IMAGE OBJECTS

An Archaeology of Computer Graphics

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Figure [illegible]
Ivan Sutherland's students mark and measure Marsha Sutherland's VW Beetle for digitization, 1972. Courtesy of the Special Collections Department, J. Willard Marriott Library, University of Utah.

Introduction

> In order to be in a relation with the world informatically, one must erase the world, subjecting it to various forms of manipulation, preemption, modeling, and synthetic transformation. . . . The promise is not one of revealing something as it is, but in simulating a thing so effectively that "what it is" becomes less and less necessary to speak about, not because it is gone for good, but because we have perfected a language *for* it.
>
> —Alexander Galloway, *The Interface Effect*

> Doing with images makes symbols.
>
> —Alan Kay, *Doing with Images Makes Symbols*

In the fall of 1972, Marsha Sutherland spent several weeks driving around Salt Lake City in a Volkswagen Beetle half covered in a polygon mesh. The car was a spectacle, its green exterior dotted with hundreds of numbered vertices connected to form a grid of irregular squares (figure 0.1 and plate 1).[1] Marsha had moved to Salt Lake from Cambridge, Massachusetts, just four years prior with her husband, Ivan, who left Harvard University in 1968 for a tenured position in the computer science program at the University of Utah. Each week Marsha would drive up the foothills of the Salt Lake Valley to the Merrill Engineering Building, where Ivan's students would carefully mark and measure the car for digitization. Along the way she would traverse a grid of a different sort: the lockstep raster of city blocks that make up the Plat of Zion, the plan for a city of God first devised by Joseph Smith in 1833, and dug out of the valley floor by Brigham Young and his followers with the colonial settlement of Salt Lake City in 1847.[2] By the end of the year, Marsha's Beetle would become the first real-world object to be fully scanned and rendered by a computer—the physical made digital (figure 0.2).[3]

Figure 0.2
Digitized Volkswagen Beetle rendered in wireframe, flat shading, and smooth shading at the University of Utah computer graphics lab, 1973. Courtesy of the Computer History Museum and the University of Utah School of Computing.

A surprising object in an unlikely place, Marsha's Volkswagen straddles two worlds. A global symbol of 1960s' counterculture, the Beetle was near ubiquitous at the start of the 1970s. Earlier that year, in February 1972, the Beetle surpassed the Ford Model T to become the most widely manufactured vehicle ever produced, its design largely unchanged since 1938.[4] It was this iconic status that drew Ivan's students to it and made it legible as an object for simulation in the first place.[5] Yet this particular Beetle marks the beginning of a radical transformation in the shape of our lived environment—a turning point in which the physical world becomes saturated with digital objects. Think, for a moment, of the building in which you now sit, the phone in your pocket, the book you now read; each of these objects have been materially shaped by a process that can be traced to Marsha, winding her way up the hills outside Salt Lake City half a century ago. Each of these objects have, over the course of their design and creation, been touched and transformed by computer graphics.

This may be surprising to anyone accustomed to thinking of graphics exclusively as visual images produced, augmented, or transformed by computation. Likewise, for most of us computer graphics are a relatively recent invention, emerging at the end of the twentieth century as spectacular visual effects and lifelike simulations in film, television, and digital games. In fact, computer graphics are as old as the modern computer itself, and their development marks a fundamental transformation not only in the way we make images, but in the way we mediate our world through the computer, and in turn come to reimagine the world as computational. We live in a world that has been structured by the visual regime of computer graphics. Whether captured with a digital camera, designed and rendered using 3D interactive software, or simply displayed on the pixelated grid of a computer screen, almost all images we view, make, and interact with on a daily basis are shaped by computation. Yet computer graphics have largely disappeared as a legible object of analysis, and the history of computer graphics remains almost entirely unwritten.[6]

This is due in part to the phenomenal invisibility of computer graphics as a distinct technical medium. Most computational images we encounter are designed to simulate and reproduce the formal and aesthetic norms of those media that precede them, be it the photo-realistic renders of special effects and digital games, or the skeuomorphic interfaces of our laptops and smartphones. Consequently the more advanced computer graphics become, the less visible they appear to be and the less we remark on their ubiquity.[7] When graphics do register as objects for critique, they are almost always framed by discourses of realism and mimesis, or broad narratives of technological development that lead inevitably toward verisimilitude.[8] Computer graphics are perhaps the only medium that is analyzed exclusively in terms of the ways it successfully produces its own invisibility. We might value and remark on the photographic, televisual, or cinematic quality of a media text, but if an image reads as computer graphics, it has failed its simulation. This is because unlike those media that claim an indexical relationship to the world they represent, the thing reproduced by computer graphics is not the world but another medium in simulation. Computer graphics are thus always already mediated, and the goal of nearly all graphical research is the accurate reproduction of the effects of this prior mediation. This mimetic quality has precluded an examination of computer graphics that takes seriously its historical emergence as a distinctly computational technology untethered from the long history of visual representation. Likewise, it has limited our engagement with computer graphics to only their most visible manifestations: as images on screens.

This book begins with the premise that computer graphics are much more than the images we see. They are one of the principal technologies of our historical present, and have reshaped the way we understand, relate with, and engage the material world today. To understand this transformation will require a material and local history of computer graphics as it developed alongside the modern computer in the second half of the twentieth century. Taking up this task, *Image Objects* traces the history of computer graphics in the thirty years prior to the technology's emergence in popular visual culture. In this it offers two interrelated stories.

First this is a history of the computational image, and those technologies that made possible its appearance on the experimental screens of academic and commercial research centers some sixty years ago. Refusing popular narratives of convergence and remediation, I argue that computer graphics is a unique medium distinct from those earlier visual forms it seeks to simulate. To understand and make visible the material specificity of computer graphics, I pull apart the rendered image and identify its constitutive parts: those historical objects that make up the material history of graphical simulation, and through which we might posit a theory of graphical computing. To this end, I ask not simply how computer graphics developed over the second data according to predetermined procedures. Computing was an explicitly noninteractive process; its inputs and outputs were punch cards and paper, and its objects were logic and numbers. Computer graphics was first developed as a means of abstracting computational processes toward human readable modes of interaction—that is, of bringing the material logic of the sensible world to bear on the informatic logic of computational systems. Through computer graphics the image world was operationalized, made to compute and perform actions, to take up and simulate space. The development of computer graphics in this sense marks a reorientation of computer science toward the object world such that it could be made subject to computational forms of simulation, transforming the computer from a *tool* for procedural calculation into a *medium* structured by a distinct ontological claim. Over the past fifty years, this claim has become one of the dominant modes of engaging with and thinking through all manner of processes, such that our contemporary world is now populated by a vast number of objects shaped by their encounter with graphical systems—that is, *image objects*.

The image object here marks a theory and method for engaging the transformation of the visible world under computation. It insists first that digital images are materially structured by those historical objects that produce them—objects that have been rendered out of the visible image, but that fundamentally shape the function and appearance of computer graphics as a distinctly computational technology. From microprocessors and graphics libraries to software suites and shading algorithms, computer graphics contain a vast number of objects whose material histories are erased if we restrict our analysis to the rendered image alone. At the same time, the image object affirms the broad influence of computer images on the shape and function of the material world today, describing the historical process whereby a vast number of material objects have been taken up by computer graphics and made subject to the logic of the digital image. Over the course of this history we will find countless objects taken up and transformed in this way. From the shape of contemporary architecture and built environments, the aesthetics of digital printing and desktop publishing, the interfaces we use to engage and communicate with our world, industrial design and rapid manufacturing, the structure of cars, planes, and other vehicles, and even the design of chips, circuits, and computer hardware itself—all are mediated and informed by this dual logic: at once visual and material, representation and calculation, both image and object.

It can be difficult to see the influence of computer graphics on our lived environment. The processes that define and articulate this relationship are so diffuse that they too often appear ordinary, naturalized, and mundane, and therefore are rarely remarked on or analyzed. In order to make visible the function of computer graphics today, we must return to those early moments in the history of the technology when the gap between the physical world and its simulation is most clearly felt, when the theory of the world articulated by computer graphics was still in formation. For over two months Marsha Sutherland's Volkswagen occupied this space between worlds: an object in practice and an image in the making; one foot in the digital and another in Salt Lake; neither image nor object, but an image object trapped in an extended moment of becoming.[14] With a few clicks of my mouse, I can drop Marsha's Beetle into any modern graphical simulation, draping it in the newest texture and lighting algorithms, modeling its behavior as part of an interactive environment made from thousands of objects structured by this same logic (figure 0.3). Today the aerodynamic curve of all motor vehicles is the product of this transformation, a spline

Figure 0.3
A contemporary VW Beetle simulation in Autodesk Maya. Note the visualization of the software's node architecture on the left, in which each of the elements that make up the rendered image (texture, lighting, geometry, etc.) are displayed as a nested structure of objects. Altered. Image by the author.

function driving around Salt Lake City, materially connected to that first digital object rendered out from Marsha's Volkswagen some fifty years ago. Ultimately this book is an effort to develop a language to speak to this quality of the world we now occupy. In doing so, we will find that computational images are not pictures of the things they represent; they are pictures of the world that produced them, and they execute a theory of that world in the world.

Visible Outputs

For over thirty years, computer graphics have been synonymous with illusion and artifice. Their appearance at the end of the twentieth century marked a crisis of visibility whereby the world was refigured as an image severed from the materiality of the thing it represents. Popular accounts of this transformation were commonplace in the enthusiasm surrounding new media technologies in the 1990s, a period often characterized by theories of the postmodern and the new, the supposed dissolution of the material into the virtual, and the rise of simulation across all facets of contemporary culture. This was also the period in which computer graphics first entered the realm of popular entertainment on a large scale, with the release of the first feature-length computer-animated film, broad success of Hollywood blockbusters that prominently featured computer-generated effects, and development of the first interactive 3D gaming consoles.[15] Along with the internet, computer graphics were one of the quintessential "new media" technologies of the decade. Just as scholars and critics touted the revolutionary power of the web, distributed networks, hypertext, and cyberspace, so too did they envision a future in which computer graphics would dominate our visual field, transforming our relationship to reality itself. As science fiction author Bruce Sterling exclaimed at the start of the decade, "The seams between reality and virtuality will be repeatedly and deliberately blurred. Ontology be damned!"[16]

Yet in many ways this moment was more aberration than innovation: a dramatic flourish of visibility that seemed to erupt fully formed before receding almost as quickly as it came. While today the internet continues to be viewed as one of the most important and pervasive technologies of our current media landscape, computer graphics seem an almost improper object whose vision of total simulation appears naive at best. Instead, the past twenty years of media theory have seen a pronounced shift away from these immaterial preoccupations and toward the materiality of digital media as historically instantiated technical objects. New media, we are reminded, are not as new as they appear to be and have much in common with those older media forms they were said to replace.[17] If there *is* a radical transformation to be found at the heart of digital technologies, it lies in the procedural, algorithmic logic of computation itself, and not in the ways that computation is made meaningful to us through visualization. This materialist turn offers a valuable corrective to over a decade of enthusiastic writing on the transformative effect of the simulated image and of reading the rendered output of our machines with little regard for the means by which such images are made possible.[18] While the digital image was once thought to reveal the always already virtual nature of representation itself, under the material turn such images would seem to hide the truth of those technologies that ground all digital media, such that if we hope to understand the true function of our computers, we must look to the software, platforms, and code that structure them.[19]

This distinction implies a broadly hermeneutic critique whereby the machine conceals its function beneath the veneer of the digital image and its simulation, such that we are compelled to open the black box and look beyond mere representation.[20] Taken to the extreme, this formulation suggests that we have not simply misrecognized our true object of analysis, but have fallen victim to the illusory and seductive quality of digital images, which hide not only their material function as technical objects but likewise their role within the broader social and political circuits of computation. To imagine computational media as virtual or ephemeral erases the physical and affective labor required to build, maintain, and dismantle technical systems; their potentially catastrophic effects on the environment, human, and nonhuman life; and their political function in the lives of their users, the culture of their designers, and the shape of our societies.[21] As media scholar Tara McPherson has warned, "Our screens are cover stories, disguising deeply divided forms of both machine and human labor. We focus exclusively on them increasingly to our peril."[22]

Yet this wholesale refusal of the screen image produces its own restrictions. Despite this turn toward the mechanical interiority of technical things, our engagement with computing remains highly visual and deeply tied to the logic of simulation. It is true that our screens are not transparent windows that lay bare the act of computing itself, but they are likewise not somehow outside that act, and play a principal role in shaping our understanding of and relationship to computational technologies. Yet in our rush to correct the visual bias of digital media studies, we have largely neglected the screen image as a material object in its own right—one with a heterogeneous history that runs parallel with that of textual or purely mathematical forms of computation. Rather than dismiss the visual as mere interface for deeper material processes, we might extend this materialist critique to include the simulated image, unpacking the means by which these images are modeled and displayed. Reading the digital image in this way—as an object structured by a set of distinct material practices—allows us to move beyond discourses of immateriality and virtuality to a theory of the digital image that is not visible in the rendered output of the screen. In doing so, we will find that computer graphics are one of the foundational technologies of our modern computational culture, and that they played a central role in the development of computing over the past seventy years.

To begin, we must unlearn the way we look at computational images. It does not seem controversial to suggest that our visual and material landscape has been fundamentally transformed by computation, yet this quality often cannot be deduced simply by looking.[23] Popular discourses of realism and fidelity dominate our analyses of digital image technologies, but are derived from an uncritical appropriation of those formal qualities that have historically defined prior modes of image making. As countless scholars have argued, digital images do not hold an indexical relationship to the world they represent, such that to analyze them exclusively in terms of their ability to reproduce the aesthetics of film and photography is to willfully occlude the means by which they are produced. This does not mean we must ignore the visual altogether. Rather, we must attend to the Janus-faced nature of digital images, which are shaped not by the etching of light but by the articulation of a set of computational objects developed to enact this simulation. Computer graphics exist simultaneously as both an assemblage of technical objects and an image that has been rendered out from them. To examine computational images in isolation from these objects is to mistake the render for the thing itself, and be drawn into an uncritical and ahistorical relationship that makes one culpable in the forms of material erasure so widely critiqued by media scholars today. If we wish to understand the function of these images, we must examine those objects

Figure 0.5
Frame capture from IBM's short film "Freeing Man's Mind to Shape the Future" (1960), showing the graphical terminal of the Semi-Automatic Ground Environment air defense system.

could track two-dimensional representations of airplanes as they moved across a screen overlaid with a map of the part of the country under the defense of a given station (figure 0.5). When an operator identified a potential threat, the system would calculate an intercept path for fighter pilots or surface-to-air missiles before a decision was made whether or not to destroy the target.[30]

While SAGE was one of the earliest applications of large-scale interactive computer graphics, the image of the world that it articulates is fundamentally different than the one pictured by Fetter some ten years later. For SAGE, an enemy airplane is a blip on a screen, a target meant to be identified, part of a global system to be commanded (figure 0.6). Its visuality is two-dimensional and cartographic; its images functioned as symbols designed to elicit a response from a technical operator.[31] The SAGE system was a product of the Cold War environment that produced it, and articulated a

Figure 0.6
Diagram of the SAGE system as a complex sociotechnical apparatus. MITRE Corporate Records and Archives, SAGE collection, M0-139.

theory of that world as a system to be directed and controlled—a vision that would have long-standing repercussions for the development of communication technologies over the subsequent seventy years.[32] Fetter's airplanes are quite different. Here the plane forms the ground of a relational environment in which a human operator is situated (figure 0.7). This plane is not symbolic but rather mimetic, used to model or simulate a three-dimensional space comprised of a discrete set of interactive objects that includes this human figure, this First Man. The figure serves a standardizing function, its size and shape derived from what is called a 50 percentile figure, built to approximate the average size of 50 percent of air force pilots.[33] The shape of this model thus forms the basis for the design of a technical system—the 747 cockpit—and the assumption that its pilots' bodies will not vary widely from this presumptive norm.[34] In standardizing its human model and designing for that standardization, Boeing Man is shaped by a particular image of the world, and in turn comes to refigure the world

Figure 0.7
Fetter's Boeing Man as an interactive object within a simulated environment, 1964. Courtesy of the Boeing Company.

according to that image—a fact made evident in the thousands of Boeing 747 airplanes in operation today.[35] Understood this way, Fetter's image is a model for the primitive simulation of a physical object, designed to approximate and standardize the complexity of real-world interaction. It is as much a theory of the world as it is an image of it, and in the subsequent decades that theory would be made actionable.

In the ten years that separate these two moments, we find a pronounced transformation, and along with it a change in how computer graphics were understood to relate to the world that grounds them.[36] While the SAGE system treated graphics as *images* that visually represent numerical data to its operators, Fetter used graphics as a medium for the simulation of graphical *objects*. This is a subtle but deeply meaningful distinction, and one that is lost when we treat the history of computer graphics exclusively as a history of images produced through computational calculation.[37] It is a logic that emerges alongside computer graphics, growing to become altogether diffuse across the field of computer science as it begins to take up graphical systems and develop novel uses for computational images. As early as 1961, Ivan Sutherland was using object-oriented structures in the development of his widely influential Sketchpad program for computer-aided design

(CAD). Likewise, Steven Russel's *Spacewar!* (1962)—considered by many to be the first graphical, interactive digital game—was designed using object-oriented principles in this same period.[38] One of the earliest modern graphical user interfaces, developed from 1972 to 1979 at Xerox for use with the Alto computing system, was predicated on the object-oriented structure of the Smalltalk programming language to such an extent that the language is inextricably tied to its interface and requires it in order to function.[39] While each of these object forms cannot be made commensurate, as they do not all adhere to a single, fixed theory of object relation, they are nonetheless exemplary of a broad transformation in which object simulation becomes a principal structuring logic for computational systems.

In this way, the act of computing is refigured from a set of procedural calculations into an interactive environment, understood as a spatially embodied field of discrete computable objects. In short, computing is transformed from a *process* into a *medium*.[40] Today this object logic has grown into one of the dominant forms of our contemporary media environment, transforming the ways we model and represent the world, and in turn reorienting our understanding of that world as a structure of computable objects.[41] In exploring the transformation of computer science and its adoption of object simulation across a range of technical practices, this book proposes that to understand this reorientation, we must look to those sites from which it emerged, both as a moment in the history of computing and as an articulation of a distinct culture of practice.

Other Places

Just off the main campus of the University of Utah sits Fort Douglas, a military garrison founded in 1862 to protect the overland mail route and telegraph lines running from Salt Lake City to San Francisco. The site was strategically chosen in the foothills of the Salt Lake Valley, as the US military was concerned with secessionist activity in the area and wanted to keep an eye on the territory's Mormon population.[42] For nearly a century, the fort played a strategic role in the economic, social, and political stability of the region, but by the mid-1960s, much of the land had been transferred to the ownership of the university, and its buildings were frequently delegated for research projects run by Utah faculty and staff. It was in this context that in late 1968, an abandoned bunker in this former military garrison was transformed into the home of one of the first commercial computer graphics firms in the United States (plate 2), known as the Evans and Sutherland Computer Corporation (E&S). In many ways the site exemplifies this early period in the development of computer graphics, with its proximity to military resources and isolation from the larger field of computer science. As is likely apparent, this was no place to start a computer hardware company, and for the first year researchers struggled to keep out dirt and drafts while working to maintain a stable electric grid. Yet this site marks the beginning of this strange history, if not the beginning of the computer graphics industry itself.

The 1960s were a transformative period in the history of computing. At the start of the decade, computation was still an expensive and highly limited resource, enabled by massive mainframes shared by dozens of researchers working asynchronously. Computing was a fundamentally noninteractive process: tasks needed to be programmed in advance onto physical media that could be submitted to a computer operator for calculation, and researchers would have to wait hours or even days for their calculations to be processed. These were industrial machines used for processing numerical data—more calculator than computer in any modern sense. Over the course of the decade this began to change, due in large part to the development of key technologies designed to interface human and machine.

The motivation for this shift was both technical and institutional, and involved the coordination of public funding with large-scale research initiatives driven by a strong vision for what the future of computing could be. In the United States, the principal player in this transformation was the Department of Defense and its Information Processing Techniques Office (IPTO), founded in 1962 and housed within the Advanced Research Projects Agency (ARPA).[43] Under the directorship of psychologist and computer scientist J. C. R. Licklider, the IPTO put forward a vision for the future of computing as a tool for "man-computer symbiosis," imagining a future in which "human brains and computing machines will be coupled together very tightly, [such] that the resulting partnership will think as no human brain has ever thought and process data in a way not approached by the information-handling machines we know today."[44] Investing heavily in time-sharing, network technologies, artificial intelligence, and computer graphics, the IPTO pushed a vision of the computer as a device that would not only connect humans to one another but likewise connect human and launching the careers of dozens of researchers who would go on to define much of the commercial computing industry in the second half of the twentieth century.[53] In this sense, Utah served both as a test bed for early research that continues to shape the function of modern graphical systems, and as a network for early researchers who distributed that work to dozens of research programs as they moved out from Utah and into the emerging computing industry over the course of the 1970s and early 1980s.[54]

That the Utah program is at once so central to the history of computing and so absent from popular narratives of innovation reflects the contradictory role of computer graphics itself as a discipline within computer science. Even in this early period, graphics were considered by many to be a frivolous use of computing technology. Computational resources were a limited and extremely expensive commodity, and making pictures seemed to many a waste of time.[55] As several of its graduates recalled during a panel on the history of the Utah program at the ACM's SIGGRAPH conference in 1994,

> They knew that they were "onto something big" while outsiders at other universities disparaged the work in computer graphics as an illegitimate application of computing machinery. Computing research at that time involved computer languages, operating systems, and data processing. Graphics research required manipulating so much data to display images, that it pushed the envelope in computing technology.[56]

Computer graphics research was objectively impractical and unrealistic. The technologies that it required did not yet exist, and the computers themselves were not powerful enough to manipulate the massive amounts of data required for interactive graphical communication between a computer and user. Despite these challenges, IPTO directors viewed graphical interaction as central to the future of the field, and Evans was given the resources to develop the technologies to make these systems possible.[57] The Utah program benefited greatly from this hands-off approach, which by many accounts fostered a culture of research that operated largely independent of any broader consensus of what an appropriate object for computational research might be.[58]

By 1968, Evans had established Utah as a key research hub in an expanding network of ARPA-funded "centers for excellence" and looked to develop this work beyond the university by establishing a commercial venture. Evans had met Sutherland several years prior during his work on Project

Genie at Berkeley, and Sutherland later provided the initial ARPA funding for the Utah program during his two-year tenure as the IPTO's director. As the most prominent graphics researcher in the country and a close family friend, Sutherland was the obvious choice for a partner in a new commercial graphics venture, and while the Evans family initially planned to move to Cambridge, Massachusetts, to found the company in proximity to the funding and institutional partnerships of Boston's Route 128, ultimately it was Sutherland who moved to Salt Lake City in 1968 to cofound E&S in an abandoned military bunker just off the University of Utah campus.[59]

Plate 3 shows that same bunker five years later. The man on the left is Evans, and standing next to him is Shohei Takada of Hitachi Electronics. I found this photo inside a holiday greeting card sent in 1973 following a visit by Hitachi executives earlier that year to see the work being done in Salt Lake.[60] Taken together with plate 2, this image is emblematic of the dual role that Utah plays in the history of computing: at once isolated and experimental, yet simultaneously central, connected, and highly influential. Ultimately the same can be said of computer graphics. While making pictures with computers has been historically viewed as peripheral and inessential to the "real work" of computing, an examination of the history of computer graphics shows its key role in the growth of the modern computer, and along with it the transformation of our computational culture.

Image Objects

To understand this transformation, we must turn to those objects that enabled the emergence of computer graphics to begin with. Following this methodological imperative, each of the following chapters is structured around a distinct technical object: its history, the conditions of its emergence, its influence, and its afterlives. Through this object-oriented approach, I frame computer graphics as a structure of objects grounded in the historical conditions of their formation, but that continue to restrict and inform the ways we produce computational images today. To this end, the book follows a broadly chronological narrative, beginning with the earliest challenges of the then-nascent field of computer graphics at the start of the 1960s and focusing primarily on the role of the University of Utah as a cultural site from which the field is first articulated. Over time these clear distinctions will begin to dissolve, mirroring the historical transformation of computer graphics as it grows across an ever-expanding range of technical disciplines and practices.

Chapter 1 explores early efforts to produce an algorithmic solution to the problem of visibility in a medium divorced from the physical restrictions of sight, optics, and light—what was known to computer graphics researchers as the *hidden surface problem*. In doing so, I critique attempts to fold computer graphics into a broad genealogy of the visual by mapping it onto existing techniques such as perspective projection, or the production of tricks and illusions, arguing instead that while computer-generated images offer the successful simulation of existing media forms, they construct vision in materially distinct ways. To examine the specificity of this construction, I look to early research into hidden surfaces for graphical display from 1963 to 1978, suggesting that the diverse and highly variable solutions to the problem of constructing visibility clearly separate computational vision from the optical regime of film and photography. Through the hidden surface problem, I contend that computer graphics are structured not by a logic of the visible but rather by processes whereby data are culled or erased such that the computer may more successfully interface with human vision. Here visibility becomes an algorithmic process of withholding whose specificity articulates a distinct theory of computer graphics as simultaneously screen image and simulated object—a tension that persists throughout this book and into the present.

In an effort to further distinguish computer graphics from the material specificity of those visual media they simulate, chapter 2 offers an analysis of memory and materiality through the history of the *computer screen* as a heterogeneous object that shifts and transforms in response to changes in the field of computer graphics from 1946 to 1975. Starting with the shift from calligraphic to raster graphics that begins in the late 1960s, I examine the affordances of early screens in order to identify those challenges that prevented computer graphics from adopting the scanline technology of early television displays. Ultimately the chapter identifies a single hardware object that structures and distinguishes the computer screen from other screen media: a piece of random-access computer memory for graphical display known as the frame buffer. This focus on the frame buffer introduces an additional set of questions around computer memory and its relationship to the visual image, the random as distinguished from the sequential, and memory as both a human and computational practice. The chapter concludes by looking to the origins of the stored program concept along with the first experiments in computer graphics at MIT and Princeton in the late 1940s in order to make explicit this relationship between the screen and the random-access memory (RAM) of contemporary computing systems.

Having established the unique function of computer graphics as both visual representation and object simulation, chapter 3 explores the standardization of graphical objects in the mid-1970s, with an emphasis on questions of computational ontology. This period marks the moment in which computer graphics begins to actively digitize objects from the physical world, and in which new methods for simulating irregularity allowed for the creation of increasingly realistic images. From an examination of early techniques for the simulation of curved and shaded surfaces, I reflect on processes of standardization in computer graphics broadly, taking up perhaps the most famous graphical standard in the history of the field: an object known as the *Utah teapot*. Through an analysis of the teapot's history as a material object, research tool, and cultural practice, I look to identify how computer graphics understands, represents, and reproduces the world through simulation. Using the teapot as a foil, I ultimately argue for the materiality of simulated things and their wide-reaching influence beyond the field of computer graphics.

Moving through the 1970s, the strict focus on the University of Utah will begin to fall away as I follow the program's graduates and faculty as they enter the growing computer graphics industry. Likewise, the objects that make up the book's second half will become less representational, suggesting the diffusion of the structuring logic of computer graphics in ways that exceed its connection with the visual. Turning to language, chapter 4 argues for the primary role that graphics played in the reorientation of computer science toward the simulation of objects, with particular emphasis on the *object-oriented programming paradigm* developed by Alan Kay while a graduate student at the University of Utah in the late 1960s. Through an analysis of two early CAD systems, I demonstrate the influence of graphical paradigms on the structure of object-oriented systems generally. In doing so, I trace the afterlife of the Utah program through the circulation of this object logic in early graphical user interfaces and the rise of desktop publishing, documenting the history of the Adobe PostScript language in an aircraft carrier simulation built by E&S in the mid-1970s. In deploying textual and linguistic objects, I suggest that computer graphics has had a structuring effect on the culture of computing that is not always legible as visual image, demonstrating the influence of the Utah program throughout the field of computer science in the second half of the twentieth century.

In examining the thirty-year prehistory of computer graphics, *Image Objects* ends where most histories begin. Arriving at the period in which computer graphics emerge in popular media over the course of the 1980s, chapter 5 pushes back against narratives that presume the inevitability of computer graphics' widespread adoption. Asking instead what technical and cultural shifts allowed for this rapid growth in the visibility of the medium, I suggest that the development of the *graphics processing unit* (GPU) by Utah graduate James Clark in the early 1980s allowed for the rapid proliferation of computer graphics across a range of applications and industries. In the GPU, each of the objects of the previous chapters is miniaturized and embedded within a single metaobject: a computer devoted exclusively to the task of graphical calculation. In this sense the GPU mirrors the object logic of this book itself, a metonym for the history of computer graphics as a whole. Tracking the emergence of the GPU as a set of conceptual shifts scattered throughout the history of computing, I assert the technology's principal contribution is its transformation of the algorithmic logic of software and memory into a physical object, formally fixing it for the purpose of acceleration and specialization. Ultimately the chapter argues that through the GPU, we can see an articulation of the historical claim of computing itself, whereby the complexity of computation as a cultural and historical practice is formalized and flattened through the crystallization of a procedural logic.

Computer graphics today are ubiquitous and invisible, as all manner of objects are produced, reshaped, and transformed by their encounter with computational images. Yet we have no language to describe this relationship, which exceeds the logical binaries we so often use to make sense of the world: the material versus the immaterial, the physical versus the digital, the natural versus the designed, the real versus the virtual. Each pair embeds different valences and represents different attempts to parse an image on a screen from a physical object in one's hand. And yet neither option sufficiently captures the tension inherent in the image object, which is neither material nor immaterial, neither natural nor designed, neither physical nor digital, but rather all of the above simultaneously. In

Figure 1.1
Hidden surface test image, University of Utah, 1968. Courtesy of the Special Collections Department, J. Willard Marriott Library, University of Utah.

One need only look to the technical papers of the annual SIGGRAPH conference on computer graphics to see how this "quest" remains a seductive aspiration for researchers today. From hair movement to skin translucence, cloth draping, and object collision, contemporary researchers are explicitly concerned with improving the visual realism of graphics one object at a time. Much like the progressivist narrative that drives the development of technology more broadly, this quest operates under the tacit assumption that total simulation is possible and a belief that we might one day produce a perfect image of the world. Indeed, this is one of the animating fantasies of the field. In his 1965 address to the International Federation for Information Processing, Ivan Sutherland outlined his vision for the future of computer graphics and visual displays, concluding that

> the ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good

> enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal. With appropriate programming such a display could literally be the Wonderland into which Alice walked.[5]

Later published as "The Ultimate Display," Sutherland's essay has become one of the most influential works of early graphics literature and a rallying cry for the industry's development over the subsequent fifty years. Its vision of total simulation has since been taken up by science fiction writers and virtual reality CEOs alike to sell a vision of the future in which the material world might be fully simulated, customized, and controlled. This foregrounding of realism as the principal effect of graphical simulation likewise produces the assumption that visual mimesis is the locus from which graphical images should be read and interpreted, and that this mimetic ability makes computer graphics the logical or necessary outgrowth of indexical visual media, such as film and photography. Under this rubric, the digital image is the mere extension of some enduring visual technique, be it illusion, perspective, or representation itself.[6] Certainly visual technologies offer us a lens through which to view the long arc of historical perception, but such genealogies likewise collapse the meaningful distinctions that mark the digital image as explicitly computational. Put another way, while so-called new media are often much older than they first appear, it is a mistake to dismiss the fundamental transformation that computation brings to the material form of our contemporary visual culture. What would it mean to take seriously the newness of new media—its unique historical articulation?

Return now to the image in figure 1.1. How did it physically come to be? Holding this picture in the special collections department of the Marriott Library at the University of Utah, I took for granted its status as a digital image, not unlike the hundreds of images I interact with on a daily basis. It depicts a virtual object programmed and rendered by a computer, and yet its physical presence as a material thing to be held in my hands, turned, and examined seemed to speak to the strange materiality of this supposedly immaterial practice. At first glance it appears to be a screenshot, but in 1968 there were no image files, JPEGs, or photo printers. One could not easily extract and preserve an image from the screen of a computer, as there was no computational mechanism to do so. This image is in fact a Polaroid taken with a light-tight camera that was physically attached to the screen of a slow-scan cathode ray tube (CRT) (figure 1.2). The image was etched

Figure 1.2
Students Alan Erdahl, Chris Wylie, and Gordon Romney in the University of Utah's graphics lab, ca. 1968. At the lower left of the image is an oscilloscope with a light-tight camera attached to its face for screen documentation. Courtesy of the Special Collections Department, J. Willard Marriott Library, University of Utah.

in a long exposure over the course of several minutes, line by line, as a mainframe computer calculated the position and shade of each part of the image to be displayed. Researchers couldn't actually see the image directly without the mediation of long exposure photography, such that producing this image was a process of exhaustive preparation, and to a degree, trial and error. While this image may resemble computer graphics as we use and understand it today, the apparatuses that enabled its production are wildly different—a fact that is nowhere apparent in the image itself, and cannot be derived from visual analysis alone. It is an image that straddles the analog and the digital, a visual cluster held together by an assortment of media technologies equally visual and invisible.

But what of the object? What was the purpose of such a simple simulation? Unlike the experimental images produced by artist researchers in this early period, this is not a principally aesthetic object. Likewise, while this image may be historically significant, it is not unique or exceptional. Its purpose was to assist in the testing of visualization algorithms developed for these early graphical systems, and its historical value is the way it indexes the everyday labor of graphical research at sites like the University of Utah. In this early period, computer graphics researchers were only just beginning to work out the question of how to produce a visual simulation. Indeed, the primary concern for researchers was not how to realistically simulate any *particular* object but rather how to simulate *any three-dimensional object at all*. How is an object constructed, what is it made of, and how does it interact with the world around it? These were the questions that most interested the field, and they display an equal investment in both form and representation—that is, in both what an object is and how it appears, its status as both image and object. Looking back at our image, it becomes clear that there is more going on here than simple visualization, something that concerns the intersection of objects, this contact between things.

From roughly 1963 until at least 1978, one of the key concerns for the field of computer graphics was the solution to what is known as the "hidden line" or "hidden surface problem."[7] It is, in effect, a crisis of visibility. Whereas photographic visibility models itself on our phenomenological perception of the world, following a camera obscura tradition whereby objects are made visible through the interaction of light with an aperture, computer graphics do not function in this way. For computer graphics, each object must be described in advance if it is to be rendered visible. In other words, graphical objects exist in their totality—as a collection of coordinate points, image files, and object databases—prior to their manifestation as a visible image. Graphical objects are in this sense nonphenomenological, known in their entirety prior to our perception of them. In order to simulate our perception of objects, graphics must not only calculate that which is to be seen but also anticipate and hide that which is known yet should not be shown, that which must be made hidden and invisible. This is what our image seeks to simulate with its intersection of object and plane: the removal of that which cannot be known through sight alone. In refusing the apparent similitude of our image, we find an object held together by a complex topology that little resembles our contemporary visual culture. While this image may be novel as one of the earliest of its kind, it is also exemplary of the struggles and challenges of this early research field, and a failure to solve for something we simply take as given in other media forms: visibility. As such, it speaks directly to this moment in the history of computer graphics—a period defined by the challenge of making the digital visible.

Problem Solving

By the mid-1960s, researchers had already succeeded in producing interactive three-dimensional computer graphics. At MIT, Bell Telephone Laboratories, Boeing, and General Motors (GM), research teams had developed systems for rendering pictures that bear a striking resemblance to modern graphical images. Yet while these images are compelling, their appearance masks significant constraints and limitations. In this early period, computer graphics was a broad field with widely varying approaches to the display of graphical images. From the SAGE system for air defense to the experimental computer animations of John and James Whitney, these early systems were highly idiosyncratic with little application beyond the research or artistic context in which they were developed.[8] Much as with early experiments in protocinematic visualization at the end of the nineteenth century, in which multiple visual forms competed with and functioned alongside what would become the cinematic image, this period is marked by a multiplicity of solutions to the problem of computer graphics.[9] If the field was to develop as an area of scientific research, it would need a shared vision of what the mimesis were understood as identifiable problems that were always progressing toward a more accurate or realistic solution.[18] Identifying specific problems in this way underscores both the technical limitations of early graphics and the way institutional structures focused the field in an effort to produce workable solutions.

Looking at the challenges articulated by Evans, it seems the most glaring problem for early researchers was less how to render a visible image than how to restrict that image into displaying only that which is sensible to a viewing subject. Absent is a preoccupation with the formal apparatuses that have historically defined and united earlier visual forms, namely the simulation of depth through perspective projection. Yet these frameworks for the analysis of visual media have dominated scholarly discourse on the digital image, which often looks to imbricate computer graphics with prior modes of visual representation rather than consider the many ways such images negotiate or refuse a preoccupation with visuality altogether.

Simulating Vision

In his widely influential *Techniques of the Observer* (1990), art historian Jonathan Crary opens not with a historical anecdote on the development of early visual technologies in the long nineteenth century but instead by reflecting on the reconfiguration of vision in his own time by the technical regime of computer graphics. Drawing parallels between the transformation of vision under industrialization and our own historical present, Crary suggests that "the rapid development in little more than a decade of a vast array of computer graphics techniques is part of a sweeping reconfiguration of relations between an observing subject and modes of representation that effectively nullifies most of the culturally established meanings of the terms *observer* and *representation*." This transformation, he asserts, is "probably more profound than the break that separates medieval imagery from Renaissance perspective."[19] Writing in the late 1980s, Crary could only speculate on the radical reorganization of our visual culture that would take place over the subsequent decade, but he clearly suggests that the site of this transformation will be vision itself as a historical mode of perception tied to the production of human subjectivity. Today this link between computer graphics and the long history of visual perception would seem undeniable, such that it is no surprise that the vast majority of scholars working on computer graphics take up Crary's call to engage with the use and application of computer graphics in the context of this history. This connection has become so conspicuous that computer graphics are taken as a given in discussions of new media technologies such as computer animation and digital gaming, while scholars working in visual disciplines from film studies to art history often presume a narrative whereby computer-generated images serve as a logical extension of the visual function of optical media, even as they displace the formal materiality of these media with simulation.[20] And yet the computer is not a visual medium. We might argue it is primarily mathematical or perhaps electric, but it is not in the first instance concerned with questions of vision or image. As media theorist Friedrich Kittler simply states in his lectures on optical media, "Computers must calculate all optical or acoustic data on their own precisely because they are born dimensionless and thus imageless. For this reason, images on computer monitors . . . do not reproduce any extant things, surfaces, or spaces at all. They emerge on the surface of the monitor through the application of mathematical systems of equations."[21] In practice, this means that in order to simulate our perception of objects as fixed in a perspective projection, a graphical program must first produce a simulation of that scene in its entirety, and then extract from that scene those parts that should be rendered visible. This process by which graphics simulates existing visual media purposefully belies the means by which this sense of mimesis is achieved. Computer graphics is a medium engaged in a disavowal of its technical apparatus, which has led to an undertheorization of its material functionality. This mapping of computer graphics onto the long history of visual representation masks a number of significant differences between the way visuality is *constructed* by computer graphics and *captured* by a camera, and has limited investigations into the technical materiality of the algorithms that produce computer-generated images.[22]

One of the few theorists of the past twenty years to examine this relationship in detail is Lev Manovich, whose pivotal work in *The Language of New Media* (2001) attempts to place new media technology within a broader history of visual culture, marking those points of distinction where computational media break from earlier models and become unique technical processes in their own regard.[23] For Manovich, computer graphics are part of a long and ongoing transformation of vision through technology, from painting and photography to radar and virtual reality.[24] In his writing throughout the 1990s, Manovich frames this evolution as a kind of visual nominalism whereby visual media have historically functioned to capture the identity of individual objects and spaces through the recording of distances and shapes.[25] Central to this transformation was the development of linear perspective as a technique for the automation of visual relations through the application of a fixed method. Tracing the development of this perspectival mode through painting, photography, and the cinema, Manovich argues that visual nominalism finds its apotheosis in the mass automation of perspectival representation made possible by computer graphics. Manovich's work here is exceptional in its treatment of computer graphics as a distinct media technology grounded in a set of principles that run parallel with but are historically distinct from those of film and photography. Nevertheless, the work is marked by an insistence—found in almost all historical writing on computer graphics and digital imaging—on a narrative of inheritance across visual media that obscures a detailed historical account of computer graphics as computational ab initio.[26]

The single most pervasive technique in this effort to stage continuities between distinct media forms is *perspective*, as it has formed the basis for the production of realism across a wide range of media technologies since at least the fifteenth century. Its adoption by computer graphics therefore clearly links graphical images to the realist visual traditions of painting, photography, and the cinema, allowing for a broad historical claim that grounds computer graphics in a legible tradition of representation. In this perspectival tradition, the world is refigured as a system of relations that center the subjectivity of an all-seeing individual, giving rise to a perspectival subjectivity grounded by an optical regime that privileges this fixed perspective. As Kittler argues, "Representational thinking delivered being as an object for a subject . . . [and] linear perspective and the *camera obscura* were precisely the media of this representation."[27] Of course, the perspectival mode of Renaissance painting and the camera obscura clearly differ in technique and form, but in examining its articulation across a range of media technologies, it becomes apparent that this relation is transmutable, shifting to accommodate the formal specificity of a given medium. Taken in isolation from those media forms that employ it, what perspective offers is a structuring system whereby space is mapped and displayed in relation to a viewing subject. As Jacques Lacan notes in "On the Gaze as *objet petit a*," "What is an issue in geometric perspective is simply the mapping of space, not sight."[28] It just happens that we tend to privilege sight in the way we map space technologically. Perspective is only one potential solution to the question of object relationality; it is one particular relational technique with a long cultural history adopted by computer graphics in the production of a culturally situated realism.

This is not to suggest that perspective is a monolithic or unified system of representation. As art historian James Elkins has suggested, there is "no coherent history, no connected tradition beneath the word [perspective]."[29] Nonetheless there is a cultural significance in its deployment across a broad range of visual media. Indeed, its prevalence as a structuring logic for visual media indicates that it operates as a kind of deeply embodied cultural technique (*Kulturtechnik*)—that is, a condition whereby "signs, instruments, and human practices consolidate into durable symbolic systems capable of articulating distinctions within and between cultures."[30] It is a form that has been naturalized through its adoption by a variety of media since the Renaissance, but whose primacy as a means of producing and reflecting the world is historically bound and exists alongside other techniques.[31] While many art historians have identified the cultural relativism of perspective, it is perhaps more useful to think through perspective as a set of culturally and historically situated practices that are maintained precisely through their adoption and transformation by emerging media technologies.[32] It is this malleability of perspective across its multiple cultural and historical forms that maintains it as a governing structure.[33] As such, it is of no surprise that perspective has become the operative relational mode for a great deal of computer graphic visualizations, but that adoption is by no means essential to the way graphics produces visualization. The perspective that computer graphics offers is algorithmically rendered by a virtual camera decoupled from any connection with the embodied position of a viewing subject, let alone optics or the physical properties of light. Indeed, an investigation into the earliest use of perspective projection in a simulated image reveals little concern for this centuries-old technique. In its place we find a new set of relations structured not by vision but instead by a theory of the nature of objects, a computational ontology for which the rendered image is only one of many possible expressions.

Computing Perspective

How then does computer graphics first approach the simulation of perspective? The earliest model of three-dimensional perspective comes from the graduate work of Lawrence Roberts, whose dissertation project—titled "Machine Perception of Three-Dimensional Solids"—is a foundational text in the history of the field.[34] Along with Sutherland, Roberts was one of several graduate students working on applications in computer graphics and machine vision using the MIT Lincoln Laboratory's TX-2 computer at the start of the 1960s. Building on Sutherland's Sketchpad software, Roberts developed a rudimentary technique for producing opaque three-dimensional models in perspective projection.[35] For architect and historian William J. Mitchell in *The Reconfigured Eye* (1994), this is a critical moment in the history of the algorithmic image, an event "as momentous, in its way, as Brunelleschi's perspective demonstration."[36] Like Filippo Brunelleschi and Leon Battista Alberti some six hundred years prior, Roberts's work would seem to make possible an entirely new form of image making—one that leads directly to today's computer-generated images in film, photography, and digital games. But while the simple graphics produced by Roberts's program bear a striking resemblance to contemporary computer-generated images, we should not assume a direct lineage of inheritance. If we set aside the rendered image and look to the structure of the program itself, we find a system for producing images that bears little resemblance to contemporary graphical modeling. What's more, this excavation suggests Roberts's use of perspective projection is largely incidental to the program's objectives, creeping in under the guise of an earlier visual form.

The stated goal of Roberts's dissertation research was to enable "a computer to construct and display a three-dimensional array of solid objects from a single two-dimensional photograph."[37] That is, rather than construct a virtual object, as is common in contemporary modeling software, the program was intended to digitize objects from two-dimensional photographic representations. To construct a three-dimensional model, a simple object would be photographed and processed by Roberts's program, which would attempt to identify the edges of objects as a set of feature points. It then would try to connect those edges, and calculate the volume and shape of the object whole (figure 1.3). Objects could then be transformed,

Figure 1.5
A perspective rendering of a house with and without hidden lines removed. The program for this image was written by Lawrence Roberts. Published in Ivan E. Sutherland, "Computer Inputs and Outputs," *Scientific American* 215, no. 3 (September 1966): 96.

transforms the photographic image into an array of points in Cartesian space connected by lines to form surfaces that may be extrapolated into three dimensions. In delimiting the world in this way, Roberts's algorithm makes objects from the visible world legible to computation—a process that includes much more than the reconstruction of something analogous to Renaissance perspective. While a desire for realistic images that simulate the visual appearance of film and photography was a critical concern for researchers from the beginning, this realism was predicated on a relational mode with no basis in earlier visual media.[44] In examining the material history of these forms we can begin to decouple computer graphics from the regime of visuality that so easily contains it, and in doing so, identify a broader technique at play.

Hidden Surface Problems

For any graphical system to calculate the appearance of an object, it is first necessary to understand the structure of that object. That is, in order to simulate our perception of an object as fixed in a perspective projection, graphics must both calculate its visible surfaces while preemptively removing any nonvisible surfaces so that they will not be calculated or displayed.[45] Prior to the mid-1960s this was not the case, as graphical objects were produced largely as wireframe models with no surfaces, from which all edges were simultaneously visible (figure 1.5). While such images are suitable for