

Computers
form have a
history nea
old as the c
outer itself



Even before the advent of the modern personal computer in the late 1970s, “computing machines” were used by designers in the aerospace and automotive industries to perform complex calculations, and by scientists to develop intricate simulations of the physical world. The advantages initially offered by computers came in the form of efficiency and precision. Exploring new possibilities was not a priority; more importantly, they were used to perform calculations in a fraction of the time. The efficiency offered by the computer extended to the production of technical blueprints and allowed complex geometric drawings to be created far more quickly than with conventional techniques. Today, computers are still used as accurate drafting machines, but new ways of using them have opened new territories.

These letters convey the way computers interpret and display typography as a series of points, lines, and curves. For example, Adobe’s PostScript language renders typography with three commands: `moveTo`, `lineTo`, and `curveTo`. To create this typeface, the `moveTo` command was removed, rendering the letters as a continuous line.



Sketchpad,
Ivan Sutherland, 1963
With Sketchpad, users
drew directly on the
screen using a light
pen. The behavior of

the pen was controlled
by a group of switches,
buttons, and knobs. This
image shows Sutherland
using his software on a
TX-2 computer.

DRAWING WITH COMPUTERS

¹ Jasia Reichardt, *Cybernetic Serendipity: The Computer and the Arts* (New York: Praeger, 1969), 67.

² William John Mitchell and Malcolm McCullough, *Digital Design Media: A Handbook for Architects and Design Professionals* (New York: John Wiley & Sons Inc., 1991), 129.

³ Christopher Woodward and Jaki Howes, *Computing in Architectural Practice* (London: Spon Press, 1998), 92.

In 1963, Ivan Sutherland pioneered the graphical user interface (GUI) with his Sketchpad; this initiated a paradigm shift in how people interacted with computers. Sketchpad's interface consisted of a set of switches and dials, a display, and a light pen—a device used to draw directly on the screen. By pressing switches on a control panel while drawing, the user was able to instruct the computer to interpret the movement of the pen in different ways. Each time the pen touched the screen, a new line was added between the last point and the new one. In this way, the user could draw simple polygons. Another switch was for drawing circles, and another for arcs, etc.; this allowed for fairly sophisticated drawing. Sketchpad gave designers a way to directly manipulate objects on screen without having to first write a numerical, code-based representation of those objects. After the objects were made, they could be duplicated, moved, scaled, and rotated to create new compositions.

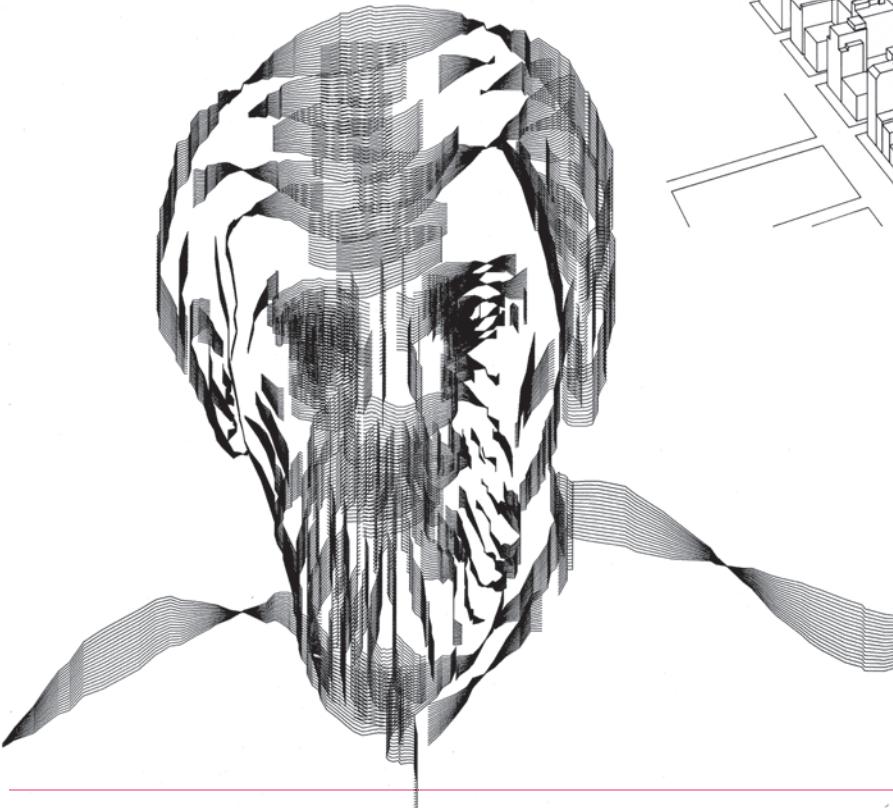
Sketchpad was much more than a crude analog of paper and pen; it was a fundamentally new way to design. When drawing in Sketchpad, the designer could make use of constraints in order to form new relationships between elements and to force them to behave in specific ways, for example: snapping the end points of line segments to other end points or lines, keeping lines parallel, or forcing them to have the same length. The user could also create more sophisticated constraints, for example: a constraint could be designed to simulate the load-bearing properties of a bridge.

With the first computer-aided design (CAD) systems, Sutherland's innovations left the lab and entered industry. The software used within the fields of engineering and architecture lacked many of his innovations and served as little more than an analog for pen and paper. They allowed designers to draw using mathematical lines and curves rather than T-squares, drawing boards, and pencils. These "high-powered drafting

machines" were hailed for their efficiency, speed, and productivity.¹ Drawings that would have taken days could now be done in hours.

Even in this capacity, drawings made on the computer were considered a poor substitute for hand-drawn sketches and diagrams. Some people felt that the drawings produced by CAD machines were cold and overly technical, preferring the "slightly wobbly line work and imprecise endings of hand-drawn lines."² There were other obstacles to integrating CAD systems into industry. Some felt that they presented a new temptation—to never stop editing a drawing or set of plans; others believed that there were too many assumptions in the software that restricted the design possibilities.³ As a result of these and other problems, computers were considered insufficient for the conceptual stage of design and were often used only at the end of the creative process. The advantages focused primarily on saving the designer's time and increasing productivity.

Within the design industry, however, the field that has been most profoundly transformed by the use of computers is graphic design. The proliferation of the personal computer—and, later on, the laser printer—laid the foundation for desktop publishing. Apple's LaserWriter could reproduce typography and images at much higher resolutions than previous home and small-business printing technologies. Perhaps more importantly, the LaserWriter included PostScript, which made it possible to use a wide array of fonts in the design, because they were now treated as software as opposed to physical metal type or transferrable lettering. This opened the door for designers to create and distribute their own typefaces and to have more control over the final typesetting. These technologies enabled vibrant activity and widespread innovation within the field of visual design in the 1980s and 1990s, ranging from the fonts of



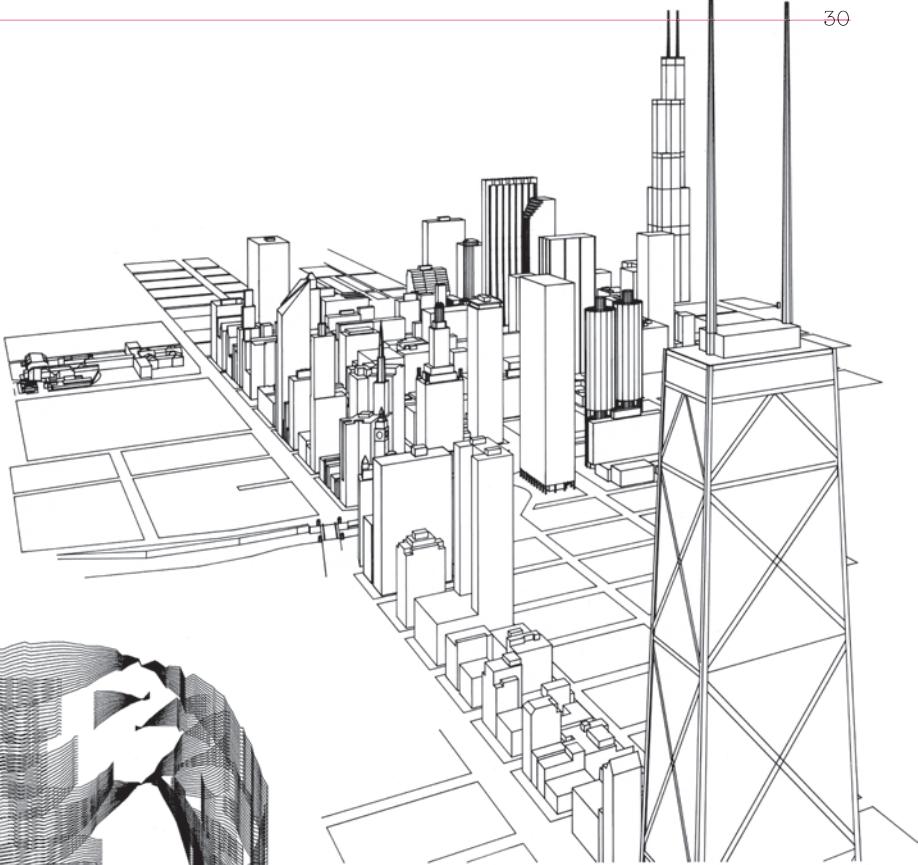
Sine Curve Man,
by Charles A. Csuri,
1967
The geometry for this
plotter drawing was
created by distorting
an image of a face.

using the values of a sine wave. Like much of Csuri's work, code was manipulated to create an abstraction of the human form.

Chicago,
by Skidmore, Owings &
Merrill (SOM), 1980
With the rise in com-
puting power and the
increasing sophistica-

tion of CAD software,
it became possible to
model entire cities.
SOM created a wireframe
model of downtown
Chicago to give viewers

a feel for the city's
form and massing of
buildings.

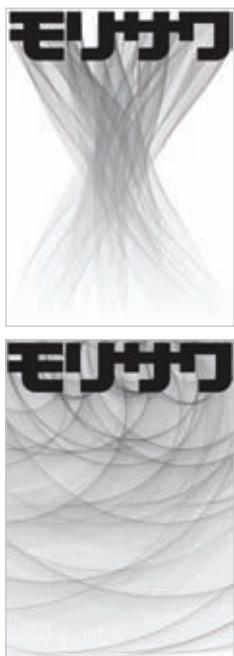


Emigre and FUSE, to the radical work of April Greiman, David Carson, and many others.

With PostScript solidifying its place as the de facto standard, Adobe introduced Illustrator as its new visual development tool. With Illustrator, anyone could draw and lay out text and graphics without having to know the intricacies of the PostScript language. Eventually Illustrator, along with Adobe's Photoshop and InDesign applications, became nearly ubiquitous among graphic designers. Interestingly, all three of these applications have introduced scripting languages in recent years that allow users to extend the tools by writing code.

Following the birth of the Internet and other networking technologies, the computer increasingly became a tool for collaboration. Global computer networks called into question the need for centralized offices, in favor of an organization consisting of individuals spread around the globe. This has had a massive impact on the open-source software movement, where large and sophisticated applications are often built by a loose collection of individuals united by a shared interest. These new ways of working also had an impact on the way forms were created. In a distributed environment, different individuals work simultaneously on different parts of the same piece, seeing the whole only after the parts are stitched back together.

Having begun to represent objects and, with the aid of Sketchpad, relationships and behaviors, the real potential for the role of computers in design started to assert itself. If computers could be used to model what we know, then perhaps we could also use them to simulate what we don't know. French architect and philosopher Bernard Cache summed up the history of CAD systems by saying they "have certainly increased the productivity of the idea, but fundamentally they offer no advances over the work done by hand. Now, we can envisage second-generation systems in which objects are no longer designed but calculated."⁴



⁴ Bernard Cache, *Earth Moves: The Furnishing of Territories (Writing Architecture)* (Cambridge, MA: MIT Press, 1995), 88.

Morisawa Posters,
by John Maeda, 1996
Rather than rely on
existing software
tools, Maeda wrote his
own code to manipulate
typographic form. This

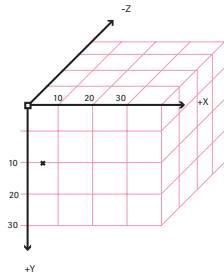
allowed him to explore a unique graphic language for the ten posters he created for Morisawa. Each poster performs an algorithm to transform the logo of the company.



Electronic Abstraction 6, Starting in the early
by Ben F. Laposky, 1952 1950s, he refined a
Laposky used an oscillo- process of modulating
scope—a technical device electronic waveforms
for viewing changes in to produce stunning and
voltage—to produce his diverse images.
abstract images.

CONTROLLING FORM

Understanding the ways that code is used in the production and creation of form requires a general knowledge of how form is manipulated by the computer. Outside the computer, form itself is physical and intuitive—it is the curve of a line on a page, the texture of paint, or the slope of a hillside. To manipulate form in the world, we don't need to understand the mathematics behind how things are put together, and we can specify where things are in relative terms, like "over there" or "next to me." If a piece of clay is close enough to touch, then it can be directly molded and shaped. In contrast, computers rely on the ability to specify everything in numerical terms.



COORDINATES

The computer needs to know the position of every mark it draws, either on the screen or with a printer. To do this, we typically use Cartesian coordinates. If you imagine laying a large piece of graph paper over the screen, an x-axis runs from left to right, and a y-axis goes from top to bottom. These axes allow us to specify a precise position on the grid using a pair of numbers, normally the x-value followed by the y-value. For example, a point at (5, 10) is 5 lines from the left edge of the screen, and 10 lines down from the top.

SHAPE

Placing a piece of graph paper on the screen is more than just a metaphor. The screen is, in fact, composed of a grid of points called pixels. One way to draw a form on-screen is to lay the grid of pixels over an image of the form and measure the color value at each pixel in the grid. This method of representing an image makes what is called a raster image.

A raster image, which is sometimes referred to as a bitmap, is a complete description of what is shown on-screen at a given resolution. Resolution refers to how many points make up an image for a given physical size. If an image has a resolution of 800×600 pixels, there is a total of 480,000



Coordinates

Most computer graphics use a square grid with a horizontal x-axis and a vertical y-axis. An additional x-axis is used to draw 3-D forms.

Raster

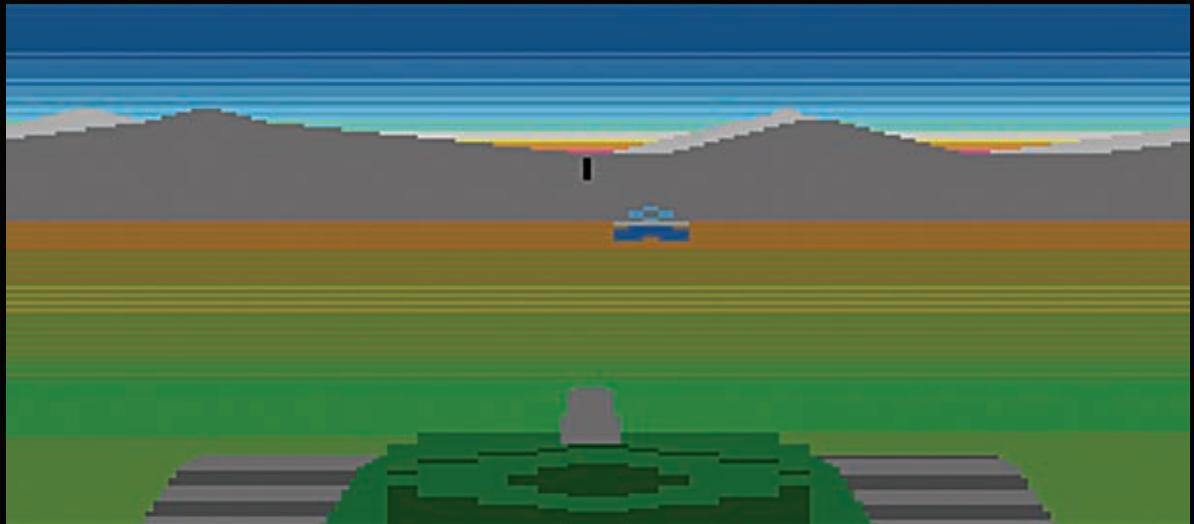
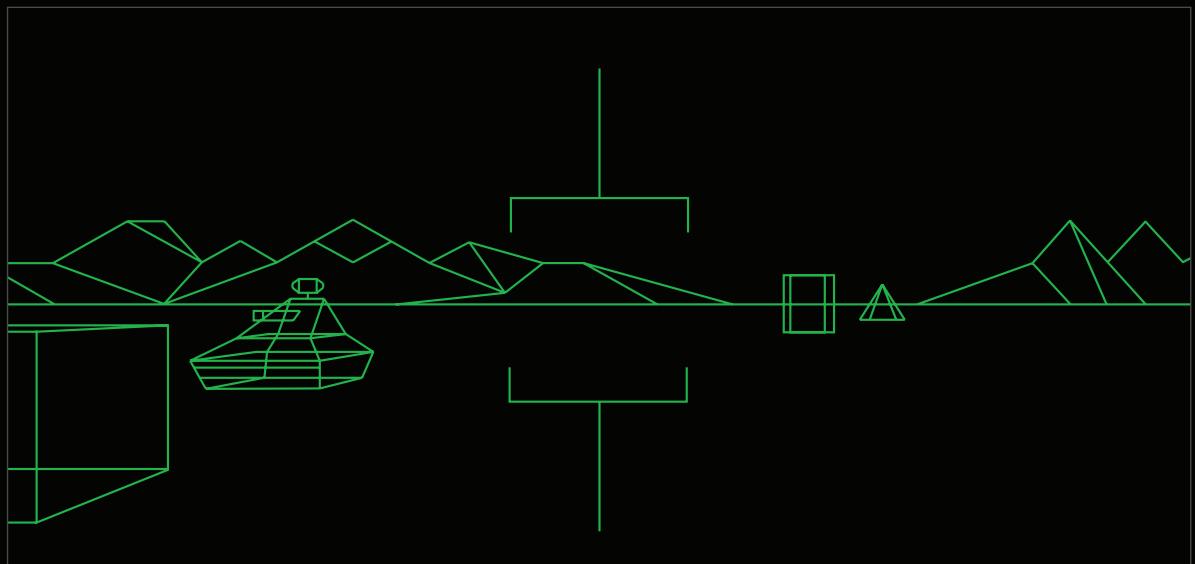
A raster is a grid of pixels. The color of each pixel is controlled to create an image.

pixels in the image, therefore requiring 480,000 numbers, with each one representing the color of one pixel. Resolution can be thought of as an image composed of tiles. There are two ways to make a tiled image look better: make the tiles smaller or move farther away from the image. On a computer, the two are related. Since the screen has a set size, lowering the resolution is like increasing the size of the tiles; alternately, you can keep the screen resolution constant and make the image smaller on-screen.

As explained earlier, an image's form, color, and shape must be converted to numbers in order for it to be useable on a computer. As a result, these qualities often lose the continuity that we have become accustomed to in the world. Every image on the computer has a resolution, or a width-by-height measurement, in pixels, but how many pixels are enough? The ever-increasing number of megapixels available in digital cameras and the popularity of high-definition television (HDTV) suggest that there are never enough.

A megapixel is one million pixels. It refers to the total number of pixels in an image. In other words, the width of the image in pixels is multiplied by the height of the image in pixels so that an image measuring 2,048 by 1,536 is said to have 3.1 megapixels ($2,048 \times 1,536 = 3,145,728$). Our eyes see a continuous analog stream of colors. The best we can do to represent that digitally is to increase the resolution to fool the eye into thinking that the image is continuous. But the fact remains that this is just a simulation, and it requires a lot of processing and memory to store enough information for the illusion to hold.

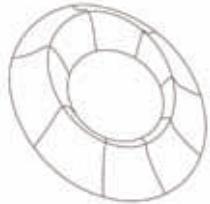
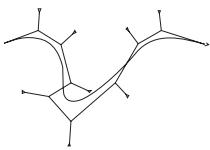
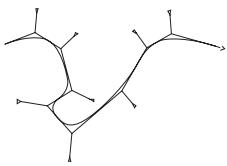
Raster graphics are an ideal way to store and manipulate photographic imagery, but they suffer from the confines of the resolution at which they are created. If we scale a bitmap image up to make it larger, the blocks of color must also be enlarged. This makes raster graphics a less than ideal way



BattleZone,
Atari, 1980 and 1983
The graphics in
the arcade version
of BattleZone were
drawn with vector

lines on an oscillo-
scope. The Atari
2600 home version of
BattleZone used raster
graphics, because it
was displayed on a

television set. It was
more colorful, but the
graphics were lower in
resolution.



to store drafting or drawing information that often needs to be moved, scaled, rotated, and reworked. For this, there are vector graphics.

Vectors graphics use the same Cartesian grid as bitmaps, but instead of storing the value for every pixel in the image, they store a list of equations that define the image. This is ideal for drafting and precision drawing, where any shape available to geometry—lines, circles, rectangles, and curves—can be combined to create a composition. Because the forms are described using geometric equations, they can be scaled and transformed easily and without losing detail. The scalable nature of vector graphics makes them an essential element in the production of printed matter. A printer may have a resolution many times greater than that of a monitor, and without vector graphics it would be very difficult to create smooth lines and crisp type. Furthermore, fabrication technologies, such as laser cutting and computer numerical controlled (CNC) milling rely on the detail and precision offered by vectors.

Objects in three-dimensional modeling software, such as Rhinoceros and Autodesk Maya, are commonly represented using vectors. In addition to the two-dimensional curves, points, and lines we are familiar with, these applications allow designers to create a number of different objects, such as meshes, NURBS (Non-Uniform Rational B-Splines), and subdivision surfaces.

COLOR

Unlike paint, color on-screen is additive, meaning that the more colors you add together, the closer you get to white. Additive color systems use the primary colors red, green, and blue to create the colors we see on-screen. The common 24-bit color depth allows each base color to be assigned a value from 0 to 255, giving a total of 16,777,216 possible colors—that's more than can be distinguished by the naked eye. For example, pure yellow has a red value of 255, a green value of 255, and a blue value of 0.

Light brown has a red value of 140, a green value of 98, and a blue value of 0. Changing this blue value to 255 produces an electric purple.

REALISM

Like the history of European painting until the end of the nineteenth century, the history of computer graphics has prioritized a realistic depiction of the natural world. The bridge between the crude wireframe engineering models produced in the 1960s and the naturalistic form, lighting, and textures of today's rendering tools has spanned over thirty years of focused research. (This transition can be traced, in part, using the dates of the work included in this book.) One of the first effects mastered was the illusion of a third dimension rendered on a flat screen. After that came the hidden-surface algorithm for hiding the lines at the back of a model and making it appear solid rather than composed of wire. Similar to how shading in a pencil drawing helps produce depth and continuity, shading algorithms were developed to create the appearance of smooth surfaces from the hard edges of flat polygon models. Over time, new and better techniques were developed to accurately depict textures and, more importantly, light reflecting off surfaces. Beyond these algorithms, a mathematical model of a camera is at the core of most rendered software images. The parameters of these models imitate those of real lenses, such as focal length, field of view, and aperture. When the image is rendered, the calculated lens optics determines how near or distant the objects appear and distorts the geometry to create perspective. The development of ever-more-realistic rendering techniques continues, but in recent years there's been a renewed interest in non-photorealistic rendering. These techniques make geometric models look as if they were painted or built from clay.

Splines

A spline is a type of curve, with a shape defined by the position of control vertices. Splines have a dimensionality that affects

how close the curve fits to each vertex.

Advanced Geometry
Surfaces can be mathematically defined in a number of different ways. A triangle mesh is a set of connected triangles; NURBS are

smooth surfaces created with splines; and subdivision surfaces use recursion to make a fine mesh to represent curvature.

Toward realism

The history of algorithms in computer graphics follows a path toward realism, from coarse outlines to smooth, solid surfaces.

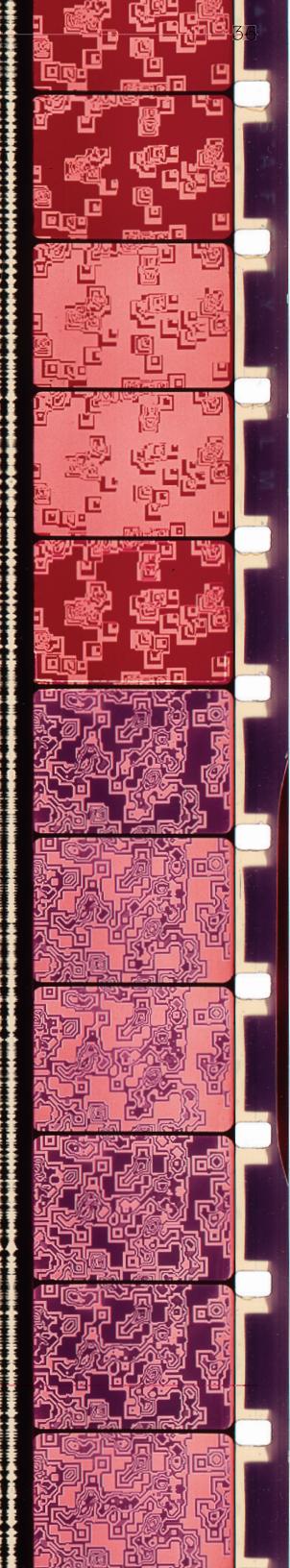


Entramado,
by Pablo Valbuena, 2008
Valbuena combines
virtual 3-D models
with precisely placed
projectors to augment
physical space with

a closely choreographed sequence of light, which appears to follow and modify the space itself.

Pixillation,
by Lillian Schwartz,
1970
Schwartz worked with
Ken Knowlton at Bell
Labs to produce the
computer-generated

sequences of this abstract film.

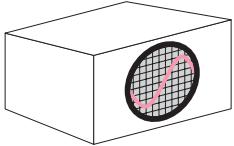


PRODUCING FORM

An important aspect of the relationship between form and code is how the abstract, immaterial, and imperceptible world of code comes into contact with our senses. Understanding how color is represented is a part of this relationship, but there are other processes by which the numerical representation of form can be transformed into something that we can perceive, such as light, pigment, or material structure.

LIGHT

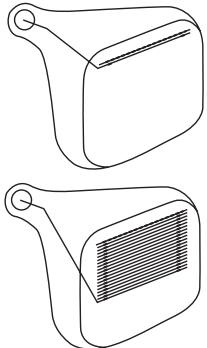
Long before the ubiquity of full-color displays, the oscilloscope served as the primary device for real-time visual output from the computer. Despite its low-quality monochrome image, systems like Sketchpad and early video games made excellent use of this device.



The full-color cathode ray tube (CRT) in the form of the television was targeted as the primary display device for early home video game systems, such as ColecoVision and the Atari 2600. The CRT consists of an electron gun and fluorescent screen enclosed in a vacuum tube. The gun fires electrons at the screen in a left-to-right, top-to-bottom pattern. When the electrons strike the screen, the fluorescent material glows. As a result of this process, the images on CRT screens have a very distinctive appearance.

The invention of the framebuffer was crucial to the widespread use of the full-color CRT, and to computer graphics as a whole, opening the door for digital painting programs, photo manipulation, and texturing. First developed at Xerox Palo Alto Research Center (now called PARC Inc.) in 1972, the framebuffer stored the entire contents of the screen in memory. Prior to this, only vector graphics could be drawn on-screen, because it was impossible to manage the amount of memory necessary to work with rasterized images.

Increasingly, the most common computer displays in use today are liquid crystal displays (LCD). LCDs have numerous advantages over the CRT. They use less power and



Oscilloscope
Oscilloscopes use voltages to control the movement of an electron beam. The movement from left to right is sometimes fixed to a clock,

while the movement up and down is controlled by an electrical signal. This setup makes it easy to visualize regular signals like sine waves.

Cathode ray tube (CRT)
Electrons are fired through a vacuum tube at a phosphorescent screen, causing it to glow on impact. In raster displays, the

are smaller, which makes them ideal for mobile computing. They can also update their image faster to provide a more vivid experience. Because LCDs can be made in a range of sizes, from the handheld to a large television, they can be used to create both intimate and public experiences. In addition, they can be modified to make touch screens and to provide physical feedback.

Modern digital projectors allow content to be seen by a large group of people at once. Beyond this basic use, projectors offer a way to immerse the viewer in imagery, augment a physical space, or create nonstandard display shapes such as circles. The front-projection setup, where the image is projected onto the front side of a screen, is the most common. A rear-projection setup, with the image projected onto the back of a semitransparent screen, is a good way to allow viewers to approach the image without worrying about casting shadows or otherwise interfering with the image.

Appearing in everything from key chains to coffee makers to animated billboards; light-emitting diodes (LEDs) are a staple of contemporary everyday life. An LED is an electronic component that creates light when a current is applied to it. Compared to traditional means of generating light, LEDs are far more energy efficient and last longer. In the context of form making, they are interesting for their highly variable appearance and small size. It is possible to create displays of nearly any size or shape by piecing a large number of LEDs together. In this way, each LED can act as a pixel in a raster display. These custom displays are then controlled using hardware and software that make them behave like traditional screens.



Volume,
by United Visual
Artists, 2006
This light and sound
sculpture is composed
of a series of custom-

designed LED columns
that respond to the
motion of viewers.

Hylozoic Grove,
by Philip Beesley, 2008
Beesley used a laser
cutter to create two
different types of form
for this sculpture.

The structure and
mechanisms were cut
from rigid plastics;
while light, flexible
plastics were used to

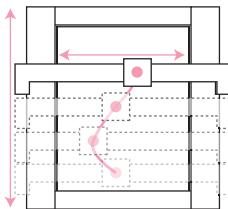
create the delicate
featherlike elements.

PRINTING

In the early days of computer graphics, images were printed on paper using a plotter in order to make the details, which appeared vague on the extremely limited displays, appear clear. A plotter is a machine that moves a pen over a drawing surface. The pen is given commands to control the direction and speed of movement, making it possible to vary the quality of the lines. By changing the material of the drawing surface or swapping the pen for a pencil, brush, or other drawing instrument, many interesting results have been created.

In the mid-1980s, the first laser printers designed for home use began to appear. Laser printers use a combination of electric charge and focused light to fuse toner to paper. This technique allows them to print 300 dots per inch (dpi), which is considerably higher than the 72 dpi available with the common dot matrix printer.

Though laser printers excel at printing on paper, the invention of the inkjet printer expanded the range of possible mediums and inks available. The basic spray-nozzle design of the inkjet is so flexible that it is now possible to print on diverse types of paper, plastic, and fabric. Even entire circuit boards can be “printed” using conductive ink.



FABRICATION

Fabrication is a catchall term used to describe a host of new technologies that are capable of producing physical objects out of digital representations. In a far more drastic way than printers and screens, various fabrication techniques are used for vastly different purposes and require new ways of thinking about code, space, and structure. The most common and straightforward fabrication tool is the laser cutter, which is mechanically similar to a plotter, except that a laser, rather than a pen, is positioned on an arm that can move in two dimensions. The computer moves the laser along the x- and y-axis of the bed to cut the material. Often, laser cutters have restrictions on the size, thickness, and



Plotter

Plotters work by moving a drawing implement, typically a pen or brush, over a surface to control its horizontal

and vertical positions with two motors. A similar mechanism is used in laser cutters and CNC-milling machines.

Cirrus 2008,
by Zaha Hadid
Architects, 2008
This sculptural seat,
built by Associated
Fabrication, is made

type of material that can be cut. In addition to movement in two directions, the power of the laser cutter can be adjusted to etch metal and create intricate burn patterns on wood. Though laser cutters are limited to working in two dimensions, many architects, designers, and sculptors have found inventive ways to cut sections (similar to topographic maps) that are then reassembled to create intricate 3-D objects.

CNC milling, Selective Laser Sintering (SLS), stereolithography, and 3-D printing are just a few of the ways to create fully three-dimensional objects; that is, objects whose representations on the computer screen include information for x, y, and z axes, which are used to control the output device. A CNC-milling machine is similar to a plotter or laser cutter, but with the added flexibility of a continuous up-and-down motion. For example, a router bit is moved over a block of material, and as the bit moves, it cuts away a small amount of material, leaving behind a sculpted surface. In a three-axis machine, the router bit can only move directly up-and-down, making it difficult to sculpt objects from all sides. Some machines mount the block of material on a lathe, which rotates the surface facing the bit in order to provide additional flexibility.

CNC milling is a subtractive process; that is, material is cut away from a larger block in order to create the object. In contrast, SLS, 3-D printing, and stereolithography are additive processes that build up the final object by adding or fusing material together. Additive techniques have the distinct advantage of being able to create hollow spaces, undercuts, and overhangs, which are difficult to do using a three-axis CNC machine.

In a 3-D printer, a model is created by layering and fusing successive cross sections of material. Layers of powdered material, such as plaster, resin, or even cornstarch or sugars, are deposited and then selectively fused together by

of milled sheets of
Formica and medium
density fiberboard.



“printing” an adhesive from an ink-jet-like printer head. After the model is complete, it is excavated from the excess powder, which is then recycled for the next model. Stereolithography and SLS both employ variations of this additive technique. In stereolithography, thin layers of a photopolymer resin are deposited and then cured with an ultraviolet laser to harden the areas where it is focused. Once all of the layers are complete, the remaining liquid is drained and the model undergoes additional curing in ultraviolet light. SLS combines ideas from both 3-D printing and stereolithography. Thin layers of powder are deposited and then fused together using a laser to build the model layer by layer. A distinct advantage of SLS is the wide variety of materials that can be used, including nylon, ceramics, plastic, and metals, making it possible to quickly create prototypes of working machine parts.

Ecorché structurel,
by R&Sie(n)+D, 2008
R&Sie(n)+D imagine pos-
sible future worlds and
ways of living. This SLS
3-D-printed model

is described by its crea-
tors as, “The cells were
no longer enclosures to
protect from the out-
side...[but]‘habitable
networks, woven space,’
an exfoliation of con-
stantly reconfigured
habitable organisms.”