FROM CVR TO CVRO:
THE PAST, PRESENT, AND FUTURE
OF CULTURAL VIRTUAL REALITY.

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The authors first sketch the development of cultural virtual reality (CVR) within the overall context of the development of computing since the 1940s. After establishing the nature and ubiquity of virtual reality systems, especially in the 1990s, and predicting their further spread in the coming decade, they argue that the time is ripe for the creation of a new professional association devoted to the computer modeling of cultural heritage sites. The proposed association will be called CVRO (or, "Cultural Virtual Reality Organization") – a play on the Latin word curo *("I care for"; cfr. English "curate"). It will be open to professors, students, and professionals actively engaged in the theory and practice of cultural virtual reality – the content developers of CVR. The goals of CVRO will include: defining and defending the interests of its members; holding an annual meeting for the exchange of information; hosting a Web site; and developing aesthetic, scientific, and technical standards for cultural virtual reality models. Readers wishing to join CVRO are asked to contact one of the co-authors.*

1. INTRODUCTION

If the ten-year rule of thumb holds true, personal computer enthusiasts by the millions a decade from now will be interacting directly with virtual worlds through their desktop reality engines.

HOWARD RHEINGOLD (1991)

All men by nature desire to know. An indication of this is the delight we take in our senses; for even apart from their usefulness they are loved for themselves; and above all others the sense of sight. For not only with a view to action, but even when we are not going to do anything, we prefer seeing (one might say) to everything else. The reason is that this, most of all the senses, makes us know and brings to light many differences between things.

ARISTOTLE, *Metaphysics* 980a (ca. 330 B.C.)

Howard Rheingold's ten-year rule worked. Now, almost ten years after he published his prediction, millions of personal computer enthusiasts are interacting with virtual worlds through desktop 3D engines. But, with a few notable exceptions, the virtual worlds they are visiting in the computer games they play and on the Web sites they visit are generally the creations of anonymous digital graphic artists and make no claim to scientific accuracy or authenticity. Now, indeed, we can make a new prediction: after another cycle of the ten-year rule, by the year 2011 hundreds of millions of personal computer enthusiasts will be interacting with hundreds of thousands of virtual worlds on a variety of devices in their homes, schools, and offices. What will these worlds be? Most will undoubtedly be a great deal more photorealistic than today's average 3D computer model, but most will also almost certainly be no less fanciful. Humanity's appetite for new entertainments and spectacles is unquenchable and probably far exceeds its more sober curiosity for visualizations of scientific models of natural and man-made objects. In a recent futuristic issue of *Time* magazine devoted to "The Future of Technology" Ray Kurzweil predicts that virtual reality will be used to offer "any type of experience with anyone – business, social, romantic, sexual – without having to be in the same place" (KURZWEIL 2000, 83). Nevertheless, since "all men by nature desire to know", and, as in Aristotle's day, learn best through seeing, we can predict that, in comparison with the last ten years, many more of the new virtual worlds waiting to be born in the next 10-year cycle will be scientific, i.e. accurate digital representations of the object they purport to model as authenticated by experts.

As scholars active in the field of cultural heritage, it is naturally computer models of cultural heritage sites (i.e., CVR) that interest us. Digital reconstructions of archaeological sites, digital restorations of existing buildings showing them in their earliest phase, computer recreations of entire cities as they appeared at earlier stages in their history: all these are examples of virtual worlds that have been created in the past decade and that will be created in even greater numbers during the second ten-year cycle that is just beginning. We write this article because we are

concerned that as the pace of virtual world creation picks up, the opportunity not be lost to ensure that at least some small portion of the new models are scientific in the sense defined above. We also write because we think that now is the right moment to pause and reflect on what it will take to maximize the number of scientific models that will be created and consumed in the years ahead. As will be seen, we think that, in view of the impressive groundwork of hardware and software already laid, the answer we seek is more theoretical and sociological than it is technological. The bad news may be the weakness of human nature, but the good news is that CVR content developers can themselves take some obvious steps – taken many times by practitioners of other professions – and become to no small extent the masters of their own fate.

It has taken a long time for computing to reach the point where authenticated, photorealistic models of the world's cultural heritage sites have been possible and economical. It is the thesis of this paper that what we call "cultural virtual reality" (CVR) has now come of age. The technological and theoretical preconditions for CVR had been laid by 1990. The 1990s witnessed the efforts of a few pioneers who seized the moment and commenced the practice of CVR. In this paper, we review the "prehistory" of CVR and argue that it is now important for CVR developers to found a professional organization that will represent their interests; give them a forum for sharing new ideas and projects; communicate with each other; provide a clearinghouse for their CVR models that third parties can license; and, most important of all, provide a structure through which new technical, aesthetic, and scientific standards can be defined and implemented.

2. BACKGROUND. THE PREHISTORY OF CVR

As is well known, the progress of computing since World War II has been based on a number of favorable and related developments: the steady decrease in the cost and size of computer power, memory, and other key hardware components; the gradual increase in the number of components that can be put onto a single integrated circuit; the relentless acceleration of computational speed of central processing units; etc. Thus, ENIAC (Electronic Numerical Integrator And Computer), an early computer built from 1943-1946 at the University of Pennsylvania by John W. Mauchly and J. Presper Eckert, Jr., occupied a room that was about 10 x 15 meters in size; ENIAC could only perform 15 to 50 additions per second.[1] In 1996, in honor of the fiftieth anniversary of ENIAC, computer science students at the same university built a single computer chip, 7.44 mm by 5.29 mm, using a 0.5 micrometer CMOS technology, that had the same architecture and power as the original ENIAC .[2] The chip was less than 1/3800th the size of the original machine. Meanwhile, by the same year, the frequency of a typical PC microprocessor had reached 200 million instructions per second.[3] Also in 1996, the United States Department of Energy's Sandia National Laboratory and Intel Corporation created a parallel supercomputer that operated at 1.06 teraflops (1.06 trillion instructions per second). By 2000, IBM had created a supercomputer operating at 12.3 teraflops,[4] Personal computer performance had speeded up even more by 2000, reaching frequencies as high as 5.5 gigaflops.[5]

ENIAC was built to generate ballistic tables for the US Army.[6]

The original applications of computing power were military, and throughout the history of the postwar era, US military investment has driven breakthroughs in hardware, software, and in the very conception of how the computer might be used. Thus, Thomas Watson, Sr. the founder and President of IBM, resisted his son's efforts in the 1940s to launch a computer division of the company, claiming that the worldwide market was minute and limited to scientists.[7] Watson Sr.'s infamous (but hard to corroborate) estimate of potential demand was "maybe five computers".[8] In the event, his son, Thomas Watson, Jr., was right in predicting the penetration of the computer into the commercial sector: by 1959 the market of computers for business far exceeded that for the military, and under Watson, Jr. IBM's valuation had grown from $900 million to $8 billion.[9]

As early as 1945, a breakthrough of another kind was made that was to be as important for the growth of CVR as progress in brute computing power. Since the earliest computing devices of Schickard, Pascal, Leibniz, and Babbage, the purpose of the computer was clear: as the name implies, it was a calculator designed to spare humans the tedious effort of solving equations that were either long or, as in the case of tables, numerous.[10] Credit for a new vision of how a calculating machine might be used goes to Vannevar Bush.[11]

In the same period that ENIAC was being built, Bush published an article in a popular American magazine that laid out a stunning vision of technological and media convergence. Bush, who served during World War II as Director of the wartime Office of Scientific Research and Development,[12] dubbed his proposed information system the "memex". The memex was to be a vast multimedia database stored on microfilm and accessed by a computerized index built on the principles of associative logic.[13] The user's meandering trail through the database could itself be recorded and accessed again.[14]

In 1963, Douglas Engelbart founded the Augmentation Research Center (ARC) with US military funding through the Advanced Research Project Agency (ARPA, later DARPA). Engelbart knew and cited Bush's article;[15] he also shared Bush's goal of using the computer for operations far beyond mere mathematical calculation. As the name implies, ARC's mission was to explore how the computer could augment the human intellect in ways that Bush had anticipated. With the passage of time, Engelbart could see that Bush's memex was a technological hybrid whose use would be cumbersome, time-consuming, and ultimately frustrating to the user.[16] In effect, the work of the ARC was completely to computerize Bush's memex and make other improvements. New devices and processes were developed at ARC to make the parts of the system more ergonomic and efficient: the mouse and pointer cursor; display editing; linking and in-file object addressing; multiple windows; hypermedia.[17] In the '60s and '70s the lab developed a hypermedia-groupware system called NLS (for ONLine System).[18] Parallel research was done at the University of North Carolina, Chapel Hill by Frederick Brooks, who founded that university's Department of Computer Science in 1965. His work since then has tested and implemented his concept of "intelligence amplification", whose similarity to Engelbart's notion of augmentation has been noted by RHEINGOLD 1991 (36).[19]

Major contributions to the prehistory of CVR were also made by Ivan Sutherland in the 1960s. In research for his Ph.D. dissertation (SUTHERLAND 1963), Sutherland developed *Sketchpad*, the first program that permitted the user to make

highly precise engineering and architectural drawings on a CRT. *Sketchpad* also had the ability to zoom in and to zoom out on the CRT. It could produce memory structures, rubberband lines, and it was able to make exact lines, corners, etc. at a scale of 1:2000.[20] In 1966, while teaching at Harvard, Sutherland's interest in computer-generated graphics led him to the first experiments in what would much later be called "virtual reality". Adapting an existing video system whose display was "head-mounted" (i.e., a so-called head-mounted display, or HMD), Sutherland substituted computer graphics input for the video, thereby immersing the wearer of the display into a virtual world consisting of a simple wire-frame room with the cardinal points (NORTH, SOUTH, etc.) inscribed on the "walls".[21] As early as 1964, Sutherland's research, like Engelbart's, received US military funding through ARPA. In 1968, Sutherland joined with David C. Evans, then a fellow professor at the University of Utah, and founded Evans & Sutherland with the financial support of Venrock, the Rockefellar family's venture capital company. The company's original products were graphics devices, such as image generators, and flight simulators. The company struggled until the Navy contracted in 1977 to purchase its CT5 image generator for use in the new CH46 helicopter system.[22]

Just as Evans & Sutherland was finally getting off the ground as a commercial venture, James Clark was arriving at Stanford to teach computer science. In 1978, he created a processor which he called the "geometry engine". This was a chip onto which the algorithms used to create 3D computer graphics had been programmed, thereby dramatically speeding up rendering time. By 1982, Clark was ready to leave the university and start up Silicon Graphics Inc.[23] By 1984, SGI (as the company was to be officially named in 1999) was shipping its first workstations and producing high-end 3D graphics systems that came to dominate the market by the early 1990s from the time when the Onyx Reality Engine was launched in 1993 and the first SGI Reality Center was created by David Hughes of SGI in Theale (Berkshire), England.[24] The Center featured a Reality Theater, which is a room in which the audience views a curved screen onto which images from a SGI supercomputer are projected. The Reality Theater provides an immersive, interactive, and real-time environment in which large or small groups of people can experience a virtual world together. Because of their high cost, Reality Theaters have mainly been sold to government agencies and corporations (particularly to companies in the field of oil and gas exploration). In 2000, UCLA was to become the first university in the world to build a SGI Reality Theater.[25]

The 1980s also saw the development of haptics, or "the use of physical sensors to provide users with a sense of touch at the skin level, and force feedback information from muscles and joints".[26] Jaron Lanier and his company VPL developed several important patents in this area and marketed the DataGlove, an early haptic device.[27]

The 1990s saw the development of several other kinds of theaters and displays dedicated to the presentation of real-time, immersive virtual reality. In 1992, the first was created for SIGGRAPH 92 Showcase. The CAVE is a cube-shaped room, typically 10' x 10' in size or bigger, onto to whose walls, ceiling, and floor the computer output is projected in real-time. The first CAVE was used for scientific visualization of a variety of astrophysical phenomena such as the Rayleigh-Taylor Instability and gravitational wave

components predicted by Einstein's General Theory of Relativity.[28] CAVEs are particularly good spaces in which to run CVR models of architectural and urban spaces, since users are fully immersed within the virtual world, and the right angles of the CAVE generally fit the angles of virtual architectural spaces. The UCLA CVR Lab has been able to run one demonstration in the CAVE of Virginia Tech, thanks to the generosity of the Virginia Tech College of Architecture and Urban Studies.[29] Also in the 1990s, Evans & Sutherland marketed the StarRider domical theater, which has mainly been used in planetaria.[30] At the invitation of Evans & Sutherland, the UCLA CVR Lab has been able to run a demonstration of its models in the StarRider theater, with results that were not quite as satisfying as those in the Reality Theater and CAVE. Owing to the StarRider's domical projection surface the rectilinear shapes of our architectural models were distorted. It remains to be seen if the StarRider can be tweaked to provide better performance for typical CVR models.

As the theoretical and practical foundations for virtual reality were laid in the 1960s, 70s, and 80s, early applications tended to be military and industrial. This is not surprising in view of the high cost of the first systems. Flight simulation and oil exploration have already been mentioned.[31] But cultural applications of the kind that interest us were not far behind. Nicholas Negroponte indeed has identified the Aspen Movie Map of 1978 – funded, inevitably, by ARPA – as the very first multimedia project (NEGROPONTE 1995, 65-67).[32] It can also be considered the direct ancestor of CVR, which could not yet exist because, as we have seen, the necessary hardware and software had not yet been created. The streets of Aspen, Colorado were filmed in each direction by taking a shot every three feet. The footage of the straight streets were put onto one videodisc; the curves were put onto a second videodisc. The videodiscs were driven by a computer, on whose display the footage was seen. The user had the illusion of driving through the town, turning right or left at intersections, as he wished. The motivation behind the project was to give the US armed forces the virtual equivalent of the kind of training the Israel army used to prepare for the successful raid on July 3, 1976 on the Entebbe, Uganda airport, where 103 hostages were being held by Palestinian terrorists. But whereas the Israeli training took place in a physical reconstruction of the Entebbe airport (which, by chance, Israelis had designed), the US solution was to create a system that could support photorealistic computer simulations of any and every possible terrorist target around the world.

Michael Naimark, a media artist who collaborated with Negroponte on the Aspen project, characterized the system as "surrogate travel", not "virtual reality", a term whose coining is generally attributed to Jaron Lanier at some unspecified time in the late 1980s.[33] Even more common in the 1980s was the term "simulation" (RHEINGOLD 1991, 24; BIOCCA, KIM and LEVY 1995, 6), which was taken over from computerized flight training. The Aspen Movie Map inspired several other prototypical CVR projects in the 1980s, including UCLA's Project CICERO, which proposed to create an urban simulation on videodisc of ancient Rome using the great "Plastico", or plaster-of-Paris model of the city in the time of Constantine. The model is housed in the Museum of Roman Civilization in a suburb of Rome (see FRISCHER 1988). In the event, test photographs showed that the Rome model, which had been started in the 1930s and

was intended to be seen from a balcony at a height of several meters, did not have enough detail to sustain a close viewing, and so Project CICERO was never implemented in the manner originally proposed. In the mid-1990s, CICERO was revivified as UCLA's ROME REBORN project, which saw the use of VR technology in effect to recreate the Plastico from the beginning, with new archaeological data – not the Plastico itself – used as the basis of the VR model.

By the early 1990s, the term "virtual reality" had come into general currency (cfr., e.g., FISCHER 1991; LANIER 1992) and the 90s were years in which true CVR projects first appeared – not always, as we will see, to great acclaim. But as with any innovation, the early failures were as instructive and useful as the successes. The spread of the term and the VR industry itself can be measured from, e.g., the following statistics gleaned from the US Patent Office database. In abstracts prior to 1991, the term "virtual reality" does not appear at all. From 1991 to 1995, we find it 22 times. But by 1996-2001, the number of attestations has increased to 172.

Given the terminological creep by which "virtual reality" displaced such earlier terms as "surrogate travel", "artificial reality", and "simulation", it is not surprising that the 1990s also saw some confusion about what virtual reality really means. One of the pioneers of the field indeed by 1997 was expressing her exasperation about the term's misuse as a catchall for any use of computers that reeked of the "bizarre and science-fiction" (CRUZ-NEIRA 1997, 2-2). She cited with approval the definition of Steve Bryson and Steve Feiner, who called "virtual reality" "the use of three-dimensional displays and interaction devices to explore real-time computer-generated environments". HEIM 1993 (109-127) attributes to virtual reality any or all of the following characteristics: simulation, interaction, artificiality, immersion, telepresence, full-body immersion, and networked communications. In what follows, we understand "virtual reality" as implying the use of three dimensional computer graphics in a system that is (at a minimum) real-time, immersive, and interactive. CVR is the use of VR systems specifically for the presentation of the world's cultural heritage sites. For our purposes, an important distinction should be made between VR and computer graphics (CG), with which VR is sometimes confused. While all VR could be called CG, not all CG constitute VR. The difference is that, whereas CG is simply "pictorial representations of objects and data using computers",[34] VR is CG requiring immersion, interactivity, and a real-time delivery system. Generally, those CG that are not properly VR fail the test of real-time applicability. Thus, whereas in a true VR system, the computer generates images at a frame rate equal or greater than the *phi*-phenomenon (ca. 24 frames per second),[35] CG used in special effects in movies require average rendering times of ten hours per frame.[36]

As the 1990s progressed, another important development could be detected: a partitioning of VR developers between what could loosely be called "artists" and "scientists". Heim humorously applied a "bicoastal" metaphor to this division: "There are two coasts in the mind. The West Coast wants VR to serve as a machine-driven LSD that brings about a revolution in consciousness; the East Coast wants a new tool for supporting current projects and solving given problems" (142). In a recent book, HOLTZMAN 1998 discusses the aesthetic possibilities of VR, reveling, as an artist, in the new creative possibilities VR technology affords. As yet there is no similar study of the other branch of the bifurcation. Below, we will argue that one reason a professional organization of CVR developers is needed is precisely to provide a framework in which such studies can occur. Ironically, it has been the UCLA Cultural Virtual Reality Lab, located on the West Coast, that has done some of the early studies on scientific CVR.

3. FOREGROUND

With appropriate programming, such a display could literally be the Wonderland into which Alice walked.
IVAN SUTHERLAND (1965)

VR has the potential to create an extremely rich perceptual and cognitive environment. Interacting with such an environment may sometimes tax mental capacities. Under such perceptual and cognitive stress people may be more likely to accept percepts and statements as real because they don't have the capacity to check for veracity, and the default value is real.
SHAPIRO and MCDONALD 1995, 334

If the cinema art is going to draw its subjects so generously from history, it owes it to its patrons and its own higher ideals to achieve greater accuracy. No picture of a historical nature ought to be offered to the public until a reputable historian has had a chance to criticize and revise it.
Prof. LOUIS GOTTSCHALK
University of Chicago, 1935 in a letter to the president of Metro-Goldwyn-Mayer (ROSENSTONE 1995, 45-46)

The theory and practice of CVR developed apace in the 1990s. As early as 1989, Reilly and Shennan proposed applying 3D computer technology to archaeological problems, especially three-dimensional modeling of archaeological sites (REILLY 1989; REILLY and SHENNAN 1989). A volume of occasional papers was published by the British Museum in 1996 that included contributions such as RYAN 1996 and CHALMERS and STODDART 1996 that followed up on Reilly's suggestions. FORTE and SILIOTTI 1997 (originally published in Italian in 1996) in effect present a catalogue of actual archaeological computer modeling projects from the first half of the 90s. From the list of contributors of the models, we can see that major players up to that point were commercial: Taisei Corp., Hochfeiler, IBM, Infobyte, Santa Barbara Studios and Pathways Production, etc. (FORTE and SILIOTTI 1997, 288). CINECA is the exceptional academic institution on the list. Given the expense of VR systems in the early 1990s, this is not surprising.

An odd feature of FORTE and SILIOTTI 1997 is the frequent disconnect between the descriptions of the archaeological sites and the computer models used to illustrate them. Rarely, if ever, are we told who made the model, whether there was any consultation between the modelmaker and the archaeologists, and what elements of the model are known with certainty and which are hypothetical. Yet, as Sutherland trenchantly noted as early as 1965, "with appropriate programming, such a [HMD] display could literally be the Wonderland into which Alice walked" – a Giuseppe Arcimboldo portrait, as opposed to a scientific

illustration by such Renaissance masters as Francesco di Giorgio Martini or Luca Pacioli (see CROSBY 1997, 232). This is not in any way to deprecate the value of Forte and Siliotti's seminal publication.

The issue of "historical credibility" raised by Forte and Siliotti is the explicit subject of RYAN 1996. As he notes (107), many early CVR projects were undertaken as "vehicles for demonstrating advanced graphics techniques with any archaeological considerations playing a less important role" (107). Ryan urged archaeologists "to communicate archaeological and historical information to their colleagues and to the public, not to demonstrate their skills in the latest computer graphics techniques" (107). In this article, Ryan's concern was to relate the appearance of a computer model to the resulting inferences that unsuspecting users might draw about the quality of the archaeological data on which the model was based.

It seems as if many people are taking for granted the "real" nature of virtual worlds. Visual models are the equivalent of sensory representations in the brain: a translation of empirical phenomena into a geometric language. As models, they are the result of a transformation of input data, into a geometric explanation of the input, with light and texture information. That is, geometry is used as a visual language to represent a theoretical model of the pattern of contrast and luminance, which is the strict equivalent of perceptual models of sensory input in the human brain. All that means that "visualizing" the real world it is not the same as "picturing" it, because the model and the graphical means for creating and visualizing the world are distinct.

Accuracy is the topic of a theoretical paper by SHAPIRO and MCDONALD (1995). Taking as their point of departure earlier psychological research showing that "belief is the default", they argue that, in VR systems, users are even more apt to lend credence to their experiences than they do in traditional media (cfr. especially 336-337). Operating from the assumption that all VR will be, to use Heim's term, "West Coast", Shapiro and McDonald confront only the issue of the effect of VR on users of artistic content. Recalling the old debate about the effect of mimesis on the viewer which goes back to Plato and Aristotle, they see both the danger of escapism and also the benefit of therapy. "Obviously spending too much time in virtual reality could be damaging to those who need to confront reality and not escape it. It could be particularly damaging to children and adolescents. But in some cases living in a VR could be therapeutic. Certain kinds of therapy encourage patients 'to abandon unproductive images and substitute more efficient images of reality.' In a skilled therapist's hands virtual reality might assist such processes" (342). Because Shapiro and McDonald do not consider "East Coast" VR, they do not discuss its possible effects on scientific research and education. We will return to this below.

The issues of accuracy, authentication, and scholarly input into the modeling process were brought urgently to the fore in the Pompeii CVR project of the now defunct Simlab of Carnegie Mellon University.[37] The Pompeii project also raised questions about the use of real-time VR in the museum context. Simlab was co-directed by artist Lowry Burgess and computer scientist Carl Loeffler.[38] It appears to have reached the peak of its existence in the period 1994-1996, when it created computer models of the Temple of Isis, the Greek theater, and the Triangular Forum at Pompeii. The models were shown in a gallery at the De Young Museum in San Francisco in 1995. The public,

which flocked in great numbers to the exhibit, was invited to don HMDs and explore the virtual world created by the Simlab team. SGI, whose platform was utilized, supplied the hardware but not a technician regularly on duty. The frequent technical glitches inevitable in any such exhibit thus often caused delays and other problems to which the museum staff found it hard to respond. The number of HMDs was far fewer than would ideally have been needed to give every visitor a chance to visit virtual Pompeii. Those that did get to visit found that they were left alone to explore the virtual world without a guide or any source of help and information.

The sense that the Pompeii exhibit was more, in Ryan's terms, a "vehicle for demonstrating advanced graphics techniques" than for conveying historical information to the museum visitor was reinforced by the poor quality of the model. Despite the project's financial support by the Archaeological Institute of America, no professional Pompeianists are known to have been consulted when the project was in its inception, nor to have had any major input on the final product. Predictably, professional archaeologists and art historians were not impressed by the results. In a thoughtful review in *Architronics*, BRIGMAN 1996 wrote:

> *Let's begin with the troubling news. Lynn Holden, representing the Virtual Pompeii design team, showed video excerpts from an interactive walk-through of Pompeii's Temple of Isis and Large Theater. The Virtual Pompeii project, which is maturing thanks to a cadre of Onyx Workstations (donated by Silicon Graphics) and a grant from the Archaeological Institute of America, got mixed reviews. Certainly the design group at Carnegie Mellon's Virtual Reality Simulation Laboratory (VR SIMLAB) have ambitiously stalked what Silicon Graphics calls in their brochures "infinite reality". At the same time, however, the effect is disturbing and uncanny, sometimes cheesy and slick. It all too frequently feels packaged. Although impressive to those craving transport (indeed, at times the Pompeian site was "spectacular"), when Mr. Holden finished narrating the otherworldly glide-through of the restored Campanian complex, replete with anachronistic musical accompaniment and an androidal priest, there was a palpable electricity in the audience. Some sighed with what seemed to me exasperation, others with wonder.*
>
> *Comments from the crowd ranged from the prosaic (i.e., the frustrations of trying to use the unwieldy navigation helmet that accompanied the project's public debut at the M.H. de Young Museum in San Francisco) to the hostile. In particular, a number of scholars observed that the design team had fashioned their temple complex out of mural vignettes excised from several different archaeological sites and contexts. Painted panels along the periphery of the reconstructed sanctuary were unsettling to many precisely because they had been filched from other Roman cities. Thus, the reconstruction took form as a pastiched continuum, a collage of recombinant parts. Not the kind of thing scholars of Antiquity are bound to love.*

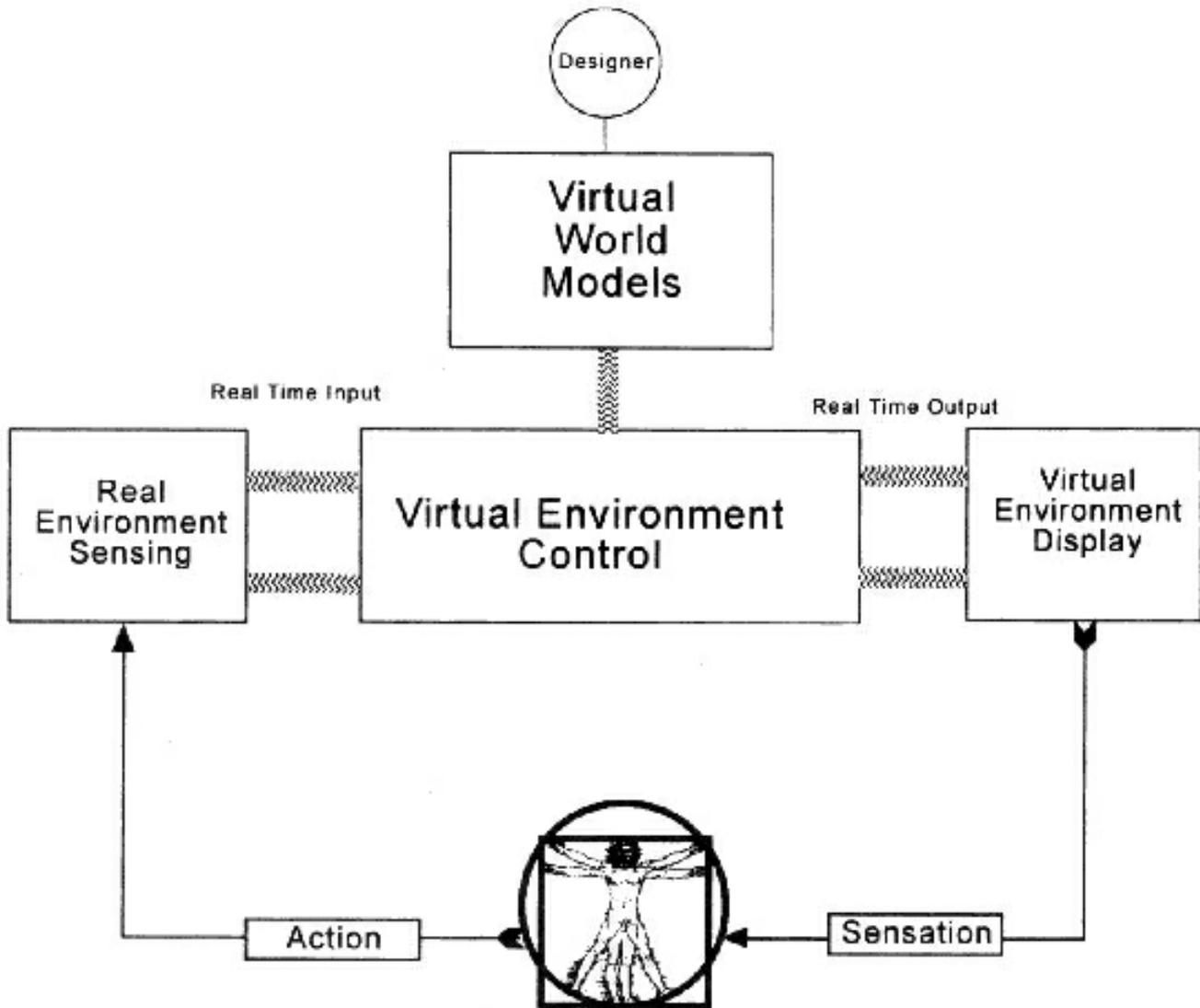But pioneering efforts that fail can be just as valuable as

Figure 1. *Diagram of a vr system (Biocca and Delaney 1995, 114).*

those that succeed. Such is the case with Simlab's Pompeii project. For those who studied the show in San Francisco, lessons could be learned about the best vr displays to use in public exhibits; the desirability of having a well-trained technician on duty at all times; and the need to make the virtual world an interactive information system, not simply an aesthetic experience. Even more important lessons could be learned about the structure and purpose of such cvr projects: although Simlab did invite some Pompeian experts to view its models, they were invited only after the completion of the bulk of the project and were not expected to do anything but admire the results.[39] This is exactly backwards: for the kind of scientific accuracy demanded by Ryan 1996, the experts should be in charge of collection of the modeling data, should regularly review the modelmaker's progress, and should be given the opportunity to sign off on the final product.

On the other side of the Atlantic in the 1990s archaeologists have also been rarely involved in the creation and interpretation of Virtual Reality models (see a general reference in Barceló 2000). In Europe, most cvr applications have developed as an offspring of engineering research in computer graphics. With a few notable exceptions, most teams have not included historians, archaeologists or humanists, but only computer experts. Only recently have museums started participating in such projects as content providers, but these concern educational multimedia applications, which are only the tip of the cvr iceberg. In these conditions, it is no surprise that the "historical method" has not been a primary concern of cvr in Europe. In the early cvr projects, archaeologists had "to agree to be guinea pigs for the research of computer programmers" (Daniels 1997), and later they did little to improve their junior status. Notwithstanding the commitment of an international group of interdisciplinary researchers, official archaeology and vr seem to have marched on separate if not divergent paths.

Within the European Union, cvr (and the so-called digital culture or Digicult, as it is officially defined) falls into the category of Information Technology (it). In the 5th Framework, the European Commission (ec) introduced ist (Information Society Technologies) Programme as a funding source for it. In July 2000, ist called for projects concerning the "virtual representations of cultural and scientific objects". While cvr was relegated in the 5th Framework to the technology-dominated world of it, the cultural initiatives of the ec are clearly inspired by a (mis)conception of culture as ephemeral, contingent, and

"artistic". Unfortunately nothing replaced Raphael, the EC's program for culture which ended in 1998 and that offered more funding opportunities for Cultural Heritage and CVR. Several "digital culture" projects have been funded through IST since 1999, and some of the most recent ones have been reported at this Conference. Those funded in 1999 that are involved with archaeology mainly exploit the resources of archaeological sites and museums – e.g., ARCHEOGUIDE, which is a HMD-system at Olympia;[40] and the TOURBOT museums project, in which an avatar of the user can visit virtual museums, while the viewer himself views the experience at home via the Internet. [41] Projects such as these – however worthwhile – confirm that adage that "Europe finances only expensive gadgets". Both projects propose to increase the quantity of information available to visitors, but in neither project proposal is there any corresponding sign of a desire to increase the quality of the content.

Nevertheless, the participation of four IST projects at this Conference (and the fact that the conference itself was funded by the EC, even if the proposal did receive some sharp criticism) shows that something is moving on the engineers' side. For their part, some enlightened archaeologists outside the circle of enthusiasts who for many years have been preaching the advent of the computer era have realized the potential of 3D visualization for scientific research and scientific communication. They understand that, besides being a powerful educational tool for presenting archaeology to the non-specialist, CVR raises "questions that tax the ingenuity of archaeologists" and is itself therefore in need of further reflection and study (RENFREW 1997). But misunderstanding and lack of communication and collaboration between the two groups still predominate. The engineers go on believing they can implement ambitious projects on cultural heritage without the collaboration of content experts. Their projects are nevertheless funded and therefore officially approved. The archaeologists react to their exclusion by relegating virtual models to the category of fancy museum exhibition tools useful, at best, for *vulgarisation* or, at worst, for videogames.

In figure 1, we see the basic functions of a VR system and note the crucial role played by the Designer as the initiator and manager of the entire system. The question raised by the Simlab Pompeii project, by recent EU-sponsored initiatives as well as by the mainly commercial models utilized by FORTE and SILIOTTI 1997 is: "who is the Designer"? If the Designer is to be a technician using CVR to display his wares or a commercial company using CVR to earn a profit, then the criticisms of Brigman will become a perennial complaint of academics. And, as has happened with historians' complaints about historical films such as that quoted above by Louis Gottschalk in the 1930s, the criticisms of academic CVR developers are likely to fall upon deaf ears. Of course, "the Designer" should ideally be "the Designers": the technician responsible for hardware and software; the content developer responsible for the image of Leonardo's Vitruvian Man in the diagram of Figure 1; and the digital graphic artist, or modelmaker, responsible for actually creating the VR file. In some settings, there will be even more experts involved: in a commercial project, for example, the producer, financier, and marketer; in a government project, entrenched bureaucrats and elected officials. Of course, the participation of some of these other "Designers" may complicate, or completely undermine, the implementation of scientific standards in CVR modeling.

This raises the question of power: for the question of "who is the Designer"? is really tantamount to "who is in control"? How can academic CVR developers ensure that in at least some instances the answer to this question in the future will be less painful than it has been in the recent past?

4. CVR TODAY

As M. Forte noted, in the 1990s CVR models tended to be designed for high-end workstations and supercomputers (FORTE 2000). But by the year 2000, real-time VR is possible on the PC platform with relatively inexpensive graphics cards. Moreover, soon to hit the commercial market are PC-based 3D engines; inexpensive graphics cards supporting anti-aliasing; and CPUs and buses supporting much faster calculations and data transfer than ever. The average PC of 2001 will indeed have at least as much computing power as the expensive SGI Onyx Reality Engine supercomputer of 1993. The pc of 2002 will make this comparison obsolete, and on and on with no end in sight. As power increases, applications will keep pace, if only because – as has been seen over and over again – chip manufacturers will provide seed money to research projects and commercial start-ups exploiting the otherwise superfluous resources of their latest models. Moreover, as Barceló et al. 2000 make clear, in the five years since the publication of Forte and Siliotti, CVR has taken hold in the academy. Many individual projects and labs such as the UCLA Cultural Virtual Reality Laboratory and the Reality Center at CINECA have sprung up with the mission of creating scientific CVR models.

Characteristic of recent CVR projects and theoretical work has been an implicit, or sometimes explicit, recognition of the key advantage that academic CVR produced by subject experts has over its commercial counterparts: what Heim referred to as "metaphysical anchoring" and what we prefer to call the added value of scientific credibility and authentication.[42] In a recent publication, Barceló noted with disappointment that "in most cases the use of virtual reality in archaeology seems more an artistic task than an inferential process. Virtual reality is the modern version of the artist that gave a 'possible' reconstruction using water-colours" (BARCELÓ 2000). In the same publication, some papers are beginning to focus explicitly on the question of accuracy (cf KANTER 2000; FRISCHER *et al*. 2000). One contribution (FORTE 2000) brought up a more fundamental issue:

Noticeable gaps are represented by the fact that the models are not "transparent" in respect to the initial information *(what were the initial data?)* and by the use of the peremptory single reconstruction without offering alternatives (*it could have been like this but we can also offer other models…*).

The questions Forte poses in his parentheses are typical issues of metadata.[43] In effect, Forte is calling for a new philology of CVR: a methodology for how CVR models should be edited and published. In a classic work on textual criticism, Maas defined the tasks confronting the editor of a text as follows:

In each individual case the original text either has or has not been transmitted. So our first task is to establish what must or may be regarded as transmitted – to make the recension (*recensio*); our next is to examine this tradition and discover whether it may be considered as giving the original (*examinatio*); if it proves not to give the original, we must

try to reconstruct the original by conjecture (*divinatio*) or at least to isolate the corruption (Maas 1958, 1).

Mutatis mutandis, recensio, examinatio, and *divinatio* have analogous procedures in the creation and publication of a CVR model. Philology also offers CVR developers answers to how Forte's questions might be handled. As Maas notes (21 ff.), a philologically prepared text is not simply printed and presented without further ado by the editor. The philologist has the duty of introducing the text with a preface that "should (1) describe all the witnesses… (2) demonstrate the relationship of the witnesses where this is at all possible in a stemma… (3) characterize the quality of the archetype… (4) settle all questions of spelling and dialect" (Maas 1958, 21-22). Moreover, in the text, certain signs are used to alert the reader to a problem: < > for conjectural additions; [ ] for conjectural deletions; † for irremediable corruptions. Finally, underneath the text, the philologist must print an *apparatus criticus,* noting: "(1) every departure from the archetype not already indicated in the text; (2) all rejected variants… (3) the sub-variants… (4) identical readings of two or more variant-carriers… (5) doubt as to the correctness of the text" (22-23). Thus, the philologist editing a text deals with metadata in the preface, in *the apparatus criticus*, and in the text itself through the use of signs.[44] None of this can be done in the same way by the CVR developer, who works in multimedia, unlike the editor of texts who works in the single medium of print. Thus, Maas' rules can only be applied by analogy, but they certainly can be applied – at least if CVR developers unite to define their own standards, rules, and conventions. On its Roman Forum Web site, and in its other products, the UCLA Cultural Virtual Reality Lab has been experimenting with the development of such philological procedures, including even the *apparatus criticus* (see http://www.cvrlab.org).

In CVR, then, accuracy means not only that the data are represented correctly; it also implies the development of a new "CVR philology" to handle metadata. The two goals of professional CVR developers – accuracy and authenticity – are two sides of the same coin. Accuracy pertains to the data and metadata; authenticity to the user's experience of the data and metadata. Research on other media suggests that, ironically, far from getting in the way of the user's experience and sense of authenticity, metadata can even add to the credibility of a CVR model, as can be seen in the following study of Condry (1989) cited by Shapiro and McDonald (1995, 338):

Condry (1989) illustrated another complexity of the relationship between sensory cues and reality judgments. He tells of watching the first moon landing with his then 5-year-old son. The same perceptual cue, the poor quality of the television picture, convinced his son that the picture was not real, but added to the adult's feeling that this was indeed real. The child apparently made reality judgments based strongly on veridicality. But the adult inferred that an image being transmitted from the moon in real time with 1969 technology would be degraded. He would have been suspicious of a studio-quality image. Thus, sophisticated, adult metacognitions about the nature of communication can create a situation in which less sensory information is more realistic.

As applied to CVR, this suggests that a philologically edited CVR model explicitly marked up by < >, i.e., conjectural supplements, and by †, i.e., areas where data is hopelessly lost, could well be perceived by users to have more authenticity precisely because it would have *less*

veridicality than a perfectly restored model presented without any philological apparatus.

On the other hand, philology itself supports the CVR developer's constant need courageously to produce supplements where evidence is lacking: "if the sense requires it I am prepared to write *Constantinopolis* where the MSS. have the monosyllabic interjection *o*." wrote A.E. Housman (cfr. Reynolds and Wilson 1968, 162), echoing the earlier sentiment of Moritz Haupt (1808-1874). There is a point at which many of our models have to go beyond empirical observations and to provide a satisfactory user experience or to suggest particular interpretations, must necessarily introduce less certain elements. Although grounded in evidence and supportable inference, many of these elements are essentially speculative in form. At one extreme, this may entail a decision about paint colors on an otherwise intact statue or on some other artifact. At the other, it might concern the form of a building where the only remains are short lengths of robber trenches or beam slots surviving between later disturbances. For many archaeologists, the latter is closer to their reality than are the impressive ruins of Pompeii or the Roman Forum. Indeed, we may often need to work far beyond this level of uncertainty, for example when visualizing a landscape or townscape in which the area known from archaeological investigation is only a tiny fragment of the whole. On such a basis we can build interactive environments suited to the needs of a wide range of audiences from casual museum visitors to advanced scholars.

Sometimes, we are not the first to integrate the fragmentary record of archaeology. When we accept a previous scholar's conjectural supplement, we need to put that on record. Even if we do not agree with earlier scholarship, we owe it to our predecessors and to our users to note and, ideally, to display within our models any plausible alternative views. There may indeed be more than one conjecture on record. In a philological *apparatus criticus*, any alternative readings should be cited, including "conjectures in order of merit" (West 1973, 87). The same should be true of a CVR model, as has been suggested by Roberts and Ryan 1997, and has been applied by Frischer *et al*. 2000 as well as by David Wheatley and Graeme Earl in the Negotiating Avebury Project.[45]

There is nothing inherently wrong in going from *o* to *Constantinopolis*, or in presenting, within the same model, alternative views of how the site might have originally looked. To the contrary. The important point is that when we add information beyond what is archaeologically attested, we need to flag our supplements or alternative interpretations of the data by means of signs.

At this point, it is important to invoke semiotics: Maas correctly calls < >, [ ], and † "signs". Most signs are arbitrary, and that is certainly the case with the standard philological specimens mentioned by Maas (in West 1973, 80-81, there are even more signs catalogued). Why should † mean "hopelessly corrupt" and not, for example, "dead" or "Christian" or, for that matter, "intersection"? As Eco notes, "the sign is a gesture produced with the intention of communicating… The existence of a certain rule (a code) enabling both the sender and the addressee to understand the manifestation in the same way must, of course, be presupposed if the transmission is to be successful… signs seem to depend on arbitrary decisions" (Eco 1986, 16). In order for the communication act to succeed, the sender and

addressee must have agreed in advance what the initially arbitrary and therefore meaningless signs shall mean when transmitted. This implies that there is a crucial social element in the development of any semiotic system. † means "hopelessly corrupt" in a philological text because philologists like Maas have long since agreed that it should so signify and since authorities like Maas have codified such agreements in handbooks that no self-respecting professional philologist would have neglected to master before attempting to practice his craft. Thus, it will not do for one CVR lab to develop metadata signs and standards. That would be like one person trying to invent a language or alphabet: it could be done, but it would mean that he could communicate only with himself.

Beyond philology, CVR developers have an interest, which this time they share with their counterparts, the engineers and technicians, in banding together to define common technical and aesthetic standards for the models they make. If each consumer electrical device ran on a unique voltage, the market for home electrical products would be only a small fraction of what it is today. You would wire your house with 135 volt current to run your heater, and then have to re-wire your house with a 55 volt line to run your new toaster. Each purchase of a new electrical device would require a major investment in new infrastructure, which would perhaps serve only your latest purchase. In the CVR world, there are many competing file formats and proprietary software packages that are used to produce CVR models. As long as different CVR developers use different solutions, the market for CVR will be quite limited. Like purchasers of new toasters or television sets, buyers of new CVR models want to be able to plug them in and operate them automatically without worrying about their computing infrastructure. They want the model of a building in one part of a city to operate smoothly with another model of a site elsewhere in the same city. They want to be able to purchase a model of the Roman Forum in 100 BC from vendor A; and a model of the Forum in 200 AD from vendor B; and they want an interface that allows seamless switching from one model to the other. For their part, CVR developers do not want to have to guess right about what hardware and software their potential customers own or are willing to purchase. Implicit in the technical compatibility of CVR models is their aesthetic homogeneity. To look right, as well as to operate properly, CVR models from different vendors should share the same texture library. Adoption of common technical and aesthetic standards thus serves the interests both of consumers – who will buy more CVR models if they can leverage their initial investment in a VR system by being able to run all possible CVR models – and of producers, who will operate with the assurance of a large installed base for their products.

Another way to solve the problem is by "learning by doing"; to learn about reality we must first build a model of reality and make it run. To understand reality and all of its complexity, we must build artificial objects and dynamically act out roles with them. That means transforming "virtual" into "augmented" reality. Augmented reality has been defined as the simultaneous acquisition of supplemental virtual data about the real world while navigating around a physical reality (DURLACH and MAVOR 1995). For information pertaining to complicated 3D objects, augmented reality is an effective means for utilizing and exploiting the potential of computer based-information and databases. In an augmented reality system, the computer provides additional information that enhances or augments the real world, rather than replacing it with a completely non-existing environment. In AR the computer contains models of significant aspects of the user's environment. In an Augmented Reality Environment, we should "imitate" the real world, describing an object by more than just computer graphics to provide a natural interface for processing data requests about the environment and presenting the results of requests. Merging graphical representations of augmenting information with the view of the real object clearly presents the relationship between the data and the object. Using AR, the user can easily perceive and comprehend many components of the queried data.

The goal of the visual model should not be "realism" alone, for the sake of imitation, but in order to contribute to understanding of non-existing objects. An Augmented Reality Environment is something more than a visually "realistic" geometric model. We also need "dynamism and interaction". A dynamic model is a model that changes in position, size, material properties, lighting and viewing specification. If those changes are not static but respond to user input, we enter into the proper world of Virtual Reality, whose key feature is real-time *interaction.* Here real-time means that the computer is able to detect input and modify the virtual world "instantaneously".

For the moment, we are restricted to the creation of virtual environments, whose purpose is to sense, manipulate, and transform the state of the human operator or to modify the state of the information stored in a computer. Future advancement of virtual reality techniques in scientific visualization should not be restricted to "presentation" techniques, but to explanatory tools. VR techniques should be used not only for description, but for expressing all the explanatory process. An explanation can be presented as a visual model, that is as a virtual dynamic environment, where the user ask questions in the same way a scientist use a theory to understand the empirical world. A virtual world should be, then a *model*, a set of concepts, laws, tested hypotheses and hypotheses waiting for testing.

5. WHERE DO WE GO FROM HERE? PROPOSAL FOR A PROFESSIONAL ORGANIZATION FOR CVR DEVELOPERS

But we need some sense of metaphysical anchoring, I think, to enhance virtual worlds. A virtual world can be virtual only as long as we can contrast it with the real (anchored) world.[46]

MICHAEL HEIM (1993)

Uniting to define their own standards, rules, and conventions for scientific CVR models is just one of several reasons why it is important, at this point in the development of CVR, for CVR developers to start their own professional organization. The main reasons can be quickly listed:
- to hold an annual meeting where members can share new ideas and projects; where training classes can be offered; and where new products of CVR hardware and software suppliers can be exhibited
- to facilitate networking and collaboration between members

- to create a Web site for ongoing communications between members and to promote the organization to the world at large
- to represent CVR developers' interests before governments, trade associations, and other scholarly organizations
- to develop philological conventions and technical standards for the creation and publication of authenticated CVR models; to develop and disseminate a common library of textures; to offer a seal of approval on members' models that conform to authentication standards; and to offer a clearinghouse on its Web site where members' authenticated models can be made available for third-party licensing.

The publication of BARCELÓ *et al*. 2000 and the success of VAST in Arezzo in November, 2000 certainly suggest that a critical mass of CVR developers now exists to make the creation of a professional organization timely and worthwhile. Research has shown that there is no such organization yet in existence, so the proposed new organization would fill a distinct gap. Various related but ultimately distinct organizations include:

- http://www.acadia.org/home.html
  ACADIA, the Association for Computer-Aided Design in Architecture. It has existed since 1981 and "was formed for the purpose of facilitating communication and information exchange regarding the use of computers in architecture, planning and building science" (see Bylaws 2.1 at http://www.acadia.org/bylaws.html).
- http://www.acm.org/
  The Association for Computing Machinery (ACM) was the world's first educational and scientific computing society. It was founded in 1947 and, among many other activities impinging on CVR, sponsors SIGGRAPH.
- http://www.caaconference.org
  Computer Applications and Quantitative Methods in Archaeology (CAA), which was founded in 1973 with the mission of encouraging communication between archaeologists, mathematicians and computer scientists.
- http://www.vrs.org.uk/public/whatisvrs.html
  The Virtual Reality Society, whose goals include the study of VR technology and software systems; VR applications; assessment of VR systems; philosophical and ethical issues; and advances relevant to VR.
- http://www.w3.org/Metadata/
  The W3C Metadata Activity, which is devoted to developing metadata standards for the World Wide Web.
- http://www.jiscmail.ac.uk/lists/vista.html
  Although less well organized, the VISTA e-mail list (vista@jiscmail.ac.uk) is also an interest group
- http://www.virtualheritage.net.
  Virtual Heritage Network (VHN), is a new international organization designed to promote the utilization of technology for the education, interpretation, conservation and preservation of Natural, Cultural and World Heritage. The network is a physical and electronic network of people and resources in many countries currently working in the virtual heritage community. This organization has been formed through the many ideas of people working in the heritage and technology industry who recognize that it is fragmented, and difficult to find other researchers and information. Membership in this organization and the use of its facilities are free. Currently all efforts to build this organization are strictly on a volunteer basis. Through the network resources you can find: News and Industry Information Conferences, Events and Collaborations, Research and Development of Local and International Projects. Currently, the International Society on Virtual Systems and Multimedia has been hosting this organization and its activities in an unofficial capacity.

A Venn diagram between the proposed CVR association and these groups would show greater or lesser degrees of overlap in missions, interests, and activities. For example, CAA and The Virtual Reality Society would appear to have a far broader purview. The W3C Metadata Activity and ACADIA have a narrower focus. The Association for Computing Machinery is a catchall association which, through its SIGs (Special Interest Groups – e.g., SIGACT, for algorithms and computational theory; SIGARCH, for computer architecture; SIGART, for artificial intelligence; SIGGRAPH, for computer graphics) could even become an organizational envelope for the proposed new CVR organization.

Of course, there is no reason why the proposed new organization could not be affiliated with any or all of these related associations. Moreover, in its infancy it would make sense for the CVR organization to hold its annual meeting in the same city and at the same time as that of a related group such as CAA or SIGGRAPH. Indeed, we would propose that the CVR meeting be held in conjunction with SIGGRAPH in years when SIGGRAPH meets in Los Angeles; and that in the alternating year it be held in conjunction with CAA. We also propose that the CVR organization send a representative to the annual meetings of the other organizations listed above. As time goes on, the advisability of formally merging the CVR organization with another professional association can be studied. Right from the start, the CVR organization should seek a formal affiliation with as many of the other professional associations as possible. In general, the CVR organization should operate in a spirit of openness and cooperation.

As the name of the new organization, we propose CVRO. This stands for "Cultural Virtual Reality Organization" and also puns on the Latin word "*curo, curare*", meaning "I take care of, am concerned about", the etymon of "curate".[47] Given CVR developers' curatorial interest in preserving ancient monuments and disseminating them to the public, we think this pun is appropriate. We further recommend that CVRO's bylaws and structure be modeled on ACADIA (see http://www.acadia.org/bylaws.html). The UCLA Center for the Digital Humanities has volunteered to offer space and staff support for CVRO's headquarters (see http://www.cdh.ucla.edu/). As is the case with ACADIA, membership should be open to academic and professional CVR developers as well as students in CVR programs of study.

The co-authors of this article have agreed to meet several times in 2001, including at SIGGRAPH 2001 in Los Angeles, to found CVRO and to build up a membership base. They furthermore agree that CVRO should hold its first official annual meeting in 2002 in conjunction with the annual meeting of CAA. A world that has a professional organization for indexers (http://www.asindexing.org/) and an HTML Writers' Guild (http://www.hwg.org/) is big enough for a new professional organization to promote the interests of CVR developers. Readers who agree and wish to join CVRO are cordially invited to contact one of the co-authors.[48]

NOTES

[1] See http://www.upenn.edu/almanac/v42/n18/eniac.html.
[2] See http://www.ee.upenn.edu/~jan/eniacproj.html.
[3] Cfr. Andy Grove's keynote talk at Comdex, 1996 at: http://www.intel.com/pressroom/archive/releases/cn111896.htm.
[4] See http://www.nwfusion.com/news/2000/0629ibmteraflop.html.
[5] The Apple Macintosh G4 which uses the 733MHz PowerPC chip; see http://www.apple.com/powermac/.
[6] ENIAC was built as a result of a contract No. W-670-ORD-4926 signed on June 5, 1942, by the Trustees of the University of Pennsylvania and the U.S. Army Ordnance Department.
[7] See http://www.fortune.com/fortune/1999/11/22/biz4.html.
[8] See http://www.nau.edu/rufis99/masterton/sld003.htm
[9] See http://www.ibm.com/ibm/history/story/era2.html
[10] Cfr. W. ASPRAY 1990.
[11] In the 19th century, Oliver Wendell Holmes had the idea of a vast multimedia database to be created on a stereoscopic film system, but he did not yet have the idea of using the calculating machine to index the contents of the database. This is one of Bush's major contributions. On Holmes, see BIOCCA, KIM and LEVY 1995, 9: "in 1857 Oliver Wendell Holmes, father of the famous jurist, saw a glimpse of the future of VR when he lifted a stereoscope to his eyes for the first time. After the initial strain, as the lenses forced his eyes to fuse the different images only inches away, Holmes saw a vision. Holmes prophesied the creation of a giant universal database that would house essential copies of all things… Holmes, of course, saw the essential copy through the eyes of the 19th century. Globe-trotting adventurer-scientists would stock a curio cabinet of essential samples of reality, a collection so large that it would be housed in an immense stereographic library or museum."
[12] http://www.nsf.gov/sbe/srs/seind00/access/c1/c1s1.htm#c1s1l1a.
[13] Cfr. BUSH 1945, section 6: "consider a future device for individual use, which is a sort of mechanized private file and library. It needs a name, and, to coin one at random, "memex" will do. A memex is a device in which an individual stores all his books, records, and communications, and which is mechanized so that it may be consulted with exceeding speed and flexibility. It is an enlarged intimate supplement to his memory.

It consists of a desk, and while it can presumably be operated from a distance, it is primarily the piece of furniture at which he works. On the top are slanting translucent screens, on which material can be projected for convenient reading. There is a keyboard, and sets of buttons and levers. Otherwise it looks like an ordinary desk.

In one end is the stored material. The matter of bulk is well taken care of by improved microfilm… Most of the memex contents are purchased on microfilm ready for insertion. Books of all sorts, pictures, current periodicals, newspapers, are thus obtained and dropped into place. Business correspondence takes the same path. And there is provision for direct entry. On the top of the memex is a transparent platen. On this are placed longhand notes, photographs, memoranda, all sorts of things. When one is in place, the depression of a lever causes it to be photographed onto the next blank space in a section of the memex film, dry photography being employed. There is, of course, provision for consultation of the record by the usual scheme of indexing. If the user wishes to consult a certain book, he taps its code on the keyboard, and the title page of the book promptly appears before him, projected onto one of his viewing positions. Frequently-used codes are mnemonic, so that he seldom consults his code book; but when he does, a single tap of a key projects it for his use."
[14] Cfr. BUSH 1945, section 7: "the owner of the memex, let us say, is interested in the origin and properties of the bow and arrow…he builds a trail of his interest through the maze of materials available to him. And his trails do not fade… Tapping a few keys projects the head of the trail. A lever runs through it at will, stopping at interesting items, going off on side excursions. It is an interesting trail, pertinent to the discussion. So he sets a reproducer in action, photographs the whole trail out, and passes it to his friend for insertion in his own memex, there to be linked into the more general trail".
[15] See, e.g., ENGELBART 1962, sections III.A.1 ("What Vannevar Bush proposed in 1945-48") and III.A.2 ("Comments related to Bush's article").
[16] Cfr. ENGELBART 1962, section III.A.2: " The Memex allows a human user to do more conveniently (less energy, more quickly) what he could have done with relatively ordinary photographic equipment and filing systems, but he would have had to spend so much time in the lower-level processes of manipulation that his mental time constants of memory and patience would have rendered the system unusable in the detailed and intimate sense which Bush illustrates."
[17] See http://unrev.stanford.edu/introduction/introduction.html.
[18] See http://www.bootstrap.org/dce-bio.htm.
[19] See RHEINGOLD 1991, 25, 36; http://www.cs.unc.edu/Events/News/TuringAward.html.
[20] See http://www.sun.com/960710/feature3/skeetchpad.html.
[21] See http://www.sun.com/960710/feature3/alice.html
[22] For a history of Evans & Sutherland, see: http://www.es.com/corporate/history.html.
[23] http://www.digitalcentury.com/encyclo/update/jimclark.htm.
[24] For key dates in SGI's history see: http://www.sgi.com/newsroom/factsheet.html. On the Reality Center, see http://www.sgi.com/realitycenter/. For additional information in this paragraph, I thank Afshad Mistri of SGI for a personal communication.
[25] See: http://www.humnet.ucla.edu/humnet/classics/faculty/frischer/000125portal.html.
[26] Quoted from the Virtual Reality Glossary on the SGI Web site at http://www.sgi.com/virtual_reality/overview/glossary.html.
[27] See http://www.redherring.com/mag/issue01/guru.html.
[28] See ROY et al. 1994; http://www.sv.vt.edu/future/vt-cave/whatis/; http://www.evl.uic.edu/pape/CAVE/oldCAVE/CAVE.html.
[29] See http://www.cave.vt.edu/.
[30] See http://www.es.com/Pressroom/99archive/pr-05-11-99.html.
[31] For early uses of VR systems, see GILLILAN 1997.
[32] Cfr. also http://www.artmuseum.net/w2vr/timeline/Naimark.html#NaimarkText.
[33] Cfr. VALENTE and BARDINI 1995, 313. According to these authors, Lanier coined the term in 1987.
[34] Oxford Dictionary of Computing, fourth edition. Oxford 1995, 95.
[35] On the phi-phenomenon cfr. PARKINSON 1995, 7: "The brain has a perceptual threshold, below which images exposed to it will appear as continuous and film's speed of 24 frames per second is below that threshold. Persistence of vision or flicker fusion prevents us from seeing the lines between each frame, while the phi-phenomenon or stroboscopic effect, analyzed between 1912 and 1916 by the psychologists Max Wertheimer and Hugo Münsterberg, provides a mental bridge between the frames to permit us to see a series of static images as a single continuous movement." As applied to VR, see PIMENTAL and TEIXEIRA 1995, 108-109.
[36] Personal communication from DEAN CUNDEY, a cinematographer responsible for Jurassic Park, Apollo 13, and other films.
[37] On the mission and structure of Simlab see http://www.loria.fr/~tombre/VirtReal/msg00030.html.
[38] Co-author of LOEFFLER and ANDERSON 1994.
[39] Personal communication of Pompeianist ANN KOLOWSKI-OSTROW.
[40] See http://www.zgdv.de/departments/z2/vc/projects/archeo/.
[41] See http://www.ics.forth.gr/tourbot/.
[42] Cfr. CHAPMAN 1991; CORNFORTH et al. 1991; KEMP 1993; SIMS 1997.
[43] For an Internet resource page on metadata see http://www.ifla.org/II/metadata.htm, which gives the following definition: "metadata is data about data. The term refers to any data used to aid the identification, description and location of networked electronic resources". Many different metadata formats exist, some quite simple in their description, others quite complex and rich". In the context of contemporary CVR we should generalize the phrase "networked electronic resources" by amending it to read "digital VR resources", some of which may be networked, others not.
[44] Philology, like all scholarly disciplines, marches on. Maas' work has now been replaced by M. L. WEST 1973, where differences from Maas (e.g., on the matter of signs) will be found. We have cited Maas above because his work has a lapidary style that makes the applicability of philology to CVR more readily apparent.
[45] See http://www.arch.soton.ac.uk/Research/Avebury/VirtualAvebury/.
[46] HEIM 1993, 133.
[47] Note that U and V are the same letter (V) in Latin; cfr. ULLMAN 1963, 38.
[48] BERNARD FRISCHER had the idea for CVRO and wrote the first draft of this article, which is based on his talk at VAST in November, 2000 in Arezzo. NICK RYAN and FRANCO NICCOLUCCI made editorial comments on and improvements to the first draft. FRANCO NICCOLUCCI added new material near the end of section 3; NICK RYAN in the middle of section 4; JUAN BARCELÓ added the fourth paragraph of section 3, the last three paragraphs of section 4, and the last two items to the list of related organizations in section 5.

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