Kim H. Veltman

Scientific Visualisation and Virtual Worlds

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Cf. http://www.iti.gr/ICAV3D/.

This is a simplified version of "Virtuality and Virtual Worlds" (2000).

Abstract
Scientific visualization and virtual worlds are new fields but they build on a long-standing tradition, which goes back at least 2,500 years to Plato's description of the cave (*Republic*, Book VI). The idea of illusionistic spaces was developed in the context of Greek theatre. The Romans developed this both in their theatre as well as the interiors of their villas. With the advent of Christianity this quest for illusionism was reduced to isolated elements rather than entire spaces. In the context of Romanesque and Gothic architecture, an interest in illusionistic space was reintroduced into physical buildings in the form of spatial treatment of doors and windows. The entrance portals to the Cathedral of Laon (c. 1200) serve as an excellent case in point. In the early 14th century, painters such as Giotto, working in light of a new realism of the Franciscan order, began simulating architectural realism in the form of painted illusionism with architectural realism. In a sense, this simulation culminated in Renaissance perspective of which Brunelleschi's *Trinità* (Santa Maria Novella, Florence, c. 1415-1425) is acknowledged as the first example. The same Brunelleschi was active in the construction of elaborate theatrical spaces, whereby the fictive space of the stage was linked with the real space of the spectators.

The Mannerist period (c. 1527-1600) began to play with the boundaries between fictive, depicted spaces and the realities of physical, architectural spaces, such that clear distinctions became blurred. During the successive Baroque and Rococo periods these distinctions were further undermined such that distinctions between painted and architectural fictive and real parts became indistinguishable. This interplay between fictive, painted and constructed worlds began with the interiors of buildings but spread also to exteriors as in the gardens at Schwetzingen.

Already in the 9th century, camera obscuras were used for observing optical and astronomical phenomena. By the 16th century they were used for projecting images onto the interiors of rooms. By the latter 18th century the rise of panoramas meant that illusionistic paintings became fully illusionistic spaces where physical and fictive space became inseparable. The *Panorama Mesdag* (The Hague, 19th century) is an excellent extant example. The themes of panoramas were originally major cities (London, Paris), then exotic places (India, Mexico) and then places which were fascinating to see virtually but where one would rather not be physically, such as at the edge of an erupting Mount Vesuvius, or in the middle of an enormous storm at sea It is striking how these themes recur in recent cinema: *Volcano* and *The Storm*. In short the virtual worlds of analog and more recently digital cinema are taking up anew themes developed centuries earlier.

From the 14th century onwards engineers such as Giovanni Fontana used magic lanterns to project images onto walls. Combinations of such magic lanterns and camera obscuras led, via a number of gadgets in the nineteenth century (e.g. the tachystoscope) to the advent of moving pictures with the Lumière brothers at the turn of the twentieth century. In the course of the 20th century, cinema evolved via a number of experiments into IMAX films where the image is no longer just on a screen in front of the observer, but also to one's side, and potentially under one's feet. As such cinema prepared the way for the spatial experiences which are becoming increasingly familiar through the development of Computer Aided Virtual Environments (CAVEs).

Scientific visualization builds on the above traditions but explores a number of different worlds, namely the visible world, invisible worlds in the form of natural processes, the nano-level, outer space, concepts, economic processes, possible world and creative worlds. Oliver Grau has provided a first survey of this entire history.[1] Ivan Sutherland is preparing a more detailed history of computer graphics. [2] Maurizio Forte has offered a first survey of hundreds of applications in the realm of virtual archaeology.[3] The lecture surveys some of these developments.

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1. Visible World

In 1878, Jules Marey, one of the pioneers in the development of motion pictures, published his classic book, *The Graphic Method in the Experimental Sciences*,[4] in which he argued that science faced two obstacles: the deficiences of the senses in discovering truths and the insufficiencies of language in expressing and transmitting those truths which have been acquired. His graphic method aimed to overcome these obstacles by rendering visible otherwise unseen aspects of the physical world.

Ninety years later, when Ivan Sutherland (1968) wrote one of the first articles on virtual reality, he was very articulate about the role of the new medium in visualizing things, which had not been seen before. In the past decades, this theme has excited ever greater interest[5] and has led to the field of scientific visualization. Here we shall outline how it is affecting almost all aspects of the visible and invisible world.

In medicine, projects such as the *Visible Embryo*[6] and the *Visible Human*[7] project are providing us with new levels of visualization concerning the entire human body. A human body is frozen, cut into thousands of thin slices, each of which is then photographed and stored digitally. These photographs of a real human can thus serve to correct proposed models. They also lead to new physical models.[8] Thus careful, detailed recording of the physical world, leads to more accurate bases for simulations thereof, which in turn lead to new discoveries about the physical world. A project at the Chihara Lab is exploring a virtual piano player in real time.[9] Virtuality leads to a discovery or rather a re-discovery of reality.

The study of the physical is also leading to new creative variations. For instance, at the Max Planck Institut für biologische Kybernetik (Tübingen), Volker Blanz and Professor Vetter produced a morphable model for 3-D synthesis of faces (Siggraph 99). Using this technique they can take a two-dimensional image of a face such as Leonardo da Vinci's *Mona Lisa* and reproduce this in three-dimensional form such that it can then be viewed form different angles.[10] A simple example of such creative visualization is to note how the work of the late Maurits Escher[11] is leading to new Internet examples.[12] More impressive is a new trend to reproduce famous actors in virtual form. For instance, the Miralab (Geneva) did pioneering work on a Virtual Marilyn Monroe.[13] This has led to a the idea of creating virtual celebrities using figures such as Sammy Davis Jr., James Cagney, Marlene Dietrich, Vincent Price, George Burns, W.C. Fields, and Groucho Marx, analyzing video clips of their movements "to create realistic animated 3D likenesses of them for commercials, television, film, and Web sites."[14]

In engineering, CAD models, which were initially applied to individual objects in the workplace, are now being applied to entire factories. A project at the University of Manchester entails a factory with over 40 person years to create a virtual reality version.[15] The Virtual Environments for Training (VET) project involves a reconstruction of the complete interior of a ship where the function of every dial is represented as a working java applet (figure 82).[16] Visualization is also used in teaching mathematics.[17]

In architecture, companies such as Infobyte have made a virtual reality reconstruction of the church of San Francesco in Assisi, which is being used to repair the original subsequent to its being damaged by an earthquake.[18] In Japan, Infobyte's reconstruction of Saint Peter's Basilica is being projected in a former planetarium called a Virtuarium.[19] CAD models, which were once limited to individual buildings are now being extended to entire cities.

Bentley Systems, for instance, is creating a virtual Philadelphia[20] which, in fact, only covers a central portion of the city. Canal + is creating a reconstruction of Paris which is presently still limited to portions of the city such as the Eiffel Tower, the Louvre, and the Place des Vosges, but is so detailed that one can see the numbers on individual houses along a street. France Telecom, has a similar reconstruction which allows one to enter shops and do tele-shopping. Slightly less detailed, but at least as interesting conceptually is Virtual Helsinki. This lets us roam virtual streets and will in future allow us to listen to sermons of ministers, lectures of professors and debates of politicians on-line.[21]

This development is emerging in parallel with a trend to install web cams in ever more public and private places (see above p. 290). A new level of recording the physical world in real time is thus linked with a commitment to reconstruct that same physical world in virtual form. Ultimately this introduces the possibility of new simulation feedback loops in the realm of everyday life. The man on the street was proverbially the random person one interviewed. In the new century this can take on altogether new meanings.

Many such virtual cities are appearing at various levels of complexity.[22] These portals to cities can be linked with national portals. For instance, there is a Virtual Portugal,[23] which gives access at a country-wide level. Parallel with this rise of virtual cities are two other trends: 1) to add videos and photographs of physical locations via web cams (cf. p. 290 above) and 2) to create historical reconstructions of these physical cities and places.

The past decades have seen hundreds of virtual versions of such historical sites and cities, the topic of a fascinating book by Maurizio Forte.[24] Cities such as Rome are perhaps the best known in this context. Some of these are also being put on line as in the case of La Rochelle where one can walk through the central part of the old town.[25]

More recently there is a quest to add a dynamic dimension to such reconstructions. Here, the Nuovo Museo Elettronico (NUME) project of the University of Bologna in conjunction with CINECA is perhaps the most important project to date.[26] It provides a dynamic version of the central section of the city of Bologna from the year 1000 to the present. The three-dimensional reconstruction is linked with evidence from manuscripts, and other historical documents. Objects, which were originally part of monuments in the city and which are now dispersed in museums are linked to each other.

CINECA[27] is also engaged in another project concerning the reconstruction of Pompeii, Herculaneum and other Roman settlements near Naples. In this case, archaeological evidence is linked with detailed topographical and geological maps and a range of historical evidence. The quest is much more than a simple reconstruction of buildings as they once were.[28] The enormously detailed models are intended to serve as simulations of life in Antiquity against which historical and economic theories can be seriously studied: Sim City goes historical.

An important project visible at the supercomputing centre of the Complutensian University (Madrid) has a reconstruction in virtual reality of the whole of North eastern Spain based on satellite images. This geographical fly-through is connected with reconstructions of historical cities such as Santiago da Compostella such that one can go from an aerial view, zoom in, walk through the streets and then, enter individual churches and buildings. This project points the way to a new comprehensive treatment of landscapes which is complementary to the important historical treatments in the NUME project. There is a Mobile Visualization (MoVi) Project (Fraunhofer, Rostock) headed by Dr. Thomas Kirste.[29]

2. Invisible World: Natural Processes

Institutes such as the UK Meteorological Office (Bracknell),the Navy Oceanographic Office (Bay Saint Louis), the Deutscher Wettedienst (Offenbach) and National Center for Atmospheric Research (NCAR)[30] use virtual reconstructions to study

ISO Layer	Hardware	Software
Network	Gate Block	Gate Task
Transport		
Technical Service	Chip Card Appliance	Chip Card Process

Figure 1. Parallels between International Standards Organization layers, functions and Brad Cox's different layers of granularity in hardware and software.

possible developments of heat in air and water (the El Nino effect), gases in the air, clouds, wind currents, storms, tornadoes and other extreme weather conditions. While some aspects of these phenomena may be visible to the human eye, the simulations allow us to see the processes in a much more comprehensive manner. In the case of storms, for instance, NCAR uses satellite images of real storms and compares these with model reconstructions of such a storm. Once again the evidence of physical relaity is being used to modify virtual models in order that they have greater predictive qualities in the future (cf. the simulation- feedback loop in figure 19 above). The Chesapeake Bay project explored environmental issues pertaining to underwater polution normally invisible to the human eye.

3. Invisible World: Nano-Level

In the past decades, new links between electron microscopes, force feedback haptic devices or nano-manipulators, and visualization have led to new fields of imagery. The Hitachi Viewseum[31] and IBM, which was a pioneer by being the first to write IBM in molecules, have on-line galleries of such images.[32] Nano-photography is essential for the evolution of nano-simulation as a field. Again the visualization of hitherto invisible aspects is leading to new fields such as nano-technology, and molecular electronics (or molectronics), which are the subject of chapter three above.

4. Invisible World: Outer Space

Ever since the invention of the telescope, instruments have been opening up the horizons of planets, stars and galaxies beyond the sight of the unaided eye. The Hubble telescope has greatly expanded the range of images now available to us.[33] New methods of visualization are also being developed to make available the results of such visual explorations of the sun, the solar system, and outer space. For instance, a project at the Haydn Planetarium, called Digital Galaxy, uses Silicon Graphics machines (with seven pipes) to project images such as those from the Hubble Spacecraft onto the ceiling of a planetarium.

5. Invisible World: Concepts

Computers are helping us to visualize many, hitherto intangible concepts, including the realm of software. In order to distinguish different functionalities in the telecommunications world, the International Standards Organisation, established three kinds of layers (entailing seven network layers). More recently, Brad Cox has made a plea for visualizing five different layers of computer hardware and software (figure

5), demonstrating how the major programming languages (Lisp, Smalltalk, C, C++ and Objective C) can be understood better using this approach.[34] In short, virtuality is being used to render visible dimensions of code which were hitherto invisible. The efforts of Dr. Steven Eick at Bell Labs to visualize patterns in software code mark another step in this direction.[35]

6. Invisible World: Economic Processes

The use of graphs is a well-known practice in economics. In the 1960's economists began exploring the potentials of three-dimensional graphs to visualize economic trends. More recently, with respect to investments, Visible Decisions[36] rendered such trends visible first in three-dimensional graphs and then with an added real time dimension. Asymptote's three dimensional real-time rendering of the New York Stock Exchange is one of the most dramatic developments in this context (figure 54):

> The Exchange has chosen the world's most powerful visualization supercomputers to generate a completely interactive virtual representation of its trading floor. By consolidating the data streams from the various floor trading systems into one three-dimensional system, a visual display is created that allows users to intuitively understand complex business transactions instantaneously, as well as see system problems at a glance.[37]

7. **Possible Worlds**

The virtual reconstruction of entire landscapes has become of ever greater interest to the military who now use such images of the real world in order to develop realistic battle and other emergency scenarios.[38] In this context, war games are deadly serious. In a first stage, such simulations involved a demonstration at a local site, not very different from the way generals traditionally had models or at least maps of battlefields at their disposal. At a second stage, these simulated models became networked such that players in different centres could play the same game: like playing networked Doom with real scenarios. A third stage is integrating such networked scenarios with physical locations. For instance, the Terravision project at SRI,[39] linked with the Army's supercomputer in Minneapolis, provides persons on the battlefield access to satellite and other aerial images of the situation. This real time information can be used to modify scenarios on the home front. Virtuality thus leads to the discovery of reality and reality leads to corrections in the reality of the moment.

In design, the software of companies such as Alias Wavefront is being used for a whole gamut of products ranging from simple cosmetics and furniture to interiors of airplanes, the design of automobiles, trucks and boats. The design of cars, tractors, and aircraft, once the domain of secretive teams within a single company, is now increasingly the domain of collaborative teams linked with global databases of engineering and design elements.

In Europe, visualization plays an increasing role in design linked with rapid and virtual prototyping. Here the High Performance Computing Center in Stuttgart (HLRS) plays an important role.[40] An excellent survey of these developments was recently given by Dr Ulrich Lang (HLRS) at the First European High Performance

Graphics System and Applications Conference (CINECA, Bologna, 16-17 October 2000).

In film, visualization in the form of special effects, has become common-place.[41] *True Lies* introduced a virtual Harrier jet into a cityscape. *Disclosure* created virtual information spaces, which bore an uncanny resemblance to St. Peter's Basilica. As *Dreams May Come* offered a visualization of the protagonist's heaven and hell and a library reminiscent of Robert's architectural phantasies.[42] *Toy Story* is an entirely virtual world. In Manchester, virtual reality was used to reconstruct the scene of a crime: said to be the first time such a reconstruction was used as evidence in a court of law.[43]

8. Creative Worlds

While many see virtuality as a means of making new scientific links with the physical world, some interpret virtuality as a blurring between the real and virtual.[44] The artist, Michel Moers, goes further and links virtuality with playful, creative, illusion:

> These simplified shapes often become archetypes that are more than true-to-nature, more colourful, more joyful and, more especially, easier to live with - all they have to do is to appear on the scene and pretend! This era of top models and virtuality has something comfortable about it. Doesn't it? All the rest is so confusing and turbulent.[45]

The musicians Martin Kornberger and Volker Kuhn, who created the music CD, *Virtuality*, in 1992 are more explicit in linking this blurring function with the creative process. Kornberger, for instance, notes that: "Virtuality - signifies the crossing of the borderlines between man, machine and nature. By means of computer technology it is possible now to scan reality and form new virtual ones - at least in music." His colleague Kuhn puts it slightly differently

> "Virtuality - this expresses in some way a longing for illusionary worlds of beauty and power beyond human restrictions. But the closer one gets to them, the more unreal and empty they seem. At last nothing remains but the lonelyness of our inner space."[46]

One of the prolific areas of development in this context is the realm of virtual reality worlds being created by artists.[47] In the literary field novelists such as John Barth have reflected on the meaning of virtuality with respect to culture.[48]

One of the most complex experiments in this context is a project on Electronic Arenas for Culture, Performance, Art and Entertainment (eERENA),[49] which includes a vision system, visual content, audio content, user representation, content/story, physical space, virtual storybook of an electronic arena and a mixed reality theatre. Information from all of these layers interacts with live players on a stage.

Meanwhile, at Manchester University, Professor Adrian West, one of the pioneers of large scale virtual reality programmes, has become fascinated with the potentials of virtual worlds to convey alternative worlds:

> Cages is a demonstration of the deva world hierarchy, and the idea of environments that impose behaviours on their contents. This is akin to specifing the properties of time, space and physical laws for a particular universe. The complexities of such laws are limited by the computational resources available to impose them. Any object placed within such an environment has these laws and behaviours imposed upon it. We believe this approach will make it significantly easier to create a range of complex virtual environments.[50]

Computer software such as Windows showed the world from one particular viewpoint within a single frame of reference. Professor West's software allows one to change perceptual worlds: e.g. to look as an individual in a room at a fish in a fishtank; then look as a fish in the fish tank at an individual in a room beyond the tank and then as an individual standing outside the room looking at the individual and the fish. Not only are the viewpoints different, but each of these spaces can have their own laws of physics. For instance, the first individual can be in a room subject to the normal laws of gravity; the fish in virtual water can be subject to different rules and the person outside could be in a space not subject to ordinary gravity.

9. Simulation

The trends towards globalisation of production are closely connected with developments in simulation and design. Lockheed Martin, also active in collaborative software and virtual environments for training, is developing simulation-based design.[51] The dVISE[52] company has Interactive Product Simulation (IPS) and digital mock-ups. At the Synthetic Environment Lab[53] (SEL) simulation is a theme along with data analysis, data fusion, manufacturing, and medical modelling. There is a Computer Simulation Council.

Simulation is increasingly important in architecture. The Getty Trust and UCLA have an Urban Simulation Team,[54] which has produced a model of the Roman Forum. There is an Environmental Simulation Center at the New School of Social Research (New York). The National Center for Supercomputing Applications (NCSA) has work on climate simulations.

The Beckman Institute (Chicago) has a Materials and Process Simulation Center (MSC) with simulations of real material systems. Mississippi State University[55] has an Engineering Research Center for Computational Field Simulation (ERC). The Mechanical Engineering Department at Iowa State University has simulation based training for manufacturing workers.[56] The University of Pennsylvania's Center for Human Modeling and Simulation[57] has a Multi-Robot Simulation Environment (MRS).

As might be expected the military is very active in the realm of simulations. There is a Defense Modeling and Simulation Office[58] (DMSO). The Army High Performance Computing Research Center[59] (AHPCRC) has Advanced Flow Simulation and Modeling. The University of Central Florida has an Institute for Simulation and Training (IST) with a Dynamic Environments Group, projects such as[60] Polyshop, Toy Scouts, Virtopia as well as Telerobotics, Teleoperation and Telepresence Research.[61] The University of Southern California uses the University of Chicago's

Immersadesk -- a monitor in the form of a workbench[62]-- for military simulations of the Kuwait desert. The Lucie Naval Lab (Stony Brook) has produced a concurrency workbench, an iterative rapid prototyping process and a distributed iterative simulation. The US Army Research Office recently organized a Workshop on Multi-Agent Systems and Agent Based Simulation (MABS).[63]

NASA and Northeastern University (Boston) have a Virtual Environments Laboratory,[64] with a virtual environments based driving simulation and a numerical aerodynamic simulation division (NAS).[65] The University of Iowa (Iowa City) at its Center for Computer Aided Design[66] (CCAD) also has a Driving Simulation.

Simulation is also entering the software domain. The Mathematics and Computer Science Division of the US Army Research Office is working on Software and Knowledge Based Systems[67] (SKBS) including modeling and simulation. Lucent Technologies/ Bell Labs is working on visual simulation discovery. There are, of course, simulation games such Sims City and the SIMS which allows one "to create, direct, and manage the lives of *SimCity*'s residents by satisfying their needs (hunger, comfort, hygiene, bladder, energy, fun, social, and room) through interaction with other Sims or objects."[68] Players can "teleport" their virtual families to other users on the Sims.com site and interact with peer groups in such scenarios as raising children, adding rooms to their homes and socializing.[69]" Inflorescence Inc.[70] (Portland) works with the Behaviour Engine Company, which has software for compositional simulation:

> for creating simulations or temporal models from reusable components. The Behavior Engine's encapsulated units of process information are known as "Simlet®s". Reusing Simlets allows efficient and low cost production of complex simulations, training materials and technical documentation. The underlying technology is integrated with the World-Wide Web, and with facilities for modeling three-dimensional objects and their behaviors.

Medical simulation is an emerging field. The National Cancer Center (Tokyo)[71] is working on surgical simulation, medical virtual reality and virtual medical communication. The University of Hull has a biomedical model of the human knee joint and haptic feedback for surgical simulation. The University of Manchester has radiation therapy planning in 3-D.

Considerable efforts are being devoted to simulation of the human brain. The Pittsburgh Supercomputing Center,[72] for instance, which is linked with Carnegie Mellon University and Westinghouse has Advanced methods for Neuroimaging Data Analysis, a project on the Brain in Action[73] and Parallel Simulation of Large Scale Neuronal Models.

At the atomic level, simulation plays a vital role. IBM Almaden's [74] Visualization Lab is working on molecular dynamic simulations. IBM's new Blue Gene supercomputer, one thousand times more powerful than the chess playing Deep Blue, Blue Gene: "is designed to do nothing but derive protein folds from DNA sequences and vice-versa. The human genome project is just providing a list of the genetic instructions that make us; Blue Gene will begin to tell us how those instructions work."[75]

The Institute for Operations Research and Management Sciences (INFORMS) has a College on Simulation[76] Scott Ameduri refers to this as one of the simulation organizations along with Agile Manufacturing Homepage, the W3 Virtual Library on Computer Based Simulations and the newsgroup comp.simulation.[77] Simulation was once with respect to an isolated object or process. The new quest is to simulate all processes ultimately in integrated form.

Simulation is also of increasing importance in Europe. INRIA (Paris etc.) has as its fourth research theme simulation and optimisation of complex systems.[78] Trinity College (Dublin) has a Distributed Virtual Environment Simulation. The University of Manchester is working on simulation of buildings. There has been a Federation of European Simulation Societies (EUROSIM) since 1989.[79]

In the United States, there is talk of a new simulation millenium in which the boundaries of simulation for science and entertainment will blur such that manufacturing, movie making, education, and web will all work together.[80] In Europe, by contrast, there is a trend towards more detailed and perhaps more fundamental understanding in specific fields. For instance a German consortium including Audi, Daimler Chrysler, Bosch, Mannesmann, Siemens, Porsche, and Volkswagen have formed an Association for Standardisation of Automation and Measuring Systems (ASAM).[81]

Notes

[1] Oliver Grau, *Virtuelle Kunst in Geschichte und Gegenwart. Visuelle Strategien*, Berlin: Reimer Verlag, 2001.

[2] Ivan Sutherland is writing a History of Computer Graphics, New York: New riders Press, 2001.
See: http://www.visualfx.com/milestones.htm

[3] Maurizio Forte, *Archeologia, percorsi virtuali nelle civiltà scomparse*, Milan; Mondadori, 1996. There are also French and English editions of this book.

[4] E. J. Marey, *La méthode graphique dans les sciences expérimentales,* Paris: G. Masson, 1878.

[5] See, for instance, Alex Pomasanoff, *The Invisible World. Sights Too Fast, Too Slow, Too Far, Too Small for the Naked Eye to See*, London: Secker And Warburg, 1981; Jon Darius, *Beyond Vision*, Oxford: Oxford University Press, 1984; Richard Mark Friedhoff and William Benzon, *The Second Computer Revolution. Visualization*, New York: Harry N. Abrams, Inc.1989.

[6] See: http://www.visemb

[7] See: http://www.crd.ge.com/esl/cgsp/projects/vm/#thevisibleman.
Cf.: http://www.nlm.nih.gov/research/visible/vhp_conf/north/vhedemo.htm
http://www.npac.syr.edu/projects/vishuman/UserGuide.html#main

[8] See: http://www.anatomy-resources.com/sh125.htm

[9] See: http://chihara.aist-nara.ac.jp/public/research/research.html

[10] See: http://www.kyb.tuebingen.mpg.de/bu/people/volker/

[11] See: www.worldofescher.com

[12] See: http://www.worldofescher.com/gallery/internet/index.html

[13] See: http://www.miralab.unige.ch/MARILYN/marilyn3.html

[14] Alex Gove, "Virtual Celebrity Productions puts the dead to work," *The Red Herring Magazine*, January 1999.
See: http://www.rhventure.com/mag/issue62/animation.html

[15] See: http://aig.cs.man.ac.uk/systems/Maverik/
[16] See: http://www.isi.edu/isd/VET/vet.html
[17] See: http://viswiz.gmd.de/~nikitin/course
[18] See: http://www.infobyte.it/catalogo/indexuk.html
[19] See: http://www.barco.co.jp/projecti/ebigdome.htm
[20] See: http://www.bentley.com/modelcity/gallery/card.jpg
[21] See: http://www.arenanet.fi/helsinki/eng/index.htm
[22] For instance, Virtual Munich has a general map with a handful of places from which one can access Quick Time panoramic views.
See: http://www.virtual-munich.de/
Virtual London.com is much more detailed, has maps which allow one to zoom from country level to street level, has lists of museums etc but does not link one to the actual sites of the institutions.
See: http://www.virtual-london.com/
Virtual New York does link their general description of institutions with the original sites, has maps and even has a real time satellite weather map.
See: http://www.vny.com/.
[23] See: http://www.portugalvirtual.pt/index.html
[24] Maurizio Forte, *Archeologia, percorsi virtuali nelle civilta scomparse*, Milan: Mondadori, 1996.
[25] See: http://www.villes-3d.com/
[26] See: http://www.cineca.it/visit/NUME/
[27] Cf. an important recent conference which surveyed many of these developments: High Performance Graphics Systems and, Applications European Workshop. State of the Art and Future Trends, Palazzo Marescotti, Bologna, 16-17 October 2000, Proceedings, Bologna: CINECA, 2000.
[28] *Neapolis. La valorizzazione dei beni culturali e ambientali*, ed. Epifanio Fornari, Rome: L'Erma di Bretschneider, 1994, particularly pp. 23-26;59-63; 115-116. (Ministero per i beni culturali e ambientali soprintendenza archeologica di Pompei, Monografie, 7).
[29] See: http://www.informatik.uni-rostock.de/Projekte/movi/
[30] See: http://www.scd.ucar.edu/vg/MM5/images
[31] See: http://www.viewseum.com
[32] See: http://www.almaden.ibm.com/vis/stm/hexagone.html
[33] For two useful sites with excellent images of outer space
See: http://antwrp.gsfc.nasa.gov/apod/calendar/allyears.html
http://www.janis.or.jp/users/kitahara/menu1.html.
[34] Brad Cox, *Superdistribution Objects as Property on the Electronic Frontier*, Wokingham: Addison Wesley Publishing Company, 1996
See: http://www.virtualschool.edu/mon/TTEF.html.
Cf. Brad Cox, "Planning the Software Industrial Revolution," *IEEE Software Magazine*, Special issue: *Software Technologies of the 1990's*, November 1990.
See: http://www.virtualschool.edu/cox/CoxPSIR.html.
[35] See: http://www.bell-labs.com/user/eick/
[36] See: http://www.vdi.com/f_default.htm
[37] See: http://www.sgi.com/newsroom/press_releases/1999/march/nyse.html
[38] Evans and Sutherland are among the leading producers for the visualisation software used by the military.
See: http://www.stricom.army.mil/cgi-bin/PhotoArchive/image_gallery.pl

39 See: http://www.ai.sri.com/TerraVision/
40 See: http://www.hlrs.de/
41 In February 2000 there is a major conference at Stanford on Special Effects.
See: http://prelectur.stanford.edu/.
42 See: http://www.whatdreamsmay.com/vers3/whatdreams.htm
43 See: http://aig.cs.man.ac.uk/systems/Maverik/gmp.html
44 Brygg Ullmer, " Physicality, Virtuality, and the Switch that Lights,"
See: http://tangible.media.mit.edu/~ullmer/courses/tat/paper1.html
45 See: http://www.damasquine.be/Pages/Photogra/Moers1.htm
46 See: http://www.memi.com/musiker/changing_images/ci_p3_e.htm
47 See: http://www.vrml-art.org/cgi/vmsprg?tplt=index
48 See: http://www.jhu.edu/~jhumag/994web/culture1.html
49 See: http://imk.gmd.de/images/mars/files/erena99_D6_2.pdf
50 See: http://aig.cs.man.ac.uk/systems/Deva/gallery/cages.html
51 See: http://sbdhost.part.com
52 See: http://www.division.com/2.sol/a_sw/sol_a.htm
53 See: http://www.cs.sandia.gov/SEL/main.html
54 See: http://www.ust.ucla.edu/ustweb/ust.html
55 See: http://www.erc.msstate.edu/thrusts/scivi/html/index.html
56 See: http://www.public.iastate.edu/~jmvance
57 See: http://www.cis.upenn.edu/~hms/home.html
58 See: http://www.dmso.mil
59 See: http://www.arc.umn.edu/research/incompCFD.html
60 See: http://www.vsl.ist.ucf.edu/~deg/deg.html
61 See: http://www.jebb.com
62 This is based on a development by the German National Centre for Supercomputing (GMD).
63 See: http://www.soc.surrey.ac.uk/research/simsoc/mabs98.html
64 See: http://www.coe.neu.edu/~mourant/velab.html
65 See: http://www.nas.nasa.gov/
66 See: http://www.ccad.uiowa.edu
67 See: http://www.aro.army.mil/mcsc/skbs.htm
68 See: http://www.amazon.com/exec/obidos/ASIN/B000040OEI/104-5354310-7670329
See: http://www.amazon.com/exec/obidos/tg/stores/detail/-/videogames/B000040OEI/pictures/3/104-5354310-7670329#more-pictures.
69 Nicolas Mokhoff, "Graphics gurus eye nuts, bolts of 3-D Web," EE Times, 28 July, 2000, See: http://www.eet.com/story/OEG20000728S0006.
70 See: http://www.besoft.com
71 See: http://medur.res.ncc.go.jp
72 See: http://www.psu.edu
73 See: http://www.psc.edu/publicinfo/brain_10_3_97.html
cf. http://www.psc.edu/science/goddard.html
74 See: http://www.almaden.ibm.com/vis/vis.lab.html
75 See: http://www.idg.net/go.cgi?id=197443
76 See: http://www.informs-cs.org
77 See: http://dora.cwru.edu/saa4/links.html
78 Institut National de Recherche en Informatique Automatisée (INRIA)
Augmented Reality Mixing Virtual Objects and the Real World
Thème 1: Reseaux et systèmes

Modelisation et évaluation des systèmes informatiques (MEVAL)
Thème 2: Génie logiciel et calcul symbolique
Thème 3: Interaction homme-machine, images
Gestion des connaissances pour l'aide
à la conception co-operative (AIR)
Représentations et langages (AIRELLE)
Représentation des connaissances (REPCO)
Systèmes de base de données (RODIN)
Base de connaissances a données (SHERPA)
Thème 4: Simulation et optimisation des systèmes complexes.

[79] See: http://iatms13.iatm.tuwien.ac.at/eurosim/

[80] See: http://www.wintersim.org

[81] See: http://www.asam.de/Homepage_ok.htm