CHAPTER 1

INTRODUCTION

The scientific community has been working in the field of virtual reality (VR) for decades, having recognized it as a very powerful human–computer interface. A large number of publications, TV shows, and conferences have described virtual reality in various and (sometimes) inconsistent ways. This has led to confusion, even in the technical literature.

Before we attempt to define virtual reality, we should first say what it is not. Some researchers refer to telepresence, in which a user is immersed in a remote environment. This is very useful in telerobotics [Sheridan, 1992], where we attempt to control robots at a distance and where knowledge of what is happening around the robot is critical. Others have used the name enhanced reality or augmented reality (AR) [Müller, 1999], where certain computer graphics, or text, is overlaid on top of real images. A technician attempting to repair an installation may look at a photo in which overlaid graphics makes apparent otherwise occluded components [Bejczy, 1993]. Both telepresence and augmented reality incorporate images that are real, so neither is virtual reality in its strictest sense.

Technologists have been joined by artists and journalists in trying to define the field. The cover of the book *The World of Virtual Reality* published in Japan [Hattori, 1991] depicts Alice in the Wonderland, as shown in Figure 1.1. This is more eye-catching and amusing than scientific. Others have referred to virtual reality in terms of the devices it uses and not its purpose and function. The general public tends to associate virtual reality simulations with head-mounted displays (sometimes called "goggles") and sensing gloves, just because these were the first devices used in simulation. This is not a good definition either. Virtual reality today is done mostly without head-mounted displays, by using large projection screens or desk-top PCs [Robertson et al., 1993]. Similarly, gloves can be replaced with much simpler trackballs or joysticks [Schmult and Jebens, 1993]. Conversely, sensing gloves can be used in other tasks than VR, such as in telerobotics [Clark et al., 1989]. Therefore describing virtual reality in terms of the devices it uses is also not an adequate definition.

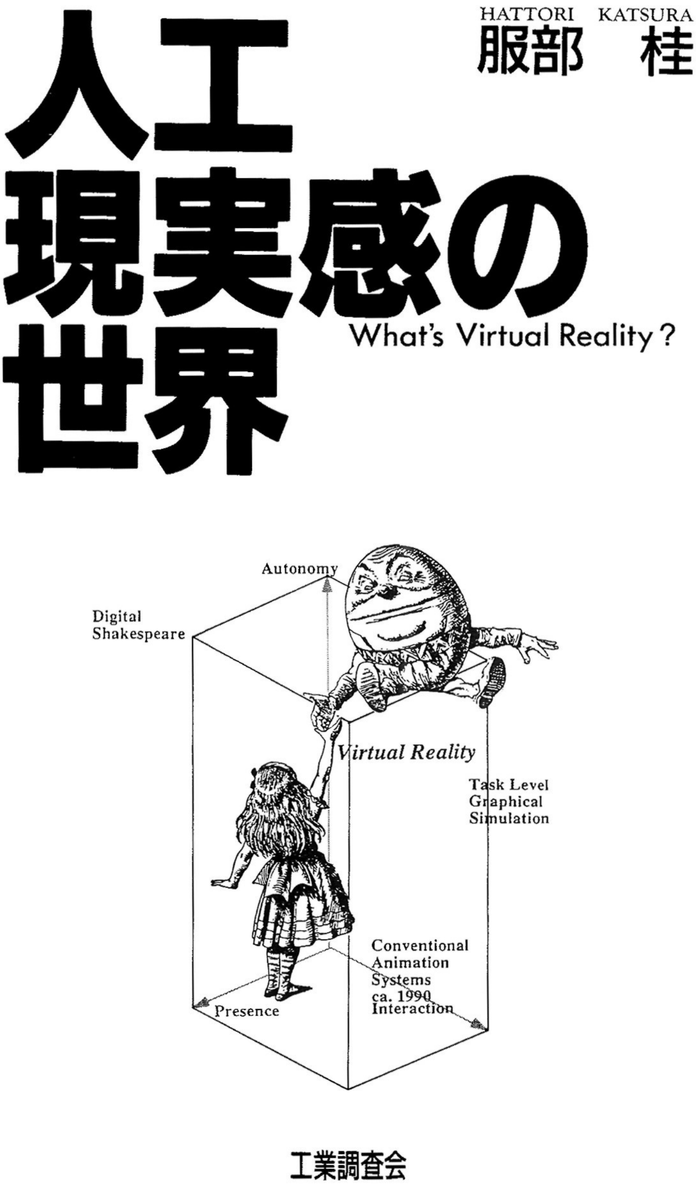

Fig. 1.1 The cover of *The World of Virtual Reality*. From Hattori [1991]. Reprinted by permission.

Then what *is* virtual reality? Let us first describe it in terms of functionality. It is a simulation in which computer graphics is used to create a realistic-looking world. Moreover, the synthetic world is not static, but responds to the user's input (gesture, verbal command, etc.). This defines a key feature of virtual reality, which is real-time *interactivity*. Here real time means that the computer is able to detect a user's input and modify the virtual world instantaneously. People like to see things change on the screen in response to their commands and become captivated by the simulation.

Anybody who doubts the spell-binding power of interactive graphics has only to look at children playing video games. It was reported that two youngsters in the United Kingdom continued to play Nintendo even though their house was on fire!

Interactivity and its captivating power contributes to the feeling of *immersion,* of being part of the action on the screen, that the user experiences. But virtual reality pushes this even further by using all human sensorial channels. Indeed, users not only see and manipulate graphic objects on the screen, they also touch and feel them [Burdea, 1996]. Researchers are also talking of the senses of smell and taste, although these sensorial modalities are less used at this time. In summary we give the following definition:

Definition Virtual reality is a high-end user–computer interface that involves real-time simulation and interactions through multiple sensorial channels. These sensorial modalities are visual, auditory, tactile, smell, and taste.

Virtual reality can also be described from the simulation content point of view as unifying realistic (or veridical [Codella et al., 1993]) realities with artificial reality. This is a synthetic environment, for which there is no real counterpart (or antecedent) [Krueger, 1991]. For the rest of this book we use the term virtual reality to encompass all the other terminology described earlier.

1.1 THE THREE I's OF VIRTUAL REALITY

It is clear from the foregoing description that virtual reality is both interactive and immersive. These features are the two I's that most people are familiar with. There is, however, a third feature of virtual reality that fewer people are aware of. Virtual reality is not just a medium or a high-end user interface, it also has applications that involve solutions to real problems in engineering, medicine, the military, etc. These applications are designed by virtual reality developers. The extent to which an application is able to solve a particular problem, that is, the extent to which a simulation performs well, depends therefore very much on the human *imagination,* the third "I" of VR. Virtual reality is therefore an integrated trio of immersion–interaction–imagination, as shown in Figure 1.2. The imagination part of VR refers also to the mind's capacity to perceive nonexistent things. The triangle in Figure 1.2, for example, is easily "seen" by the reader, yet it only exists in his or her imagination.

1.2 A SHORT HISTORY OF EARLY VIRTUAL REALITY

Virtual reality is not a new invention, but dates back more than 40 years. In 1962, U.S. Patent #3,050,870 was issued to Morton Heilig for his invention entitled Sensorama Simulator, which was the first virtual reality video arcade. As shown in Figure 1.3, this early virtual reality workstation had three-dimensional (3D) video feedback (obtained with a pair of side-by-side 35-mm cameras), motion, color, stereo sound, aromas, wind effects (using small fans placed near the user's head), and a seat that vibrated. It was thus possible to simulate a motorcycle ride through New York, where the "rider" sensed the wind and felt the pot-holes of the road as the seat vibrated. The rider could even smell food when passing by a store.

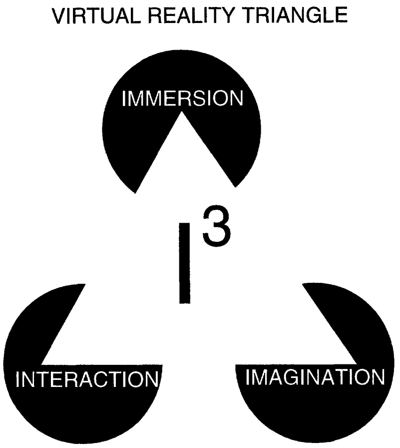

Fig. 1.2 The three I's of virtual reality, immersion–interaction–imagination. Adapted from Burdea [1993]. Reprinted by permission.

Heilig also realized the possibilities of head-mounted television. He designed a simulation mask that included 3D slides with wide peripheral effects, focusing controls and optics, stereophonic sound, and the capability to include smell. A depiction from U.S. Patent #2,955,156 issued to him on October 4, 1960, is shown in Figure 1.4. Heilig, a cinematographer by profession, was well ahead of his time. Like Jules Verne, he imagined a new machine that would replace the classical cinematographic experience of today. He was also like Thomas Edison, an inventor who not only dreamed ideas, but also transformed them into real machines. At the time of Heilig's inventions, nobody realized the revolutionary technological progress they represented.

Heilig's initial work on head-mounted displays (HMD) was continued by Ivan Sutherland. In 1966 Sutherland used two cathode ray tubes (CRTs) mounted along the user's ears. Today's high-end HMDs use miniature CRTs mounted in the same configuration. Since the tubes available in 1966 were much heavier than those in use today, Sutherland had to rely on a mechanical arm to support the weight of the display. This mechanical arm had potentiometers that measured the user's view direction. Most of today's HMDs use noncontact position tracking (magnetic or ultrasound), but this technology was not available in the 1960s.

While working on his head-mounted display, Sutherland realized that he could use computer-generated scenes instead of analog images taken by cameras, and began to design such a scene generator. This was the precursor of the modern graphics accelerator, a key part of VR hardware. The computer generates a sequence of scenes each a bit different and each displayed in a fraction of a second. The overall effect is that of animations such as flyby simulations used to train pilots. Early graphics scene generators produced by Evans and Sutherland around 1973 could display simple scenes of only 200–400 polygons. Each scene took about 1/20 sec to compute and display, so that about 20 scenes (or frames) were displayed every second. More complex scenes were made of more polygons, took a longer time to display, and therefore consisted of fewer frames per second. As a consequence, animation (which requires more than 16 frames/sec to be smooth) suffered.

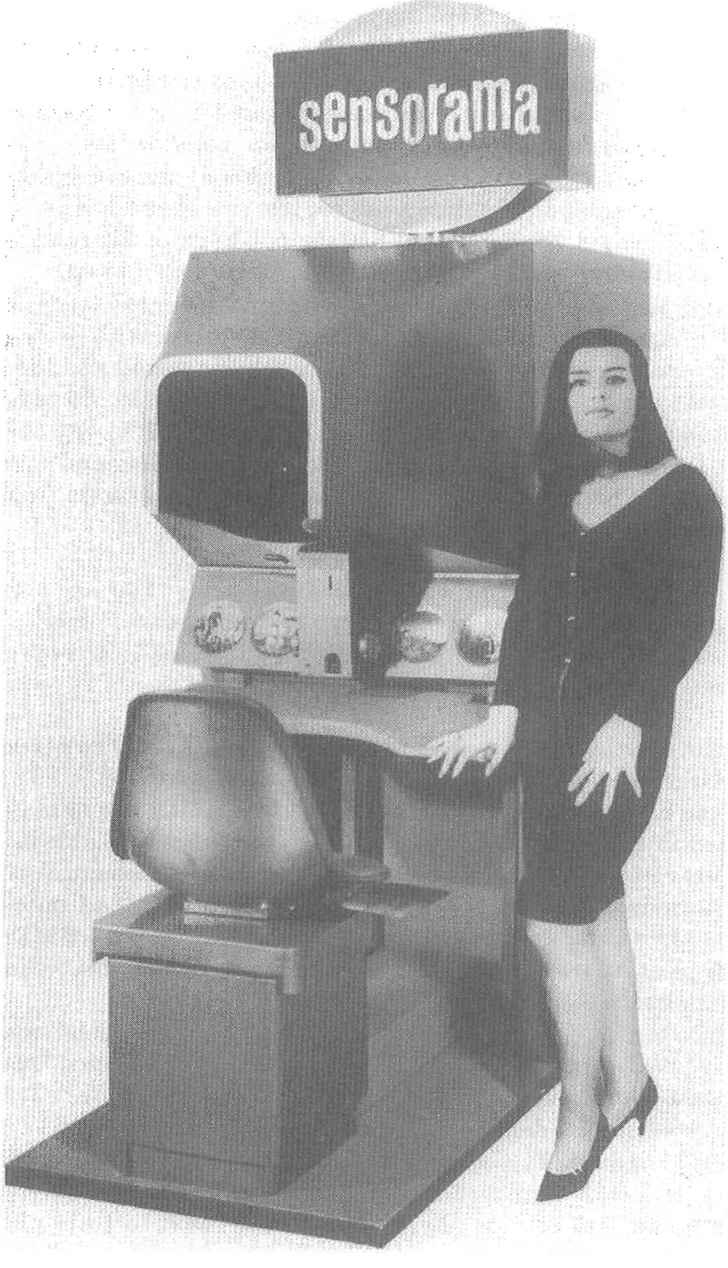

Fig. 1.3 The Sensorama Simulator prototype. Courtesy of M. Heilig.

Sutherland's vision of an "ultimate display" to the virtual world was not limited to graphics. In 1965 he predicted that the sense of touch (or haptics) would be added in order to allow users to feel the virtual objects they saw [Sutherland, 1965]. This idea was made reality by Frederick Brooks, Jr., and his colleagues at the University of North Carolina at Chapel Hill. By 1971 these scientists demonstrated the ability to

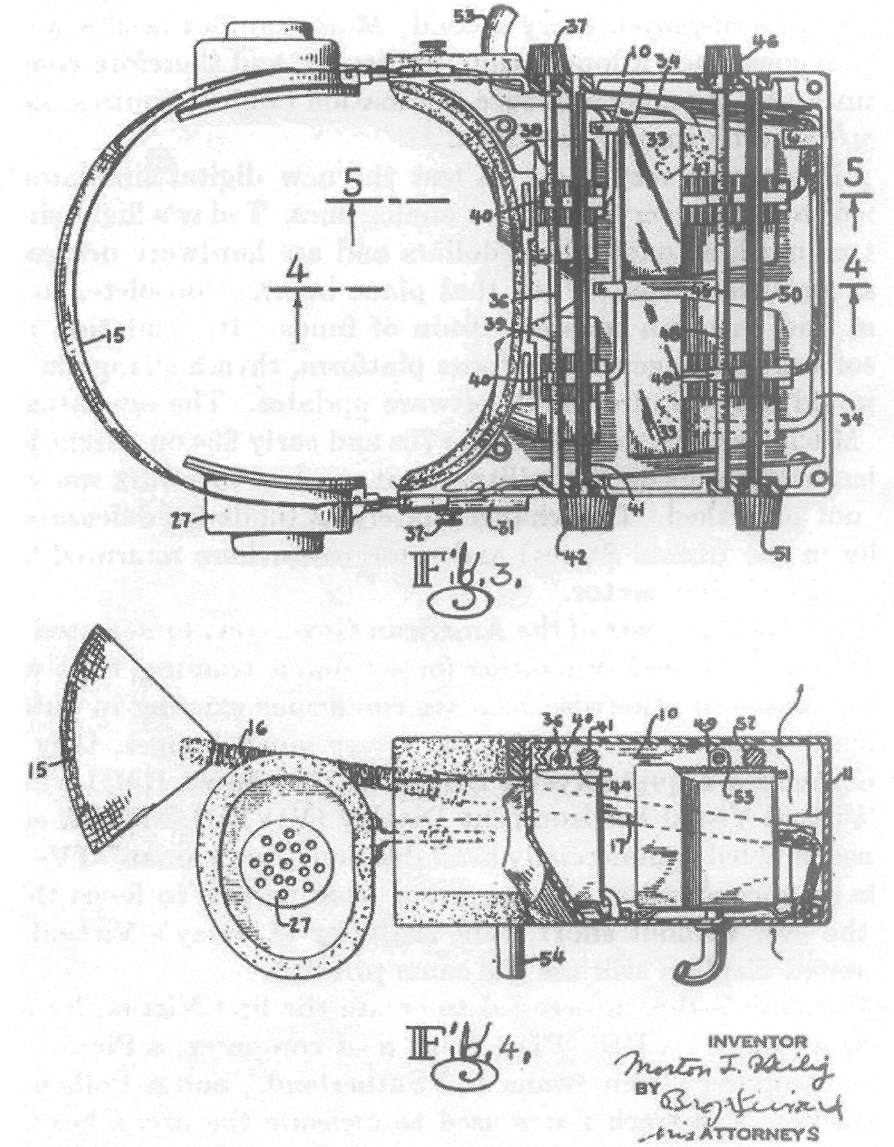

Fig. 1.4 Heilig's early head-mounted display patent. From Heilig [1960]. Reprinted by permission.

simulate two-dimensional continuous force fields associated with molecular docking forces [Batter and Brooks, 1971]. Later they simulated three-dimensional collision forces using a surplus robotic arm normally used in nuclear material handling. Most of today's haptic technology is based on miniature robotic arms.

The military was very eager to test the new digital simulators, since they hoped to replace very expensive analog ones. Flight simulators were hardware designed for a particular airplane model. When that airplane became obsolete, so did its simulator, and this was a constant drain of funds. If the simulation could be done in software on a general-purpose platform, then a change in airplane models would only require software upgrades. The advantage seems obvious. Much research went on in the 1970s and early 1980s on flight helmets and modern simulators for the military, but much of this work was classified and was not published. This changed when funds for defense were cut and some researchers migrated to the civilian sector.

The National Aeronautics and Space Agency (NASA) was another agency of the American government interested in modern simulators. It needed simulations for astronaut training, as it was difficult or impossible to otherwise recreate conditions existing in outer space or on distant planets. In 1981, on a very small budget, NASA created the prototype of a liquid crystal display (LCD)-based HMD, which they named the Virtual Visual Environment Display (VIVED). NASA scientists simply disassembled commercially available Sony Watchman TVs and put the LCDs on special optics. These optics were needed to focus the image close to the eyes without effort. The majority of today's virtual reality head-mounted displays still use the same principle. NASA scientists then proceeded to create the first virtual reality system by incorporating a DEC PDP 11-40 host computer, a Picture System 2 graphics computer (from Evans and Sutherland), and a Polhemus noncontact tracker. The tracker was used to measure the user's head motion and transmit it to the PDP 11-40. The host computer then relayed these data to the graphics computer, which calculated new images displayed in stereo on the VIVED.

In 1985 the project was joined by Scott Fisher, who integrated a new kind of sensing glove into the simulation. The glove was developed earlier by Thomas Zimmerman and Jaron Lanier as a virtual programming interface for nonprogrammers. A photo of Fisher experimenting with the VIVED system is shown in Figure 1.5. By 1988 Fisher and Elizabeth Wenzel created the first hardware capable of manipulating up

Fig. 1.5 NASA VIVED prototype. Courtesy of Telepresence Research Inc.

to four 3D virtual sound sources. These are sounds that remain localized in space even when the user turns his or her head. This represented a very powerful addition to the simulation. The original VIVED project became VIEW (for Virtual Interface Environment Workstation) and the original software was ported to a newer Hewlett-Packard 9000, which had sufficient graphics performance to replace the wireframe rendering used in VIVED with more realistic flat-shaded surfaces.

With all the aforementioned technological developments, scientific exchange of information among the small group of specialists of the time followed. France was one of the first countries to organize a major international conference on the subject, held in Montpellier in March 1992. The name of this conference was Interfaces for Real and Virtual Worlds, and it drew hundreds of papers and many vendors. Later the same year the United States organized the first conference on Medicine Meets Virtual Reality. In San Diego, about 180 medical practitioners met with 60 scientists and engineers to discuss the great potential of virtual reality as a tool for medicine. In September 1993 the world's largest professional society, the Institute of Electrical and Electronics Engineers (IEEE), organized its first VR conference in Seattle. Virtual reality had become part of the mainstream scientific and engineering community.

1.3 EARLY COMMERCIAL VR TECHNOLOGY

The first company to sell VR products was VPL Inc., headed by Jaron Lanier. Until its demise in 1992 this company produced the first sensing glove, called the DataGlove (Figure 1.6*a*) [VPL, 1987]. The standard interfaces of the time (and still today) were the keyboard and the mouse. Compared to these, the VPL DataGlove represented a quantum improvement in the natural way one could interact with computers. Its fiber-optic sensors allowed computers to measure finger and thumb bending, and thus interaction was possible through gestures. Its drawbacks were high price (thousands of dollars), lack of tactile feedback, and difficulty in accommodating different hand sizes.

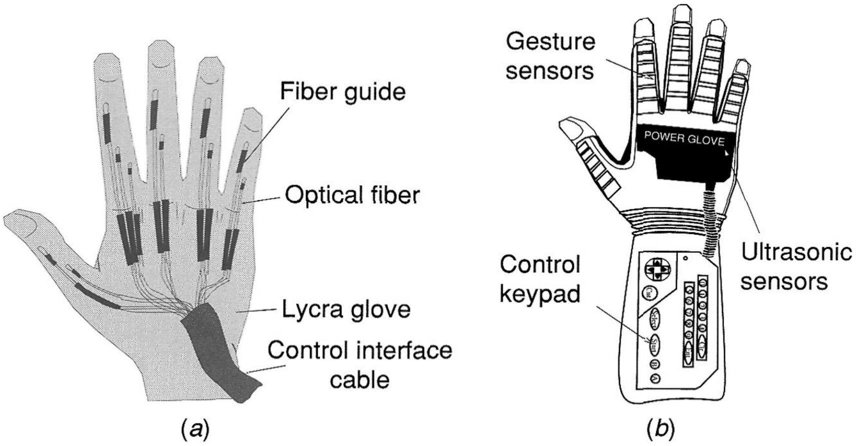

Fig. 1.6 Early sensing glove technology: (*a*) the VPL DataGlove; (*b*) the PowerGlove. From Burdea [1993]. Reprinted by permission.

Shortly after the appearance of the VPL DataGlove, the game company Nintendo introduced the much cheaper PowerGlove, shown in Figure 1.6*b* [Burdea, 1993]. It used ultrasonic sensors to measure wrist position relative to the PC screen and conductive ink flex sensors to measure finger bending. In 1989 almost one million such new game consoles were sold in a consumer frenzy that was later repeated with the introduction of Sony Play Station. The downfall of the PowerGlove was lack of sufficient games that used it, such that by 1993 its production had stopped.

The first commercial head-mounted displays, called EyePhones, were introduced by VPL in the late 1980s. These HMDs used LCD displays to produce a stereo image, but at extremely low resolution (360 × 240 pixels), such that virtual scenes appeared blurred. Other drawbacks were high price ($11,000 each) and large weight (2.4 kg).

Researchers now had an initial set of specialized hardware with which to start developing applications. However, they first had to solve various integration issues as well as develop most of the required software from scratch. The idea of a turnkey VR system originated with VPL as well. Its RB2 Model 2 offered a rack assembly housing the EyePhone HMD interface, the VPL DataGlove Model 2 electronic unit, a spatial tracking unit for the HMD, a design and control workstation, as well as connections to an SGI 4D/310 VGX graphics renderer and to an optional 3D sound system.

The next step in integration was to shrink each of these components and put them on a board in a single desk-side cabinet. In early 1991 a company in the United Kingdom, Division Ltd., introduced the first integrated commercial VR workstation. It was called Vision and was followed by the more powerful Provision 100 [Grimsdale, 1992], which is illustrated in Figure 1.7. The Provision 100 parallel architecture had

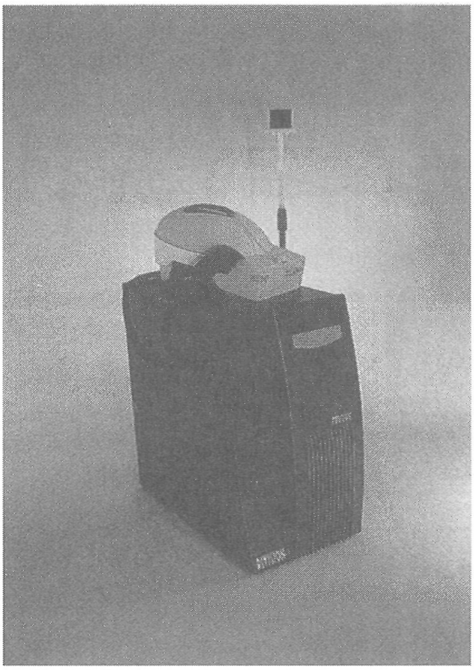

Fig. 1.7 The Provision 100 VR workstation. Courtesy of Division Ltd.

multiple processors, stereo display on an HMD, 3D sound, hand tracking, and gesture recognition. The architecture also had an input/output (I/O) card and was scalable, allowing additional I/O processors to be added. Its i860 dedicated geometry processor with a custom polygon accelerator provided 35,000 Gouraud-shaded and Z-buffered polygons per second. This was a clear improvement over the speed of the HP 9000 computer used in NASA's VIEW system, but it came at a high price ($70,000).

Although turnkey hardware systems appeared in early 1990s, the VR software development and debugging time continued to be a problem. In 1992, the small U.S. company Sense8 Co. developed the first version of its WorldToolKit (WTK) [Sense8 Co., 1992], a library of C functions written specifically for VR applications. With this toolkit developing VR software became more like a science, and debugging time was reduced significantly.

Another popular toolkit of the 1990s was the Virtual Reality Toolkit (VRT3), developed in the United Kingdom by Dimension International (the company later became Superscape PLC) [Dimension International, 1993]. Unlike WTK, VRT3 was designed to run on multiple computing platforms without the need for (then) pricey graphics accelerators. Also, unlike WTK, which is text-based, VRT3 used graphical programming through menus and icons. This made programming easier to learn, but less rich in functionality, owing to the limited menu of available functions and the limited number of supported interfaces.

1.4 VR BECOMES AN INDUSTRY

The fastest graphics workstation in 1993, the Silicon Graphics Inc. Reality Engine, cost over $100,000. This points to a very important drawback of early virtual reality hardware: It was expensive. Only large corporations, governments, and highly endowed universities could afford it. The VR market was small, estimated at $50 million [Donovan, 1993]. Most VR pioneering companies were also small, lacking adequate resources to invest in fixing some of the problems with their first VR products. These companies relied mostly on private and venture capital. At the same time the public expectations were unrealistically high due to sustained media hype. It became clear VR could not deliver overnight all that was expected of it, and funding dried up. As a consequence many VR companies such as VPL, Division Ltd., Superscape PLC, and others disappeared. This in turn compounded the problems for VR application developers. Not only was the market for such applications untested, there was no technical support and no possibility for equipment upgrades.

By the mid 1990s VR had reached a critical point. While public attention and funding migrated to the emerging Internet and Web applications, a small group of scientists continued their VR research. Steady progress lead to a rebirth of VR in the late 1990s [Rosenblum et al., 1998]. What were some of the contributing factors? One of the most important changes was the tremendous improvement in PC hardware. Not only did the central processing unit (CPU) speed get faster, but so did the speed of PC-based graphics accelerators. According to the well-known Moore's law, CPU performance doubles every 18 months. The same law could be applied to PC graphics accelerators. In the early 1990s the speed of PC graphics boards was very poor, at 7000–35,000 polygons rendered in a second. Based on that, Moore's law predicts a speed of 20 million polygons rendered every second by 2003 [3Dlabs Inc., 2001]. Rapid technological advances in 3D rendering chipsets made this happen much earlier, such that by 2001 the performance of PC graphics matched or exceeded that of high-end SGI graphics supercomputers, as illustrated in Figure 1.8. The tremendous reduction in price for the same performance meant that interactive 3D graphics became available to almost everyone.

Other technological advances occurred in the very important area of VR I/O interfaces. Early LCD-based color HMDs were very heavy and had poor resolution. For example, the Flight Helmet shown in Figure 1.7 had a weight of 2 kg and a resolution of only 360 × 240 pixels. By 1997 the LCD-based HMD resolution increased to 640 × 480 (VGA). A breakthrough in HMD ergonomics occurred in 1998 when Sony introduced a much slimmer Glasstron with a weight of only 310 grams. Shortly thereafter Kaiser Electro-Optics launched the first LCD-based HMD with extended graphics array (XGA) resolution (1024 × 768 pixels). Such resolution was previously available only on much more expensive and heavier CRT-based HMDs or on desktop color monitors. The steady increase in HMD resolution during the 1990s meant much sharper images without the unwanted jagged pixelation effect of earlier models. The significant improvement in HMD image resolution in the 1990s is illustrated in Figure 1.9.

Another factor in the rebirth of VR was the introduction in mid 1990s of large-volume displays capable of much larger images than those available on even the most modern HMD. With such wall-size images, more users could participate in the same simulation. Fortunately for the VR manufacturers, such large-volume displays were very expensive and the VR market increased from $500 million in 1996 to $1.4 billion in 2000. Carl Machover, a consultant following computer graphics industry trends,

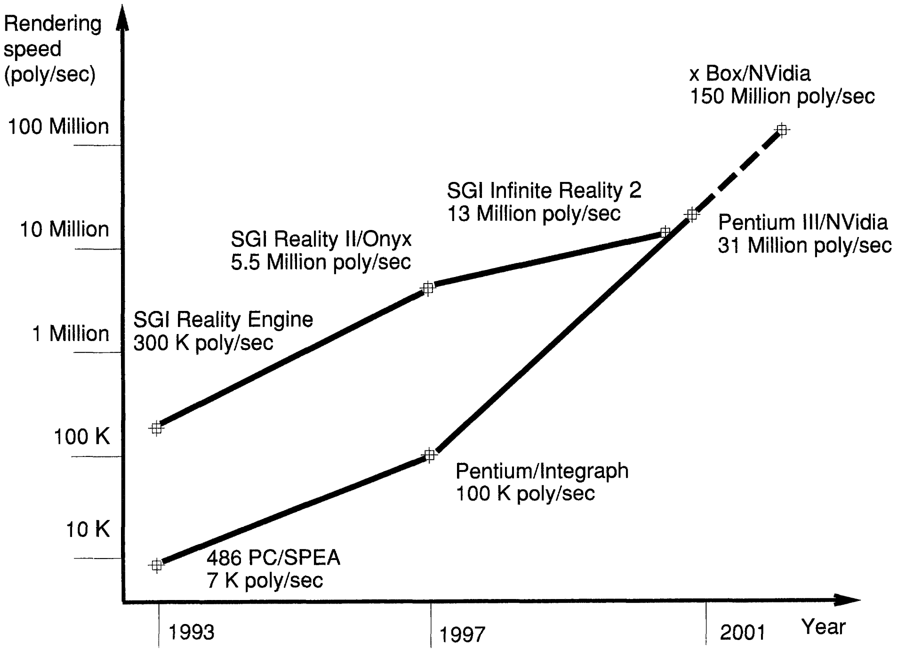

Fig. 1.8 Graphics performance comparison between PCs and high-end SGI workstations. Speed is given in polygons per second. Adapted from Burdea [2000]. Reprinted by permission.

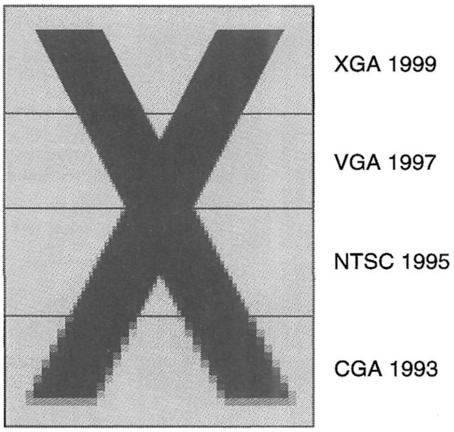

Fig. 1.9 LCD HMD image resolution evolution in the 1990s. XGA, Extended graphics array; VGA, video graphics array; NTSC, National Television System Committee; CGA, color graphics adaptor. Courtesy of Kaiser Electro-Optics Co. Reprinted by permission.

predicted that 3D VR would enjoy a healthy growth at a yearly rate of 21%, and estimated that by 2005 the VR market would reach $3.4 billion [Machover, 2000]. Figure 1.10 illustrates the growth in VR industry size, excluding the related fields of scientific visualization and real-time multimedia simulations.

1.5 THE FIVE CLASSIC COMPONENTS OF A VR SYSTEM

The discussion in this book will focus on the five classic components of a VR system, as depicted in Figure 1.11 [Burdea and Coiffet, 1993]. Chapters 2 and 3 concentrate

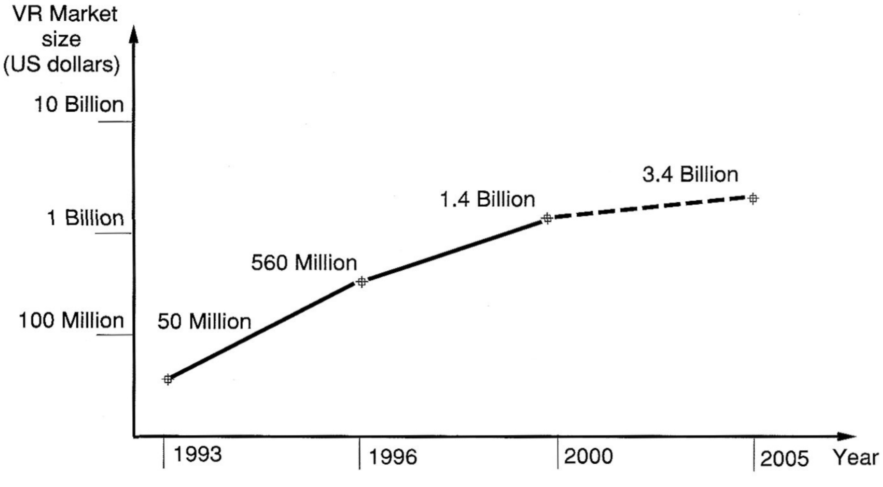

Fig. 1.10 Growth of the virtual reality industry since 1993. Based on Donovan [1993], Delaney [1997], and Machover [2000].

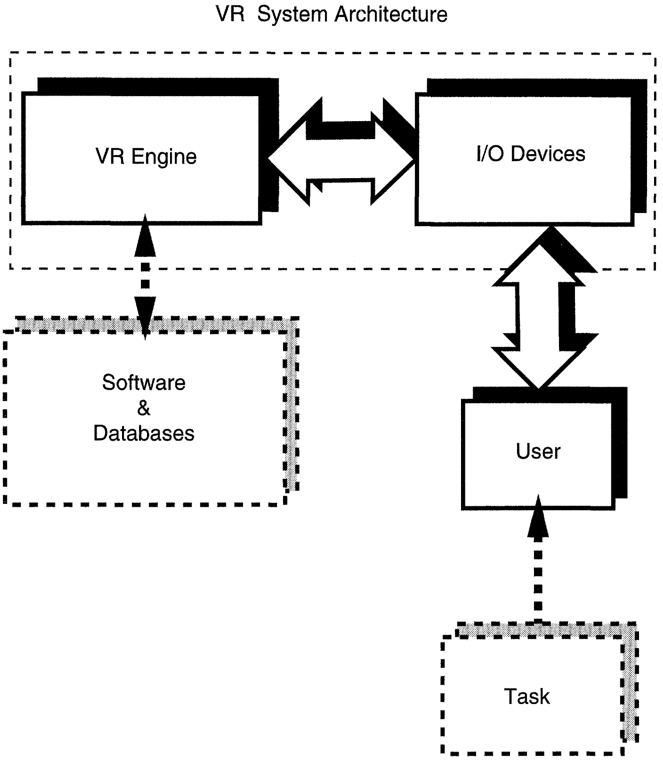

Fig. 1.11 The five classic components of a VR system. From Burdea and Coiffet [1993]. © Editions Hermes. Reprinted by permission.

on the very important I/O devices used either for user input (such as trackers, gloves, or mice) or output (such as HMDs, large-volume displays, force feedback robotic arms, etc.). The special-purpose computer architecture designed to match the high I/O and computation demands of real-time VR simulations is presented in Chapter 4. Chapter 5 deals with software for virtual object modeling, involving its geometry, texture, intelligent behavior, and physical modeling of hardness, inertia, surface plasticity, etc. Chapter 6 reviews a number of powerful programming packages, such as WorldToolKit and Java 3D, designed to help the virtual reality application developer. In Chapter 7 we analyze several human factors issues affecting simulation efficiency as well as user comfort and safety. Chapter 8 discusses traditional VR applications. These integrate all the aspects discussed in earlier chapters and make VR a tool for solving various practical problems in medical care, education, arts, entertainment, and the military. A look at emerging VR applications in manufacturing, robotics, and information visualization makes up the subject of Chapter 9, which concludes the book.

1.6 REVIEW QUESTIONS

1. What is virtual reality?
2. How does virtual reality differ from augmented reality and telepresence?

3. What are commonalities and differences between virtual reality and 3D computer graphics?
4. What was Heilig's role in the development of VR?
5. What was NASA's role in early VR developments and why was it interested?
6. What were the first commercial VR products?
7. What happened with the VR industry in the 1990s?
8. What are the five classic components of a VR system?

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