will be a long time coming, but the general course of inquiry should be clear. Vision is key: its mechanisms can inform technology design, and its cognitive power can make sense of symbolic orders. Both vision and computation are very prone to abstraction, and the trick is to get them to coincide.

Image Culture

There is no denying the power of visual thinking, for it is everywhere. In the course of a single day, you will see more artificially constructed images than a seventeenth-century Englishman would have seen in his entire lifetime.[11] Between the morning news and your bedtime reading there will be road signs, billboards, computer screens, junk mail, posters, photo prints, presentation slides, pictures on people's shirts, snippets of television shows, maybe a movie, a computer game, maybe a couple of downloads from the internet, a videotape—thousands of images in all. There has been an explosion of image production. The 1989 Biennial at New York's Whitney Museum charted some data.[12] Despite the electronic age, Americans in 1989 produced 15 billion conventional photographs—triple the number taken twenty years before. They continued to spend billions of dollars on going to the movies. They upgraded millions of computers to begin using graphical user interfaces. Their overall domestic advertising expenditures cleared $118 billion. This was up by a factor of six from twenty years before, and came to nearly $500 per capita. As a result Americans were subjected to 1,600 advertisements per person per day. Many of these ads appeared on the nation's 160 million televisions.[13] The total image flow over television alone is staggering. If it is on for just one hour, and the camera shot changes about once every two seconds (a very conservative estimate these days, especially given the popularity of channel surfing), television transmits 1,800 images. More aggressive content, as might be encountered in a nightclub or arcade, can have hundreds of edits not per hour but per minute. Of course, statistics routinely indicate that the average American household runs a television for more like six or seven hours a day, which if anyone is watching, comes to many thousands of images.

Now as the critical theorists are so fond of telling us, those thousands of images are neither literal nor free. Consider the latter. The usual argument goes that images have replaced tangible things as essential economic commodities.[14] In postmodern culture, aesthetics and consumerism fuse, and even basic physical commodities get overlaid with images. Consider the plight of an ordinary cotton shirt. The overlay can happen directly: the shirt could be imprinted with an image. But the indirect method is more significant: a plain cotton shirt might be marketed in mail-order catalogues that represent several different ways of life. Consumers would then make a selection guided by these images—more than by any inherent distinctions in the style or workmanship of the actual shirts—and the product they receive would include a logo indicating which lifestyle image they have bought. This insignia can double the retail value of a shirt, and indeed there have been lawsuits over counterfeit shirts.[15]

Of course image culture goes beyond simple commodities. For instance, politicians cultivate images by staging photo opportunities. Business managers manipulate statistics with animated charts. Market analysts use automated graphs to detect feedback loops in investment patterns—and thus to oil the wheels of runaway finance. Television news editors broadcast sponsored simulations as events. Cinematic merchandise (especially computer games) competes with merchandised cinema for leisure-time attention. Electronic reproduction and transmission now confer legitimacy—they make reality. For example, on the streets of Los Angeles, crowds gather around anything at which TV cameras are pointed, because people want to see what other people are going to see, because that alone is most real. Conversely, forms not onscreen tend to fade from consideration. For example, in a research library, those books cited in the computer database enjoy much more circulation than those listed only in the old card catalogue. Visual media determine what gets noticed, what gets demanded, what gets admired. In the marketplace, visual identities such as the controversial cigarette-smoking Joe Camel are carefully cultivated to generate demand for products, events, and services. To be viable, then, is to be visible. The safest way for work to be sustainable is for it to be presented though the image.

Meanwhile the image itself is transformed. Now made of bits, it is increasingly malleable. The same image can appear in a growing range of media: produced on conventional film, or in a digital camera, a photo CD-ROM, a file moving about the internet, or as pixels on your screen. And so we get "memes"—ideas, usually images, that proliferate like viruses. These are not just mechanically reproduced, but come in versions, with content altered almost as easily as format. Some of these versions and recombinations capitalize on the presumed veracity of the camera to present altered instances as photographic reality. And more generally artists of all kinds appropriate and invert famous images, whose fame consists anyway in copious reproduction, or more accurately, transformation. The origin of a meme is of far less concern than its proliferation. Electrified culture produces a flux of images for which there is no original, and all of us can just sit back and enjoy the free play of signifiers, much as we would admire a good sunset.

Dematerialization

The pertinence of these conceits to our question of digital craft is essentially twofold. On the one hand, the image culture reduces the importance of physical objects; on the other, it generates many new forms of individual knowledge and production.

Dematerialization is not new, for in a sense it began with mechanization. We can recite from Walter Benjamin's celebrated essay, "The Work of Art in the Age of Mechanical Reproduction" (1934), which stands sixty years later as one of the perennial favorites of aesthetic theory—the essay itself mechanically reproduced everywhere on college copy machines. Benjamin's argument certainly pertains to our question of craft, for it refers to an archaic condition, similar to the one evoked by Paz, which Benjamin calls "aura":

> The presence of the original is the prerequisite to the concept of authority . . . Confronted with its manual reproduction, which was usually branded as a forgery, the original preserved all its authority; not so vis-à-vis technical reproduction. The reason is twofold. First, process reproduction is more independent of the original than manual reproduction. For example, in photography, process reproduction can bring out those aspects of the original that are unattainable to the naked eye and yet accessible to the lens . . . Secondly, technical reproduction can put the copy of the original into situations which would be out of reach for the original itself . . . One might subsume the eliminated element in the term "aura" and go on to say: that which withers in the age of mechanical reproduction is the aura of the work

2.4 The work of art in the age of mechanical reproduction: Roy Lichtenstein, *Image Duplicator* (courtesy of Lichtenstein studios)

> of art . . . One might generalize by saying: the technique of reproduction detaches the reproduced object from the domain of tradition.[16]

As we know, none of this bodes well for traditional craft. When its aura fades, an artifact loses its authenticity—that is, its history, its cultural identity, or its autographic, personal stamp. It becomes a merely useful thing. Moreover, if people see the copy before the original, or never see the original at all, they become more likely to accept the image for the thing. The material aspects of the object lose any importance except with regard to appearance. This in turn means that things get made expressly for the images they shed, indeed in some cases just for how they appear from a particular vantage point, like a movie set. Conversely, artifacts about which there are no images, or which were never intended to be experienced as images, seem destined for obscurity. Whether a noble "last" craft like the bark canoe or a mundane folk commodity like *huaraches* being replaced by Tevas®, artifacts not merchandised or loaded with a marketing image tend to disappear in the image culture.

At the same time, common sense becomes visual sense. Innate sensibilities—always the blessing of the artisan—become increasingly visual, and other skills slowly vanish. The experience in which most people become most practiced is no longer the workings of nature or the use of hand-held tools, but rather the reading of images—staggering numbers of images.[17] We get the picture, or, more accurately in the era of target marketing, the picture gets us.

Much the same trend was prophesied long ago by Oliver Wendell Holmes, who in 1859, just twenty years after the invention of photography, exclaimed: "Matter in large masses must always be fixed and dear; form is cheap and transportable. We have got the fruit of creation now, and need not trouble ourselves with the core. Every conceivable object of art and nature will soon scale off its surface for us. Men will hunt all curious, beautiful, grand objects, as they hunt cattle in South America, for their skins, and leave the carcasses as of little worth."[18]

The camera was an appropriate metaphor of modernity for other reasons as well. Its power to chemically fix light and shadow came out of, and effectively represented, the overall project of an innocent scientific realism.[19] Its product, the photographic print or film, was celebrated by the moderns for its immediacy, its objectivity, its closure, and its freedom from codified interpretation.[20]

Now a digital image culture separates practical production from traditional artisanry by a second order of magnitude. Bits replace atoms, and digital signal processing undermines the very physicality of reproduction. Where industrialism diminished the role of the hand, now postmodernism diminishes the role of the physical artifact.

Painting, for example, is now twice removed: if the camera succeeded painting (at least for practical representation), the digital computer in turn now succeeds the chemical camera. One of the first to explore this idea was William J. Mitchell in *The Reconfigured Eye* (1992). Much as in 1839, after seeing the new Daguerreotype, critic Paul Delaroche announced "From this day on painting is dead," Mitchell updates, "From the moment of its sesquicentennial in 1989 photography was dead—or, more precisely, radically and permanently displaced—as was painting 150 years before."[21]

Where a photographic print requires little more work to make many identical images, a computer image requires little more work to make many, no two of which are exactly alike. The digital image file is synthetic, multivalent, fragmented, sampled, appropriated, independent of output format—every version the original, without degradation, no matter how many transmissions, no matter how many transformations. Filters, geometric transformations, tone scale adjustments, synthesized textures and lighting, plus incredible powers of layered adjustable cutting and pasting are all provided in everyday image-processing software capable of transforming a computer into a digital darkroom for just a few hundred dollars. So where the mass-produced photograph was the characteristic metaphor of the modern, today the digitally generated image, in its place, has become the effective metaphor of the postmodern.

Of course such abstract manipulation is hardly limited to the production of images. Designers do it with three-dimensional form. Industrial engineers do essentially the same thing with flexible production. Business planners do it with site selection and product distribution scenarios. Unfortunately, some such abstractions contribute to a growing rift between high-tech factories without many workers and low-tech third-world sweatshops. People become operands in optimized numerical models. Organizations become virtual and recombinant. This may be getting ahead of the narrative, but we can see that Henry Ford-style manufacturing, too, is being radically and permanently displaced—as was artisanry 150 years before.

It follows that artisanry, like painting, now becomes twice removed. For purposes of practical production, hand-eye-tool work must now compete not only with the leverage of standard mechanized production, but also with the leverage of process models and design computation. Hence any return to traditional artisanry becomes all the more unlikely. A century ago, in the time of Ruskin and Morris, hand work may have seemed only recently displaced—and perhaps recoverable. But today the separation is so great that traditional methods seldom survive as anything more than a personal recreation or a form of protest. Truly practical craft, practiced as a livelihood, is reserved for esoteric production, where cost is no object or where the main impetus is not the product, but the process. In most other forms of work and play, the hand is no longer any match for the eye.

Visual Production

Although physical objects may decline in importance, that loss could be offset by gaining new forms of abstract visual knowledge and production. The latter is certain: to work in a technologized image culture is to produce and deliver all manner of visual information. Our products are electronic graphs, charts, maps, plans, diagrams, pictures, movies, hypertexts. Much as industrial goods formed a "second nature" that supplanted the "first nature" of agricultural production, so now has postindustrial visual information established a "third nature." We work this nature, and make these dematerialized artifacts, using computers—which are increasingly necessary in a world already shaped by computers. To produce is to employ a range of digital media, against which analog media are increasingly hard pressed to compete. New media have upset old distinctions of trade and profession, especially where work has become equated with information delivery alone. For example, architects might occasionally imagine that they are in the business of producing sets of drawings, except now those drawings have become just reports on databases, which themselves have become a matter of professional service and responsibility to administer. Organization itself, and not only the document delivery it structures, increasingly relies on digital media. But at the same time new practices have revealed that the real basis of professions remains to administrate knowledge.

Many other givers of form encounter similar circumstances. There are few exceptions to this change in the means of production. Three-dimensional designs are produced in geometric models, process models, machined part parameterizations, global illumination models for renderings, scores for animations. All these various representations are constantly mediated through images. All this abstract work is monitored on a computer screen. Even physically formed artifacts can be mainly visual. For example, the product of a rapid prototyping system, such as a laser-sintered model of an airplane part (made by incrementally fusing metal flakes and resin) lacks the structural, inertial, or thermal properties of the manufactured thing it represents. It is only for testing form fit or appearance.

Although image production comes first, new forms of visual knowledge should follow, and this is the second side of our interest in image culture. New forms of production invite corresponding changes to outlook, artifacts, and methods.

The computer has already reshaped many forms of thoughtful work. Writing, the traditional medium of focused thought, is itself influenced by the technology of word processing. Design, which is especially visual work, is especially transformed. Composition and printing of two-dimensional images benefit from the instantaneous verification provided by graphical computing. Projection and construction of three-dimensional models may employ the rigors of operations formerly practical only in two dimensions, as well as a flexibility similar to that of word processing. This might become understood as "form processing." In the fourth dimension of time, digital apparatus enables the orchestration of forms, images, and text into compelling visual presentations.

In these many different facets and guises, the computer has become a visual medium. It has subsumed many older visual technologies such as photography and video as well. Throughout these endeavors, computing has not so often introduced the strict formal methodologies for which it was initially notorious as it has opened up possibilities—for involvement, for expression, and for individual talent. Visual computing has provided a new form of hand-guided, continuous processes. Its dynamic representations invite incremental refinement of artifacts. So far both the conduct of process and the presentation of artifact are purely visual, and the artifacts are what we might call virtual, but even this state suggests aspects of a workable medium. Increasingly computing shows promise of becoming the medium that could reunite visual thinking with manual dexterity and practiced knowledge.

This reunion lies at the heart of any proposition for a digital craft. New approaches to the likes of continuous process, refined artifact, workability, and the application of individual talent all relate to traditional notions of craft. This is the point. Reuniting hand, eye, tools, and mind, at the level of visual (and otherwise sensory) abstraction, may be the way toward more satisfying and more incisive work.

One distinct advantage comes from the way the computer couples graphic representations with symbolic notations. Consider the spreadsheet, the application that drove the initial spread of the personal computer. In essence, the spreadsheet takes the most fundamental abstract data construct (the variable) and makes it into the most fundamental visual element (a location) that can be pointed to. The first popular spreadsheet was thus named *VisiCalc* (1980). Given this fundamental relation, the spreadsheet can then include the names of locations (cells) in expressions held in other cells, and include those cells in others still, and so on. As a result, we can point to a single location, enter a single number, and see the consequences that ripple though an entire ledger of calculations. And this is what first made personal computers popular—*seeing* the results of quantitative propositions.

Similarly, one can couple graphics with physical activities. For example, manufacturing engineering software lets us visualize, study, and correct machine tool paths before implementing them in physical production. It also permits fabrication of complex physical forms, such as curved surfaces, directly from abstract geometric models. (Today's sleek car parts are a common example.) And conversely, it supports the development of geometric models from found physical artifacts—that is, reverse engineering. Graphical-kinetic couplings support digitizing processes such as the three-dimensional motion capture used by game animators.

Computer-aided design and manufacturing recasts relations between images and things. It models and manipulates not only objects, but also the processes by which they are made. By converting geometric models into machining instructions, and conversely basing those models on machining variables, CAD/CAM closely couples design geometry and process models in a feedback loop. For example, a parametric model of an injection-molded ski boot makes it easier for designers to identify and explore the design variables most inherent to the process by which the boot is made. This is superior to simply drawing up a design and tooling up production because manufacturing processes become more easily visualized and more quickly adaptable, and design becomes more easily executed as physical things. Thus, conversely to the widespread condition noted by the cultural critics, wherein things become images, here there occurs an inversion: thanks to CAD/CAM, and more controllably than ever before, images can become things.

In like manner, general organization has become more visual. Desktop environments let us see—and graphically organize—the structure of our workplaces. Image databases, clickable image maps, navigable virtual spaces, and other such access structures give us access to information by means of visual devices and appearances. Graphical access popularized the World Wide Web, for example—where before one had to know the name and location of remote data, now one can simply point and click at labels and images of data elements without any concern for their actual address. Instead of having to know in advance what one was looking for, one can see possibilities presented visually onscreen.

Let us generalize. Work has begun on making our data constructions coincide with our abstractive powers of visual thinking. Visual computing has expanded our capacity to visualize abstract symbolic structures as physical images. It lets ideas become things. Many high-level abstractions, some now as common as the evening weather forecast, are made visual and dynamic by computing. At the same time, many of these structures are coupled to continuous manual operations. For example, a mouse stroke might give us a tracking shot in viewing a three-dimensional model, or slowly change the proportions of a shape, or adjust the contrast in a photograph, or alter the composition of a set of forms. Visual production demands, and visual computing increasingly supports, a cultivated practice of abstraction based on direct manipulation of graphical symbols. Computing has taken its first steps toward our senses. Our work involves a limited role of the hand, empowered by a very particular mode of the eye.

Personal Vision

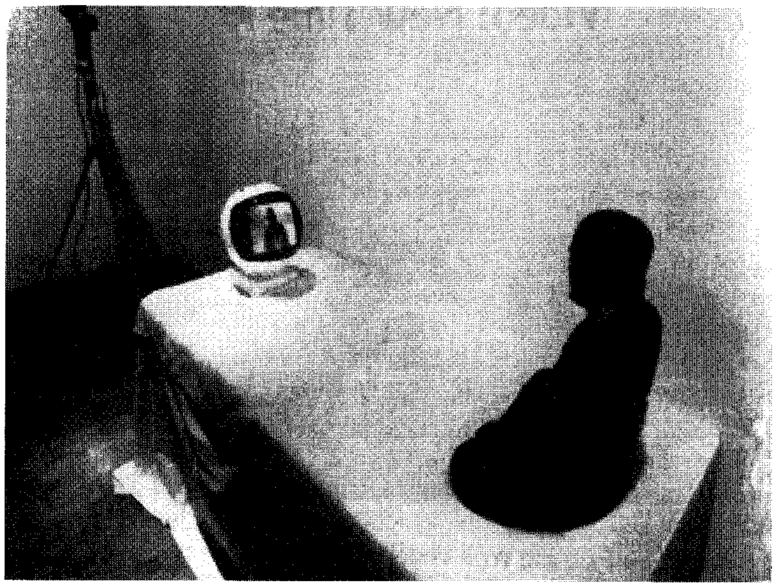
Who could doubt that the quality of work is somehow in the balance? Yet too little is said about what it is *like* to use computers. For example, what would it be like to have an abstract craft? How does it feel to assimilate the skilled hand, the contemplative eye, and the technology for manipulating abstract structure? The underemployed hand has been noted, and the capacities of symbolic structure will be explored later on; consider here the place of vision.

Imagine a design and fabrication technology that lets us explore a continuum of formal possibilities by means of rapid, continuous transformations between related versions (as opposed to executing individual pieces by trial and error). Imagine that we have the means to productively and playfully navigate that continuum—by reversible operations on bits as opposed to irreversible operations on atoms. Assume that we still care to produce physical artifacts, which we might then use and contemplate without need for the apparatus by which they were made. In this case no skill should remain more important than design vision, that is, the capacity both for envisioning what to try and for recognizing desirable form amid the flux of possibilities.

Where a discrete trial-and-error process, such as drawing successive iterations of a design on layers of tracing paper, involves some preconception, or some explicit quantitative specification, a continuous exploratory process such as realtime sculpting a spline-controlled curved surface depends much more on qualitative recognition and discovery. Note that although vision's technological context becomes thoroughly externalized, its arresting capacity remains internal (and this is exactly the power described by Focillon). This ability to develop an image in the mind's eye from which to give form to artifacts in the outer world, by means of discovering appropriate states of continuously manipulated materials, should be a far better acknowledged aspect of electronic art, digital craft, and computer-aided design.

Unfortunately, electronic image technology presents a compound challenge to the mind's eye. First, it pummels people into passivity with its ever-intensifying barrage of external stimulation. Visions are furnished, and attention spans are eroded, until the result is "couch potatoes"—people lacking the discernment by which one book read, piece finished, or argument reasoned can dictate the next. Personal agenda, which is required for craft, seems to have become merely optional for leisure.[22]

Second, interactive computing invites a reflex-based kind of activity often difficult to reconcile with thoughtfully planned work. Computers fragment our thinking by substituting discrete events for continuous actions, and by requiring us to learn and manage a bewildering multiplicity of processes. They provide the temptation toward proliferation, rather than



2.5 The contradiction of quiescence: Nam June Paik, *TV Buddha* (courtesy of Stedilijk Museum)

unity and refinement of pieces of work. They invite a certain myopia by denying any opportunity to step back and study the big picture. Moreover, they too can erode concentration—or at least calmness—by a spectrum of interruptions from nanoseconds to days, especially the endless quarter-second to ten-second delays typical of today's software operations. At the same time computers are a bit too rewarding to the short reflexive response: too much of what they ask of us takes just a second, gives an instantaneous reward, and requires something more the next second. Instead of thinking, we are just pointing and clicking, and the result is "mouse potatoes"—people content to keep working a computer without pauses for reflection or quiescence.

Third, computation encourages evaluation to take the form of analysis rather than contemplation. Note for example that engineering began as a visual discipline, but then evolved into a numerical one in which visual thinking has relatively low status. Although there are some recent trends toward social and conceptual approaches to problem solving, engineering schools of today seldom teach design directly. The overwhelming science of numerical analysis, fueled by computer-based calculations, has obscured the role of judgment and created fewer engineers capable of understanding the accuracy or validity of precise numerical models.[23] The same thing is happening in visualization, even for artistic rendering: calculations of lighting intensity models yield "photorealistic" images that despite the precision of their textures and lighting intensities may be inaccurate, incoherent, or rhetorically inappropriate. We might learn from such examples that in general, any detection, reporting, or validation of data, however exact and objective, also needs to incorporate some personal participation and vision. Polanyi argued this for scientific research; Tufte said as much for reporting.

Personal vision and personal computing are hardly incompatible: reconciling them just takes the right attitude. Benjamin wrote this of cinematic apparatus, arguing that "The thoroughgoing permeation of reality with mechanical equipment [offers] an aspect of reality which is free of all equipment."[24] To pursue this reality with digital equipment, first we must master the technology to the point where it becomes more transparent (and without our becoming mouse potatoes along the way). Then we must use this paradoxical freedom more effectively. We must recall that the mind works perfectly well without any external action or apparatus. We must assert that behavior is not the mind's only manifestation: awareness and intent may occur without any corresponding measurable action. Next we must admit that Paz is correct in suggesting that what we are missing in our work, in both the making and the employment of physical artifacts, is contemplation—the playful shifting back and forth between use and beauty. Therefore we must find ways to cultivate vision and play amid the transparency of ubiquitous technology. We must combine our personal vision with our perpetual desire to make something. We must develop good habits about letting our current piece of work dictate the next, nurture our hope that the next piece will somehow be a bit better, and mix our meditative play with ongoing work. Then we can talk about craftsmanship.

To realize the proposition of craft, we must also acknowledge that visual computing is far from mature, and that future software design must go deeper and strike better balances. For example, software designers should do more about reconciling direct with indirect actions, structure with improvisation, work with play, use with beauty. These combinations are worth pursuing, but to reach them will require going places where explicit software code cannot. Any better-balanced medium should approach our intelligence not only through formal logic, which computers perform better than humans, but also through visual insight, which humans perform better than computers. For whatever technical advances may come our way, one thing is unlikely to change. Computers are very good as calculators, constructors, and transmitters of visual information, but we're the ones who can see.