SKETCHES

CONTINUED ▶

APPLICATIONS

ANIMATIONS

Welcome to SIGGRAPH 97 Sketches! This is the fourth year for the Sketches program, and it is evolving like a large, collaborative sketch or drawing. Each year, the contributors and Sketches committee members add new vision and form, redefine pieces, and add more detail to the drawing.

Andrew Glassner created Technical Sketches in 1994. Art & Design Sketches were added in 1995, and, in 1996, Animation Sketches. This year, Applications have become a type of Sketch, instead of a separate program.

Sketches have something for everyone and provide an opportunity for intermixing ideas among people from all areas of the SIGGRAPH community. Just like the Creative Applications Laboratory, Sketches provide a common tie between the technical programs, Ongoings: The Fine Arts Gallery, and the Computer Animation Festival, bringing artists, animators, designers, programmers, technical directors, and researchers together.

Building upon the success of the SIGGRAPH 96 Sketches program, we received 215 submissions this year -- almost double the number of submissions in 1996. The four Sketches juries selected 100 Sketches for inclusion in this year's program.

In Art & Design Sketches, you will see innovative uses of computer graphics for art and design, new artistic tools, explanations of the use of technology for creating art, and social provocation. There are also two Art & Design sessions featuring panel discussions by the artists featured in Ongoings: The Fine Arts Gallery.

In Application Sketches, you will see innovative uses of computer graphics technology for visualization, virtual reality, Web-based applications, interaction, education, and art.

Animation Sketches feature examples of new research in animation techniques, commercial use of motion capture and special effects techniques, character animation, tracking technology, dance, and illustrative Sketches describing the process of commercial production and movie special effects. Several Animation Sketches were solicited from the Computer Animation Festival, to explain how the animations were created.

Technical Sketches feature a wide range of new graphics techniques and early ideas, including realistic rendering, non-photorealistic rendering, modeling and simulation, shading, illumination, graphics hardware, and virtual environments. Technical Sketches allow presentation of both early results (late-breaking research) and small, useful results that may not warrant a full technical paper.

This year, one-page abstracts of all Sketches are published in the Visual Proceedings. The choice of short abstracts was deliberate to allow documentation of techniques and ideas, but not to prevent future publication of full-length papers based on further development of these techniques.

The Sketches program is continuing to evolve, and its success is largely derived from those who contribute their work to it. I encourage you to attend Sketch presentations, participate in lively Sketch discussions, and, most importantly, submit a Sketch next year. Sketches are a great opportunity to contribute to the annual SIGGRAPH conference, whether you are a seasoned contributor or a newcomer.

Finally, I would like to thank the Sketches committee members for their hard work and incredible contributions to this year's Sketches program.

DAVID EBERT

CHAIR, SIGGRAPH 97 Sketches

Sketches Committee

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Using Video to Create Avatars in Virtual Reality

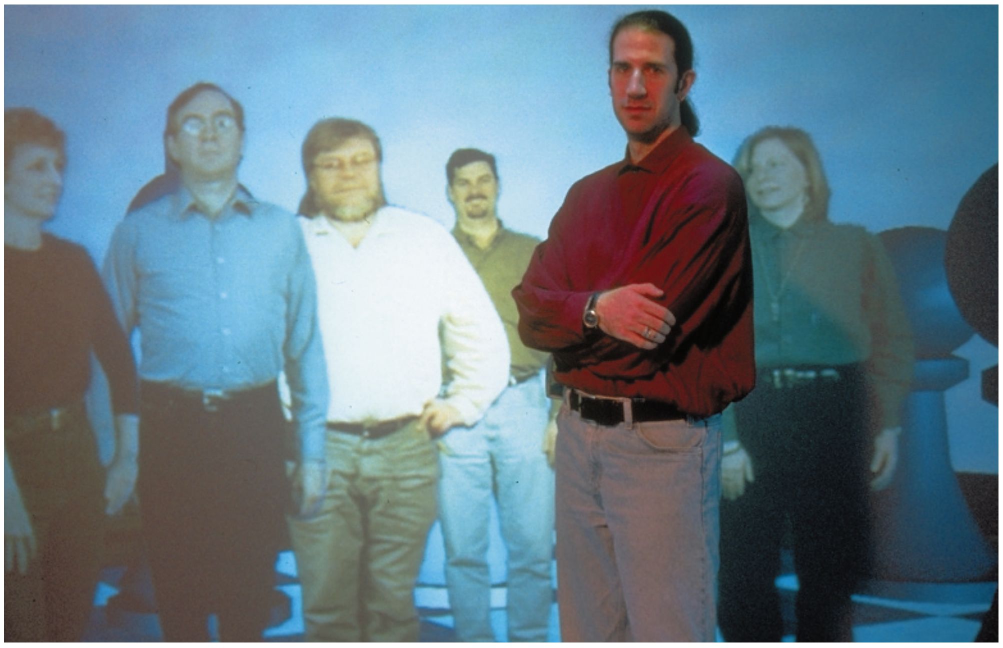
The VideoAvatar Library is a collection of functions that works in conjunction with the CAVE Library and can be used to add static, photo-realistic, three-dimensional representations of remote users, as well as other objects or agents, to virtual reality applications. The process involves obtaining views from 360 degrees around the person, then selecting two of these images, one for each eye, to represent the user in 3D space.

To acquire these images, the person stands on a turntable placed in front of a blue screen at a distance of 10 feet from a video camera, which is at eye level. We preview the images and set the levels of the various parameters that are to be used in calculating the chroma key to drop out the background. Once these values are set, we record one revolution of the person turning on the turntable and capture the chroma key settings. Recording at 30 frames per second for the 15 seconds required for one revolution generates a movie file consisting of 450 frames. A configuration file can later be used to specify the maximum number of images that should be used, as well as other pertinent information. This allows individual users to adjust parameters based on the specific hardware and memory capacities of their machines.

From this series of images, a different image is selected to represent the person to each eye. Which two images are to be used is calculated based on the positions of both the local and remote users in the space, and the direction that the remote user is facing. These images are then texture mapped onto two separate polygons, each of which is rotated around the vertical axis toward the eye which is meant to see it.

As we are not actually creating a three-dimensional model, but using two two-dimensional images to represent the avatars, not all depth cues are supported. Among those supported are convergence, binocular disparity, horizontal motion parallax, and occlusion. The proper perspective of the VideoAvatar is maintained in relation to the other objects in the modeled environment.

Despite the limitations of using image-based versus model-based rendering techniques for the VideoAvatars, the results are stunningly realistic. The goal is to supply a range of avatars with varying capabilities. Future versions of the library will incorporate multiple positions within the avatar model and real-time live video in order to fulfill this goal.



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The authors wish to acknowledge **Dave Pape, Javier I. Girado, and Terry Franguiadakis** for their valuable input to this research.

Dream Grrrls: Metaphors

The process of designing multi-user virtual environments (VE) is similar to the process of designing code or imagery, in that it is necessary to passionately maintain a catalog of ideas and references. VE design combines these passions to construct a consistent graphical user interface (GUI) with metaphors for exploration and self-reflection in a collaborative team effort.

Dream Grrrls, a VE created in the CAVE, focuses on the immersive nature of dreams. A typical GUI has elements or icons that function as navigational tools and sit on the periphery. VE icons do not operate like a toolbox, but are spatially based, like the galleries in an art museum. *Dream Grrrls* is a journey through five different environments presented in a labyrinth filled with paths and three-dimensional objects or "icons."

Much as art attempts to convey insight, *Dream Grrrls* attempts to generate a new awareness based on interaction and immersive experience in order to create an exciting new level of communication beyond verbal know ledge. Dream imagery presents itself in a way that makes the real uncertain. On one path, the participant can ignore the warnings ("Don't go up there!") and enter a commanding head. Inside, the navigational wand becomes a flashlight to reveal walls made of whispering faces and creatures. The light provides illumination – a gateway to another level of consciousness and ultimately, the many sides of ourselves.

In a world inhabited by large vessels, the user approaches the unfamiliar territory like a desert island of loneliness. One vessel has imposing eyes that follow the participant wherever she goes. She comes face to face with what could be her psyche. If she chooses to confront it, she finds herself unable to move, rattled by the world around her, only to awaken back where she came from (the labyrinth), the same, yet somehow different.

Dream Grrrls allows users to experience their world in a new and dynamic way, much like an active or lucid dream. Participants "cooperate" with the computer in such a way that one is uncertain of the action / reaction hierarchy. *Dream Grrrls* becomes a medium to create a personal performance by learning to interact with the environment and recognize its plasticity.

Dream Grrrls could not have been possible without the artist's library of images and the focused dedication on software by Grit Sehmisch. Audio consultation was provided by Joe Reitzer, and programming consultation was provided by Marcus Thiebaux, Dave Pape, Bor-Tyng Lin, and an Electronic Visualization Laboratory of sages. Special Thanks to Dan Sandin, Tom DeFanti, Maxine Brown, Dana Plepys, Jim Costigan, and Maggie Rawlings.

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CyberHuman Dances Series: An Articulation of Body, Space, and Motion in Performance

The CyberHuman Dance Series is an experimental dance work exploring simulations of physical and virtual phenomena in the context of performance. By integrating innovative digital technology with the choreographic and design process, this work investigates all aspects of design and performance in cyberspace, with particular emphasis on issues of real and perceived boundaries between virtual space and real space, and the possibility of a blurred distinction between two intersecting worlds.

Questions are raised as to possible metaphors for construction of virtual spaces and the bodies that inhabit them, leading to new ideas about the behavior of the body and its expression through motion. What, for instance, are the ways in which the cyberdancer begins to claim a virtually constructed space through movement? What kind of relationship (physical, emotional, psychological) can be established between real dancers and their cyberspatial counterparts? How can narrative identities be exchanged, modified, or made explicit? Finally, how can these investigations be brought to performance as a means of formulating an appropriate language for dance in the virtual age?

An analysis of the work in progress offers an opportunity to discuss design issues related to the development of cyberspatial environments and virtual bodies. Issues of space, time, physicality, and gravity are visited, as is the question of how the body is to be represented and inhabited within a virtual space. What is the connection between humans and their representational presence in cyberspace and what, exactly, does it mean to be cyberhuman? How can an articulation of the process of the design of the cyberfigure provide an answer to this question? What is an appropriate representation for a physical figure in a space that lacks physicality? How can a sense of bounded space be accommodated within an environment defined through its lack of edges?

In offering an analysis of the design and performance process, and the questions raised in the development of both cyberfigure and environment, a model for collaboration is proposed between individuals and across technologies. This model illuminates how a collaborative technological investigation infuses the work with a concern for methods of expression in virtual spaces and how innovative digital processes can be explored through experimentation with choreographic software, three-dimensional rendering programs, and their combination into output to digital video.

The creative process of making the work is examined in the collaboration between choreographer, designer, composer, and video artist. The conclusion argues that integration of the working methods of a group of individuals trained in different aspects of the arts offers insight into the range of methodologies available for study and infuses the series with an energy of human discovery.

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Life with a physical disability has allowed me a unique and humbling perspective that has manifested in my art work. I create art with and for people who live with various types of physical and / or mental limitations.

Because my work deals with issues of accessibility, it is essential for me to make my work accessible to people with a range of different abilities. The use of non-traditional materials and technology in my installations allows me to incorporate the senses of smell, taste, sound, and touch in addition to providing the more traditional visual experience.

Because I live with a wheelchair, collaboration has been an essential element in my work and life. Using the computer as an art medium has allowed me the freedom and access to create virtual worlds that would have been impossible in my life. No longer do I need assistance to move a block of marble or build a room. The computer has given me all the tools I need to accomplish these tasks. Imagination is now my limitation.

My work is often referred to as interdisciplinary because I often use more than one medium to provide additional access to communication. Often the work is interactive, so the participant can experience art rather than just see it. The focus in my studies lies in educating and encouraging participants – regardless of prior experience, physical limitations, age, or ethnicity – to examine the relevance of art and accessibility in their own lives. For example, by incorporating a medium like Braille into an installation, I can attempt to change an art piece to be more inclusive for a visually impaired audience.

I believe art is fundamentally a communicative experience that can be and should be shared by all. My research method includes a hands-on approach, working collaboratively with several different groups and individuals to create art pieces that have been specifically designed to incorporate more than the traditional visual experience.

What one person might feel is important or beautiful another may not. I have found that by displaying work without an emphasis solely on the visual aspect, artistic integrity is still maintained. By including elements such as a wheelchair, Braille translations, and audio descriptions, individuals without mental or physical limitations may re-evaluate and gain a deeper appreciation for their own abilities by not only seeing art but experiencing and interacting with it.

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Multi-Media Metamorphosis (or making the medium shoe fit)

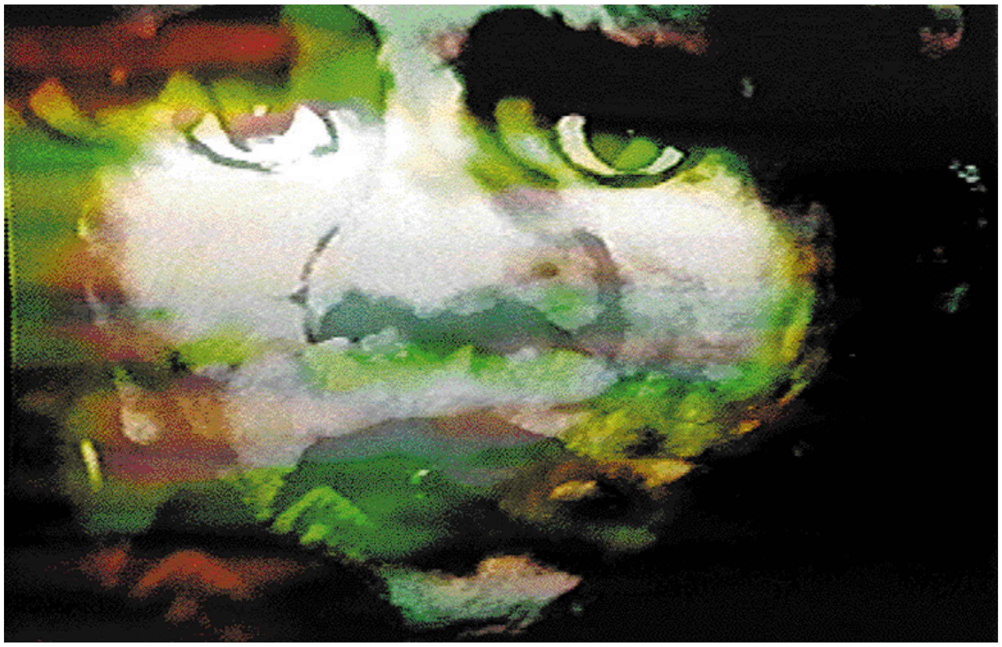
A large portion of my work has entailed taking a theme or story and giving it life in a variety of media. *The Mutant Gene & Tainted Kool-Aid Sideshow* CD-ROM (completed October 1995) is a navigable interpretation of a series of performances I staged in 1994, by the same name. The performances incorporated live and pre-recorded, multiple-monitor and projected video; animation; text; both sequenced and live instrumental music; and dramatic artifacts and performance elements such as masks and dance.

Beginning with the psycho-dramatic confession of an extraterrestrial, the piece journeyed into a series of multicolored, entropic landscapes. My intent with the performances, and the use of technology, was to create alternate or augmented realities for an audience. I wanted the audience to be immersed in an environment of sound, light, and motion, which often paralleled the content – in essence, making certain fantasy states real. The CD-ROM emerged from a desire to break down the linear constraints of a performance to create a more personal "circular" experience, where an individual can explore the environment in any order, without being guided as a collective "audience" through various states.

Similarly, *The Grimm Tale (or the Story of the Youth Who Went Forth to Learn what Fear Was)* began as a Web site. Clay puppets were created to represent each of the characters in the tale. Hours of footage were shot, keying the characters on top of beds of analog video patches. Then, after the video was digitized, dozens of small loopable gif animations were made, and a continual MIDI soundtrack was constructed. In its second incarnation, *The Grimm Tale* is a performance, similar to *The Mutant Gene*, with MIDI triggering multiple video and animation events.

Taking a piece and creating a work as a performance, CD-ROM, or Web site presents fascinating progressions and developments. Each of these media has individual advantages, limitations, opportunities, and constraints, all of which have to be worked within, taken advantage of, and manipulated to make the piece a wholly new and unique work in its own right, in its new form.

This presentation examines the implications of traversing media, the technical issues involved in crossing medium boundaries, and related conceptual issues.



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Technophobia is a collection of original multimedia art in an interactive exhibition. In addition to the original multimedia artwork, the CD-ROM includes a studio visit with each artist.

The Vision Behind the Project:

I think that this new technology offers the most exciting, perhaps the only exciting thing happening in contemporary art today. I'm using the technology to transcend the limitations of physics and history inherent in other art methods.

From the creative point of view, working in a new medium is both exacting and liberating. On this CD-ROM, I worked with other artists who covered the whole gamut from those with no computer experience at all to those who had training in specialized tertiary institutions.

I've felt for a long time that art has to go outside itself, that deconstruction has worked itself out as a modus operandi. For me, working with digital technology provides the freedom to create something that is almost indefinable but reflects the obsessions of my generation: cinema, popular culture, cutting-edge art, and electronic culture.

Of the greatest interest to me is how digital culture will alter human experience – in practical day-to-day matters, in the deployment of corporate information, in entertainment, and in the art of the next phase of human and technological development.

The artists on this CD-ROM are not coming from a naive position, and the artworks we've made represent a highly considered position from the point of view of making art with new technology.

The Artists

Judith Ahern
Bill Albertini
Huma Bhabha
Joseph Ferrari
Alan Koninger
Tim Maul
Christian Perez
Troy Innocent
Guillaume Wolf and Genevieve Glaucker
Jody Zellen
Lynne Sanderson
Dooley Le Cappellaine

Electronic and Ambient Music

David Barnes and Charles Cohen
Moniek Darge
Joshua Fried
The Happy Jacks
Fugitive Pope
Phil Niblock
Mike Hovanscek with Pointless Orchestra
John Hajeski with Post Prandials

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izzy bombus and the story of flight is a prototype CD-ROM consisting of an animated story with associated games and educational activities for children ages four through seven. Izzy, a young bumblebee, discovers that according to the laws of aerodynamics, the bumblebee cannot fly. Dismayed but undeterred, izzy collects implements from a kitchen drawer to build a flying machine and asks her viewers for help with the construction. With izzy in the cockpit, the viewer pushes the launch button, the countdown begins, the smoke swirls… lift-off!

What happens next? izzy bombus is a story of resolution and innovation in overcoming obstacles. Izzy is a girl bumblebee involved in activities not traditionally considered the domain of girls, such as aerodynamics, flying, building, and exploration. The adventure is accompanied by original delta blues music by Blind Mississippi Morris. Ten games and educational activities are linked to the story and can also be accessed directly from a menu screen.

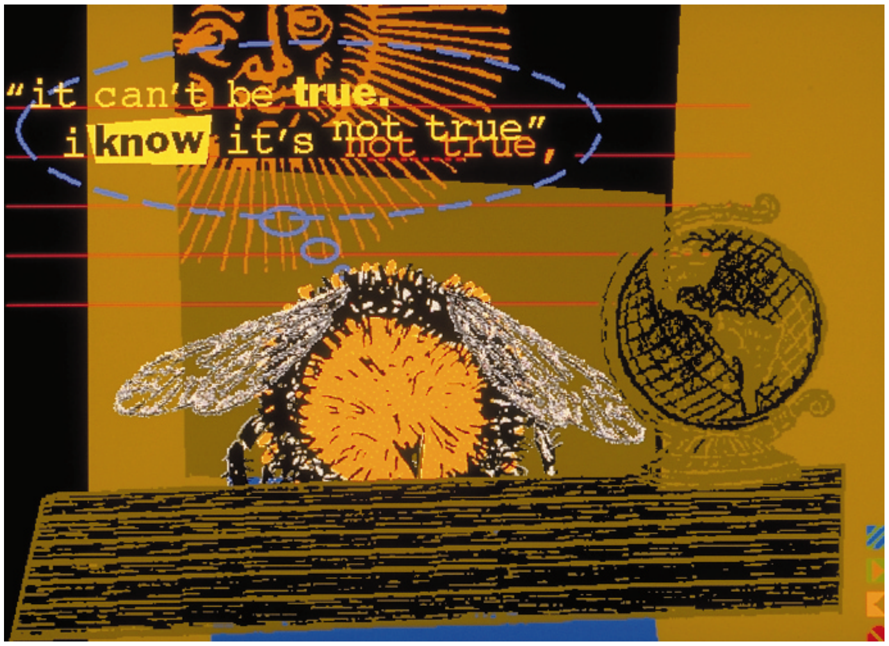
The story is complete and fully interactive to the point where it branches to the various endings. A short animated introduction leads to a menu where viewers choose between the story or the games menu. The "know-it-all-bug" serves as a guide, offering instruction and advice. Games and activities can be accessed as the viewer progresses through the story or directly from the menu.

Through this project, I am attempting to make connections between my experience as a designer of traditional print graphics and new media. My goal is to produce a viable commercial product for the children's CD-ROM market as well as to incorporate the experience into the planning and implementation of coursework in multimedia. Work began on the project in January 1996 and is continuing.

In crossing the boundaries between graphic design for print and graphic design for new media, I explored and considered the possibilities and at the same time dealt with the realities and limitations of desktop multimedia. As a graphic designer, my interest is in innovative design that combines an understanding of traditional principles of visual communication with the unique possibilities offered by the interactive experience.

With this project I have employed a collage method of assembling the illustrative elements of the story in an eclectic style. Elements are painted, drawn, and assembled from old engravings. Traditional methods are used for parts of the illustrations, while others are entirely computer-generated. The combination of techniques produces a rich, textural quality and unexpected combinations.

Another unexpected aspect of the project is the music. The blues, a part of the unique cultural heritage of the South, has gained an appreciative audience throughout the world. Although this type of music is unusual in the domain of children's products, the connection between the sound and the movement and activities of the bumblebee makes it an appropriate choice.



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Manifest destiny: In “Excerpts from the Vancouver Lectures,” Jack Spicer relates the story: Yeats, 1918, a train bound for Los Angeles. His wife in a trance, automatic writing, taking dictation from “spooks.” Yeats poses the question: “What are you here for?” And the spooks reply: “We are here to give metaphors for your poetry.”

Poetry, according to Ezra Pound in *The ABC of Reading*, is language concentrated, condensed. Pound postulates that poetry “is the most concentrated form of verbal expression.” It is this metaphorical (or possibly malaphorical) condensation, this condensed cultural automatic writing, or dictation, that I strive for.

Throwing Apples at the Sun and *Eye Sling Shot Lions* are enhanced CDs that consist of integrated multimedia compositions of sound, images, poetry, and QuickTime movies. Each disc also contains 30 minutes of original music and spoken-word poetry.

The 1995 release of *Throwing Apples at the Sun* could best be typified by the substitution of referential density for narrative coherence. The linear logic of story telling gives way to the field of intertextuality and the beauty of sliding signification. With the release of *Eye Sling Shot Lions*, this impulse is extended and elaborated through the incorporation of a series of loosely structured micro-narratives. This confluence of overt referent and micro-narrative weaves an open text, mirroring the archetypal patterns in tragic poetry.

Both discs are the direct result of the semantic experimentation begun while I was at the Cranbrook Academy of Art. These early syntactic and formal explorations of typographic form, image, and music serve as the foundation for both discs. In the most basic thematic terms, both discs are attempts to construct meditations on power, religion, language, and culture through construction of computer “applications.”

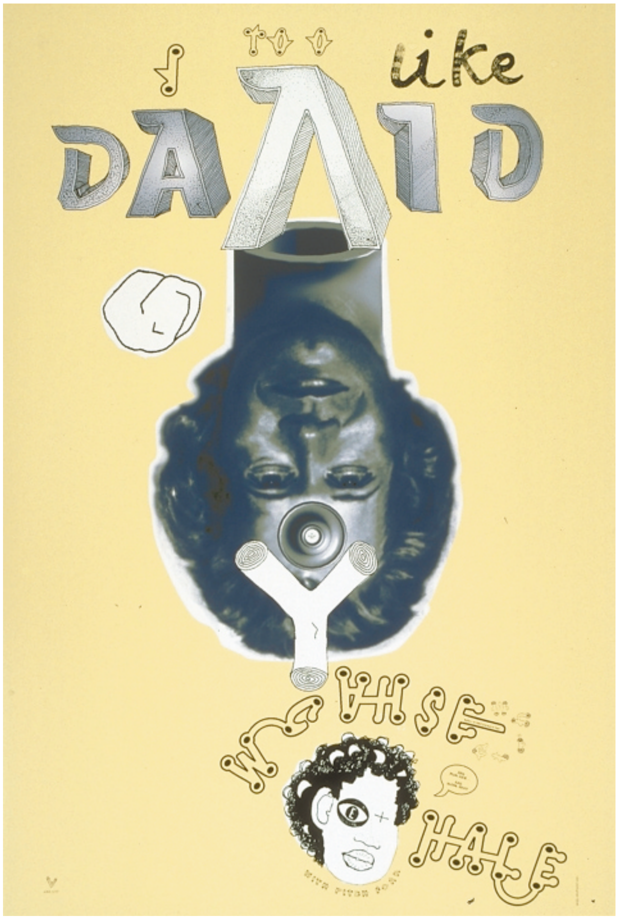
Utilizing Allegiant Technologies’ Supercard allowed me to examine the idea of the work of art through the filter and language of a standard computer application. Specifically, the ability to easily adhere to Apple Computers’ human interface guidelines allowed for an interesting semantic slippage between the language of the “application” and the language of the artwork proper. I involved myself in the process of mapping upon this desktop terrain, with its familiar menus, windows, and dialog boxes, a series of home movies, poetic sound fragments, typographic experiments, photo-montages, and spoken word texts. During the construction process, there was a constant interplay between intent and a sense of natural wholistic growth.

The formal construction of both pieces, and the thrust of all of my work, has been based upon a series of related concepts dealing specifically with macro-procedure. On a macro-procedural level, we may, with a little effort, reduce all creative acts down to a two-step process consisting of analysis and synthesis. Obviously, this process may be extended with the introduction of numerous other processes, including analysis, selection, definition, ideation, implementation, and evaluation. And while this collection of processes represents an abstraction of the actual physiological creative process, it is this “mapping” that allows us to begin to understand the complex, non-linear, and interrelated acts that comprise all creative endeavors.

The first phase of construction for both discs, could most easily be categorized as the creation of individual, traditional media that was informed by their respective disciplines. For instance, during the creation of the fonts for *Throwing Apples at the Sun*, typographic tradition, history, and formal principals were examined in a semi-rigorous analytical phase, only to yield to a a synthetic phase that dealt primarily with cultural association and marginalized typographic forms. The second phase was typified by hybrid processes. For instance, pieces of music were written, composed, and constructed utilizing some of the primary principles of digital video editing, or utilizing ideas borrowed from photography. This phase yielded typography constructed as poetry, prose generated as if it were music, and video edited with an intimate awareness of haiku. The third and final phase of design and construction continued to blur the distinction between the media. At this point, the design and construction process became extremely wholistic, kinetic, and organic. Disparate media were brought into the authoring environment, and the process of finding commonalities and themes began.

As in traditional Western music composition, theme gave way to modulation and finally recapitulation. As in non-traditional Western music composition (rap), flow, rupture, and looping structures were emphasized. As in traditional English composition, the four master tropes of figurative language – metaphor, synechdoche, metonymy, and irony – were articulated. And as in the Russian Formalist movement, the process of “defamiliarization,” or strange making, was a primary focus.

Throwing Apples at the Sun and *Eye Sling Shot Lions* have given me the opportunity to involve myself in a process of over-simplification or mapping. I have made maps of the varied terrain of self expression. I have attempted to rigorously approach and understand the fundamental principals underlying different artistic disciplines and then use the rules, not be used by them. I strive to see the big picture, to understand the method and means by which a human being can express something deeply personal. *Throwing Apples at the Sun* and *Eye Sling Shot Lions* represent these honest attempts.



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Design Speech Acts: "How to do things with words" in Virtual Communities

Cyberspace is language-based (cf. Cicognani, 1996, 1997; Winograd, 1987), and so are virtual communities. The author argues that virtual communities are ideal places to experience and enhance a language for design, and for designers.

Design in virtual communities can actually be performed using speech acts that in real life wouldn't perform any design: we will call these acts "design speech acts." For example, the command "@create wall" issued in a MOO environment corresponds to the creation of a (virtual) wall in that environment.

Beyond the interest of computer-mediated communication researchers (cf. Cherny 1995), who deal with the content of the communication in text-based virtual realities, there is a possibility for designers to finally employ speech acts for the purpose of designing cyberspace, for cyberspace's sake. Speech act theory has been applied as a way of designing computer systems and feedback processes to natural language interaction. It is interesting to observe that these applications have been abandoned, mainly for two reasons: on the one hand, the intentionality and on the other, the meaning of utterances, which create ambiguity in the interpretation.

To "perform" with natural language, there is the need to consider the context in which the speech act is uttered, and how that speech act is going to be interpreted by the hearer(s). The theory, then, has been restricted to the analysis of speech acts as content of messages issued in a computer-mediated environment, rather than commands issued to "make the computer do things with words," to actually create virtual things.

The author argues that the coincidence of functionality and appearance in text-based virtual realities can be an advantage for design in these environments, through the application of speech act theory. CAD system interfaces are not considered as relevant in the scheme of definition of design speech acts in a text-based virtual community, due to their lack of correspondence between appearance and functionality. It is in fact this discrepancy that the application of speech act theory tries to fill. Even though graphic interfaces seem to be the only actual solution to computer-based design representations, text-based virtual realities can become a relevant area of study and application for alternatives to those interfaces.

This sketch presents an hypothesis and a methodology for structuring and defining design speech acts, so that a language and interface for design in a virtual community can be subsequently developed. The author has selected and categorized a list of design verbs that can be used in a virtual community for design. A first model of this categorization is also presented and discussed. The author has developed a specific virtual community in which designers can articulate their needs and produce text-based design objects.

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Agree to Disagree Online

Any collaboration is a negotiation. While most artistic teams hide the filibustering, intellectual posturing, and shifting alliances that lie behind their decisions, *Agree to Disagree Online* brings these facets of collaboration to the fore.

Especially designed for the World Wide Web, this interactive work charts an argument among the three artists that begins with the inflammatory statement "In the future, books will be replaced by maps." *Agree to Disagree Online* maps this negotiation in time and space. Viewers can navigate through an individual argument by clicking one at a time on the participants' responses to each other. These responses are represented both in words and by a series of arrows that indicate agreement or disagreement in spatial terms: if the negotiation is nearing consensus, the arrow moves toward a central point between the artists' three initials. If the discussion is becoming more divisive, the arrow moves toward the periphery of the screen. In this way, the cumulative overlay of arrows expresses the shape of the argument, and viewers can trace this final trajectory in animated form.

The larger-scale structure of *Agree to Disagree Online* is determined by digressions from one argument to another, which the viewer is free to pursue. The forking paths that result from these digressions wander into such absurdly unrelated topics as Watergate, the way buffalos roam, and the efficacy of the Evelyn Wood speed-reading course.

The authors have been agreeing to disagree since their first adversarial collaboration in 1992. Unlike most artistic teams, they emphasize the conflict inherent in collaboration by basing each work on a particular competitive event, such as marking territory by spitting pins, targeting an opponent with projectiles, or evaluating each other's ideas for an artwork.

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Is there a way to make a meaningful shape from a collection of the individual words of the English language? What would that shape look like? Why would this approach be preferable to a traditional representation – a printed dictionary, for example? These were among the questions we asked when we set out to visualize the English language as a single entity.

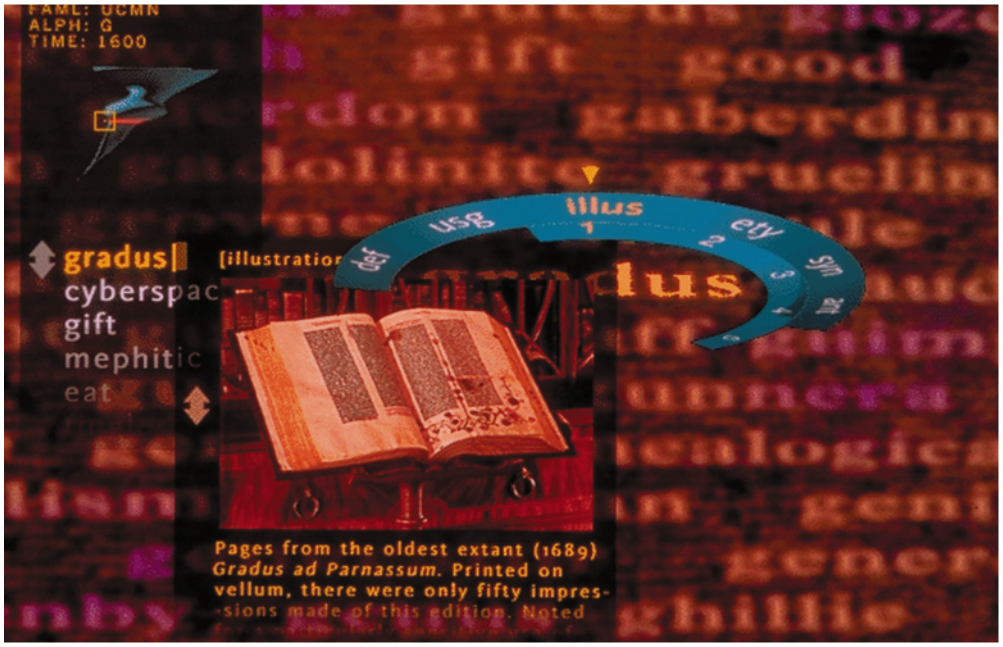
The first assumption we made was that our daily interaction with three-dimensional objects would give us leverage in establishing meaning through familiarity. We set out to create an object that would, as a result of regular observation, begin to afford the same level of information about its state as the plant you observe on your breakfast table each morning.

The initial step in the process of developing the formal attributes of the object was the identification of salient ways to categorize our data (individual words). Because the intent of the project was to propose a system that would function primarily as a reference tool, the dimensions we chose were tailored both to enable the retrieval of a particular word and to facilitate the recognition of broad trends throughout the base of data. Presumably, we are all used to locating words in a dictionary by wading through an alphabetic ordering. Based largely on this familiarity and the efficiency this familiarity affords, we chose alphabetic organization as our first axis of description.

The remaining axes of description, or "descriptors," were chosen for their perceived ability to contribute to the overall expressiveness of the resultant form: word familiarity and temporal etymology. Determined on a word-by-word basis, the most likely methodology to be used in the measurement of the familiarity of a particular word would be based on the number of times that word appeared in a statistically significant corpus. Temporal etymology would be determined by the first recorded use of a word. Once plotted along the axes, the polygonal representations of the words would be packed along their vectors to the origin. Additional expressiveness would be added to the resultant form through the assignment of color to a particular word based on the national origin of that word: for instance, words with a Germanic root would share a common hue.

The interface to this reference tool would allow the user to extract information specific to a particular word such as its definition, etymology, or illustration (if appropriate). One could also use *Gradus* to browse synonyms and antonyms, replicating the essential functionality of a thesaurus. The emergent form would be tornado-like – relatively few words at the tail of the object (the beginning of the language) and a burgeoning of words following the industrial revolution through the 20th century. Herein lies one of the major advantages of this approach over traditional means: unlike printed dictionaries, *Gradus* offers information about its content through its form.

Gradus, as an expressive, sculptural representation of the English language offers an efficient way to develop an understanding of the nature and the history of specific words and the language as a whole.



Pages from the oldest extant (1689) *Gradus ad Parnassum.* Printed on vellum, there were only fifty impressions made of this edition. Noted

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Computer Graphics as Stainless Steel Output

Project Description

A history of hand-held graphics might include Tarot cards, playing cards, the *carte de visite*, business cards, credit cards, and more recently telephone cards. While each of these subsets has a differing history and function, they also have shared attributes that continue to attract our interest. Proportions, scale, content, cost, and techniques of production all merge with more recent communication functions. Borrowing from these physical and conceptual traditions suggests possibilities for an artist using digital typography to create a kind of permanent ephemera. Incorporating stainless steel output offers an option for the designer to employ a technology similar to computer chip technology and to investigate the conversion of digitized art to artifact.

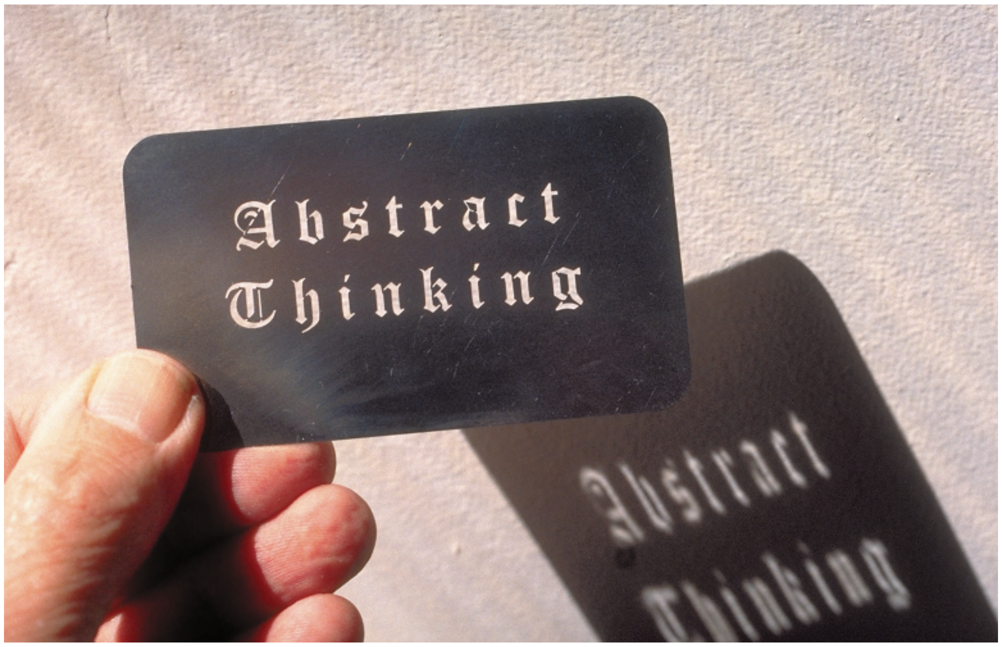
The cards examine the discrepancy between the technology of chemical machining, high-resolution digital output, non-corrosive steel material, and the language of the street: doggerel, the vernacular, the pun, a japer, or the sadness of an epitaph-in-waiting. The computer unleashes the typographic possibilities. Reversing type, customizing the fully etched openings in the metal, low embossed textures, shaping the perimeter, and scaling graphic elements are just a few of the options made possible by the digital process.

Procedure

A template was created in Freehand 7.0 that defined the format for 21 traditional business cards arranged in a grid on a tabloid-sized sheet. A space 1/8-inch wide was used to separate the individual cards. The final design was proofed on the laser printer before being used to create the film output on a Linotronic film recorder. Two tabloid-sized pieces of positive film output were generated, one emulsion down for the front side of the cards and one emulsion up for the back side exposure of the .007-inch stainless steel metal plate. After exposure and development, the metal plate was submerged in acid for chemical machining. The final etched sheet contains the cards, held in place by tiny sprews or connecting points. At this point, the cards are broken out of the sheet by hand and touched up with 600-grit emery cloth to smooth the edges.

Conclusions

A computer equipped with graphics software can be used to facilitate design and execution of art that combines text and images for output on metal surfaces using chemical machining technology. Further applications are likely – for example, limited-edition artist books with metal pages, light fixtures with metal shades that project light and shadow through the openings, and folded-metal, free-standing sculpture with surface engraving. Text and design are used to evoke expressive and conceptual issues such as: material as metaphor, the vernacular context, new cards of identity, and corporate hand-held art. A blueprint for a miniature samizdat … or maybe just another business card.



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Hand Held Tools for Navigating Information

If computers are tools for manipulating information, they have been notoriously poor at using the hands of the people who use them. By engaging the hands of the user, it is possible to get a literal handle on complex visualizations of information. In this project, the goal is to design a more practical, productive, and fluid kind of interface.

A Mathematical Twist

This project was inspired by a model of a hyperbolic paraboloid in the Collection of Historical Scientific Instruments at Harvard University. Built of brass and wood, with strings held taut by lead weights, it allowed students to create and examine a variety of hyperbolic paraboloids. We built a scale model with potentiometers mounted at key mechanical points. The change in resistance at those points is used to determine the state of the model as users modify it in real time. On the computer display, a synthetic model is shown, along with dynamic equations that show how variables such as volume and surface area change in tandem with the model.

The goal is to match the real and virtual model smoothly so that users feel as if they are the same object. Future work on this project will include using better graphic representations of the underlying math in the virtual space, which should clarify the connection between the form and the equation.

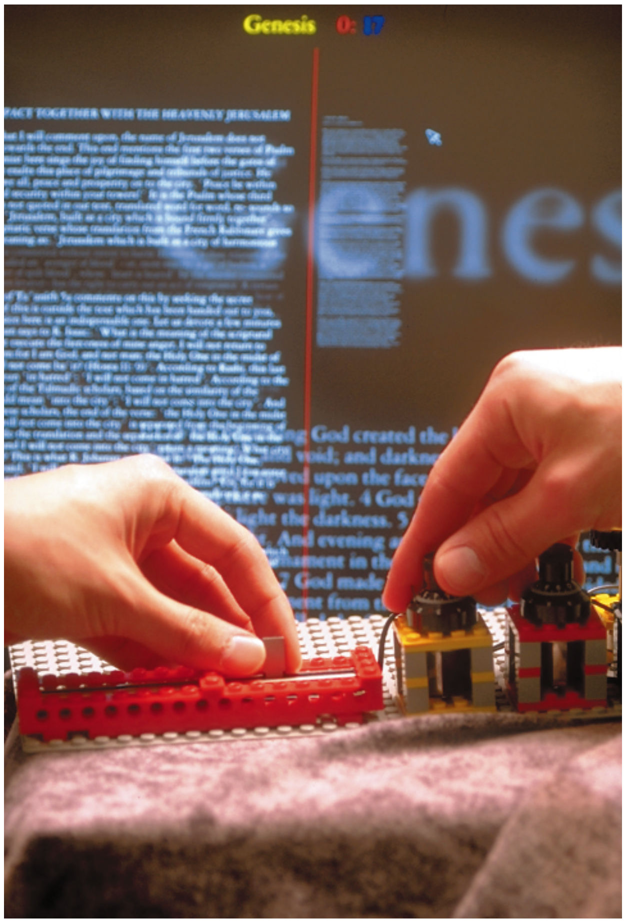
Talmudic Typography

This project was built around an essay by the philosopher Emmanuel Levinas, whose commentary on a tract of the Talmud, which itself is a complex, nested series of references to the Torah, forms an intricate web of text and connections. A visual representation of these interconnected texts should construct a space for discussion and argument in which scholars can pull and push the words as they dissect the intellectual issues posed by the text.

The Talmud is traditionally read by two people, so that it can be argued and debated. The controls were designed to facilitate this style of polemic. While discussing some fine point of logic, either reader can grab a control and modify the visual relationships between the texts in order to support an argument.

Conclusion

If you hold a hammer in your hand, everything in the world begins to resemble a nail. Likewise, we tend to get stuck in the conventional mouse-windows paradigm. By designing new interfaces, we can bridge the gap between the space people inhabit in front of the computer and the abstract landscapes inside the computer.



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Dynamic3: Interactive Physics and Physicality In Three Dimensions

We lose the joy of pliability in our interactions with the computer when we get lost in a cacophony of visual iconic references. There is no grace. *Dynamic3* emphasizes the subtleties of interaction. Not what is seen, but what is felt. A physics-based computational model and a fluid physical interface amplify the expression.

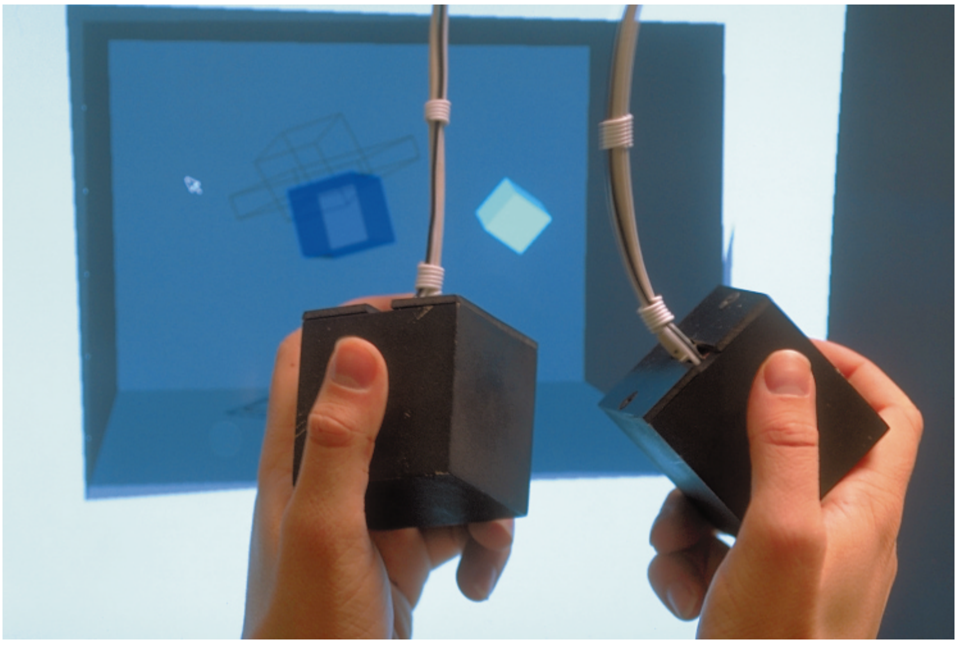
Two physical cubes control a malleable, hierarchical data structure represented as abstract objects on a virtual stage. The external appearance of the physical cubes mimics the simple geometrical forms on the screen. By using interactive particle physics, virtual objects react in ways that correspond to our existing assumptions about our physical world.

The two physical cubes control the position and orientation of their virtual counterparts. A change in position of one of the physical cubes exerts a force on the parameterized particle physics model. By variably weighting various data objects, a new paradigm is introduced, by which the dynamic/motive reaction of information structures gives subtle cues as to the contents of the object.

Through repeated exploration, users are able to feel differences in reactivity and modulate their decisions accordingly, without sacrificing aesthetic or metaphorical continuity.

A firm gesture towards the rear of the virtual stage allows the user to view more detailed information about the contents of the abstract data objects. The camera tracks and pans to a position behind the translucent rear stage. From this position, it acts much like an X-ray machine, revealing the information structure within each data object. The objects' shadows transform into projections of their corresponding data.

Today's supercomputers and tomorrow's desktop machines have tremendous capabilities for display of three-dimensional information in real time. A great deal of work has been done in realistic creation and display of bodies of information, yet navigation and manipulation of these spaces remains frustratingly rigid. Using advanced visualization techniques and traditional design principles, this project creates visceral, intuitive methods for modulation of 3D space for both commercial and design purposes. The physical underpinnings of the interface architecture allow for the possibility of functionally and aesthetically graceful interactions.



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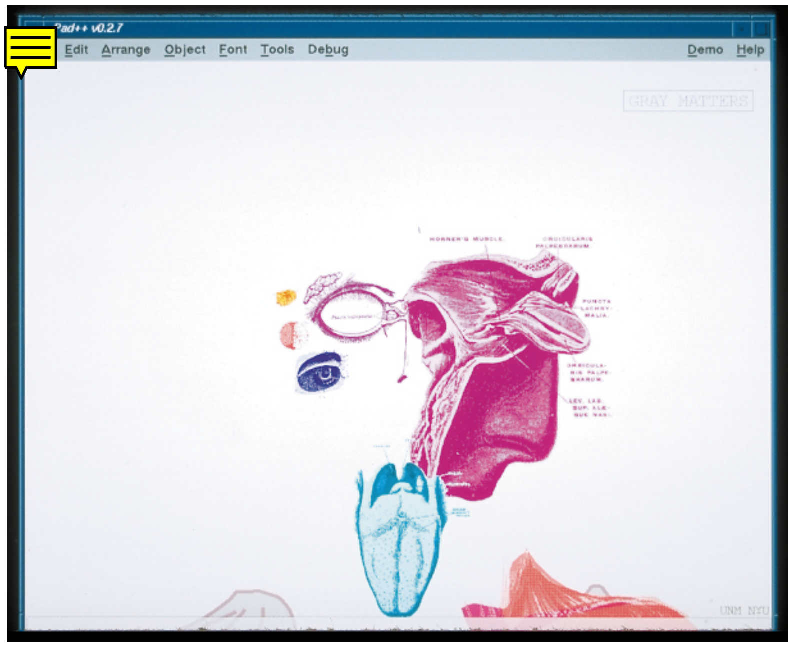
Pad++, a general-purpose zoomable substrate for creating and interacting with structured information, is under development by researchers at the University of New Mexico and New York University. All Pad++ objects support zooming, and there are mechanisms for navigating through a multiscale space using panning, zooming, and hyperlinks. Pad++ includes a number of efficiency mechanisms that help maintain interactive frame-rates with large and complicated graphical scenes.

Applications based on Pad++ attempt to tap into our natural spatial ways of thinking by supporting views of information at multiple scales. These applications move beyond the simple binary choice of presenting or eliding particular information and present a continuous context in which information is encountered. Arrangement, proximity, size, and scale-based representation may be used to present semantic information in manners unique to zooming interfaces. Very large amounts of information may be embedded at successively deeper levels, making it easier to provide effective access to a structure of information much larger than the available display.

PadDraw is a sample application that supports many of the features found in drawing and hypermedia programs, but it adds a zooming component. Zooms are smooth and continuously animated, much like using the zoom controls on a video camera, so users always retain a sense of context. When a link is followed in PadDraw, the system automatically pans and zooms the view, taking the user to the appropriate piece of data. Readers are left with the sense that the starting information point is “up to the left” or otherwise in an intuitive relationship with their current view. This helps readers to orient themselves in a complex hypermedia document.

Gray Matters is a collaborative, multiscale hypertext artwork/fiction. Using a subset of the PadDraw functionality, it creates an environment for multiscale reading and exploration. Fifteen images from *Gray’s Anatomy* are tinted and arranged in a patchwork body. Each image has two representations: a scanned and manipulated bitmap, and a simplified vector graphic. The bitmap is seen when the view is zoomed out, and this cross-fades into the the vector graphic as the view moves closer. At the same time, color-coded labels representing texts fade into visibility. As the view zooms in further, the labels dissolve away, and the full texts are displayed against the color fields of the vector graphics.



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Creative options and challenges: a digital art archive grows into a dynamic showcase with new views of the art.

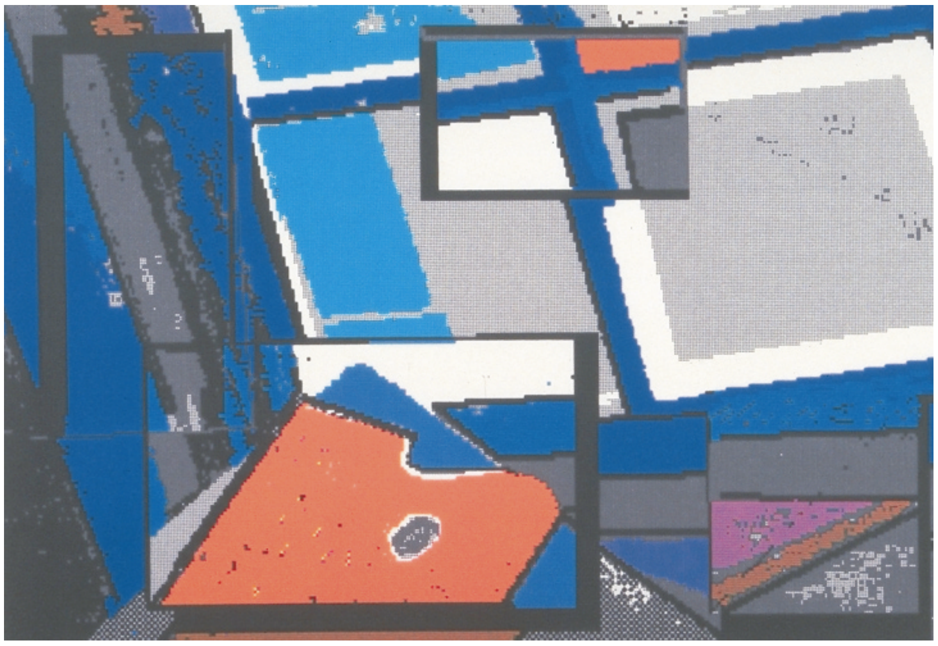
This archive is an independent, solo production that gauges the efficacy of CD-ROM publishing for, and by, individual artists as well as for groups, galleries, and other larger institutions. The set of discs is more similar to an artist's portfolio than a commercial product and is intended primarily for art and educational institutions, rather than for distribution through strictly commercial channels.

The art included in "The Art dimension: an artist's archive and retrospective" (an overview of a half-century in the fine arts) and "The Image Circle: a life in photography" was digitized using one of two methods: scanned on a flatbed scanner or transferred to Photo CDs. Such scans require a considerable amount of "tweaking" or retouching before their appearance is acceptable. In this process, many aspects of an image can be adjusted or altered: color, contrast, sharpness, and even composition.

Sometimes this leads to creation of entirely new versions of the earlier work, and rediscovering the work in its digital form with its new options to alter and create new versions of the original renditions at will constitutes one of the most creative and exciting parts of the task.

The process of developing a digital portfolio provides a whole new view of the art vis-a-vis the potentials of the new media. Creating animated versions of once-static traditional collages has also led to Dada-esque moving image/sound collages and numerous other dynamic variations of the original art. The possibility of combining simple motion with the existing art has also added a new dimension to the current work: new animations that utilize and recombine parts of earlier imagery into new meaning and a new dynamic creation.

More advanced techniques include such explorations as "mapping" photographic work onto dynamic 3D structures to explore new(ly) anomalous content as well as spatial relationships.



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This presentation reviews three works: *Genderbender*, *Smart Stall* (exhibited in The Bridge: SIGGRAPH 96 Art Show), and *The Automatic Confession Machine* (exhibited in Machine Culture, SIGGRAPH 93).

Genderbender 1.0, loosely based on the Bem Sex Role Inventory (BSRI) (1974) and the Turing test for artificial intelligence, scavenges the trash heap of psychological testing in pursuit of the “Virtual Personality.” It allows a user to self-administer a gender test of 20 masculine, feminine, or neutral traits. The Morph-o-meter and the Tile-o-matic give instant feedback on whether masculine or feminine characteristics predominate in the user’s personality by morphing towards identifiably male or female visual representations and revealing the user’s digitized image. Based on the user’s input, the “psychologist” displays: “You are a man!” or “You are a woman!” or “You are androgynous!”

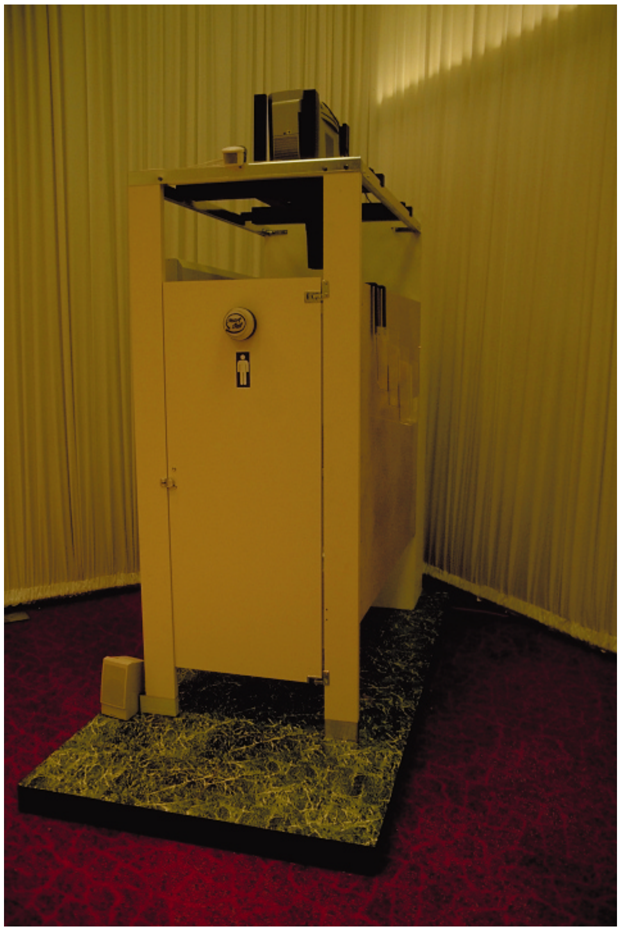
Smart Stall is the Master/Slave Duchampian Telecommunications Interface. It is conceived as an immersive, interactive theatrical experience inspired by Antonin Artaud’s “Theatre of Cruelty.” The user’s motion triggers “orders” and “instructions” from an abusive semi-intelligent agent suffering from multiple personality disorder. In homage to Duchamp’s avatar, R. Mutt, this installation looks like a public toilet stall, but it actually is a telecommunications terminal. Two non-functioning bathroom toilet stalls are equipped with digital white boards, which digitize handwritten graffiti and transmit the messages to remote stalls where the messages are projected. *Smart Stall* is especially interesting in light of Roger Penrose’s lawsuit alleging that Kimberley Clark Corporation infringed a copyright when it sold toilet paper bearing the Penrose Tiling pattern, a demonstration of a class of non-computable problems that forms a key part of Penrose’s argument that “human understanding and insight cannot be reduced to any set of computational rules.”

The Automatic Confession Machine: A Catholic Turing Test is a stand-alone kiosk that resembles an automatic banking machine. Users must kneel and confess committed sins, after which they receive a printout indicating how many Hail Marys and Our Fathers must be said for digital absolution and silicon salvation. This work is inspired by Alan Turing’s test for judging whether or not a computer can be said to think.

These three installations use technology to question our infatuation with the brave new world of AI, VR, and ubiquitous computing. They put users “on the spot” by requiring a commitment or a theatrical suspension of disbelief and forcing them to make choices that require examination of their own beliefs and biases. As Brenda Laurel has noted, the potential of the computer is “not in its ability to perform calculations but in its capacity to represent action in which humans could participate.”

Genderbender can be viewed at the Transverse Worlds web site:
http://142.232.132.45.80/dedocs

Users can go to confession at the Lightfactory web site:
http://www.lightfactory.org/artists.html



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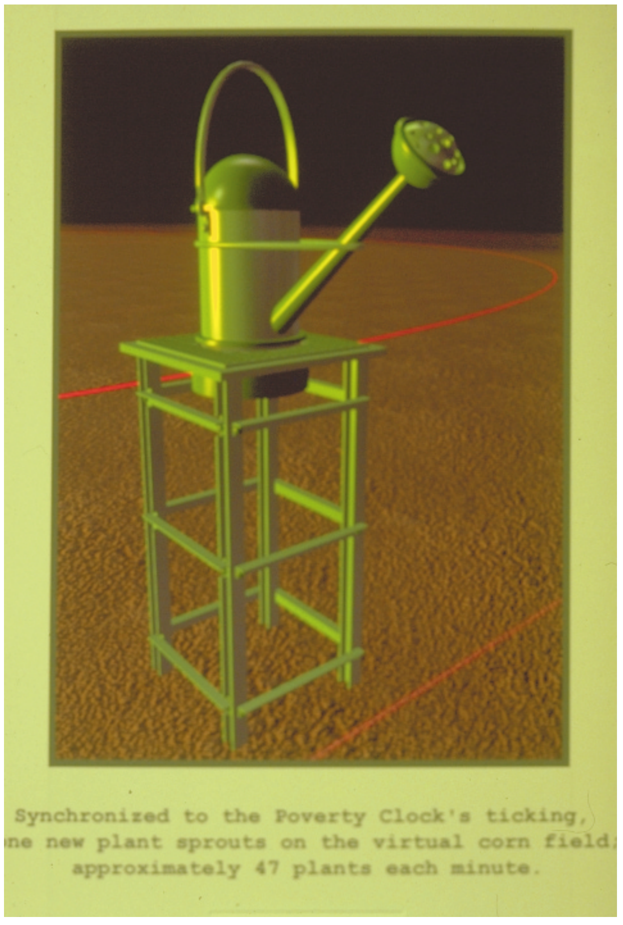
The Virtual Harvester Project

The Virtual Harvester project is an effort to address the need for global commitment and action to fight one of human society's most basic problems: food insecurity. The United Nations Development Program (UNDP) created the Poverty Clock to illustrate how quickly poverty grows. Each successive digit on the clock indicates another person living on less than $1.00 (U.S.) per day. Synchronized to the Poverty Clock's ticking, one new plant sprouts on the virtual corn field; yielding approximately 47 plants each minute.

In *The Virtual Harvester,* one new plant sprouts on a virtual cornfield with each tick of the clock, yielding approximately 47 plants each minute. Proposed to be experienced in the harbour simulator facility in Rotterdam, the project surrounds viewers with virtual corn plants, each representing a person living in poverty. Instead of a ship's bridge, the platform displays a fictional harvester cabin. In front of the viewers, virtually attached to the pilothouse, is an enormous virtual harvesting device. The device produces a loud mechanical noise (amplified by the harbour simulator's 3D sound), vibrating the pilothouse from side to side while it reaps the harvest. As the yield is blown into virtual storage trucks moving slowly alongside the pilothouse, viewers become aware of the scent of fresh grain rising from a thick layer of yellow maize that covers the entire inside floor of the simulator. As they stand protected inside the pilothouse, viewers will be able to steer the virtual combine through green virtual cornfields, leaving a trail of scorched earth behind the harvester's reaping blades. Protruding from the fields are gigantic communication towers, which serve as beacons amidst the vast virtual landscape. While viewers "play the game," it is subtly revealed (via incoming messages on the harvester's two-way radio system) that the virtual cornfields are in fact 3D visual data fields that represent the number of people living in absolute poverty across the globe.

The Virtual Harvester questions the motives of the Western world's immersion in information technology as it constructs "the global village." The work asks if the Western world is not paradoxically isolating itself even further from the social and economic realities of its impoverished neighbors.

"Alongside the ever-widening social divisions, another apartheid is being created between the 'information-rich' and the 'information-poor.'" (excerpt from *The Californian Ideology*, Barbrook & Cameron)


Synchronized to the Poverty Clock's ticking,
ne new plant sprouts on the virtual corn field;
approximately 47 plants each minute.

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The talent of a caricaturist is important when using traditional media such as pencil and paper. Since traditional media are not interactive, caricaturists must complete the caricatures in their minds before starting to draw. Since this ability does not exist in most people, it has always been considered some sort of magical talent of a gifted few.

I have noticed that when using an interactive morphing tool, there is no need to have the special talent of a caricaturist. Based on my experience as a professional caricaturist, I have developed a procedure to make caricatures from photographs by using morphing tools. With this method, people need only have the ability to recognize others from their caricatures. Judging from the popularity of caricatures, I expect that most human beings have this ability.

Procedure for Making Caricatures

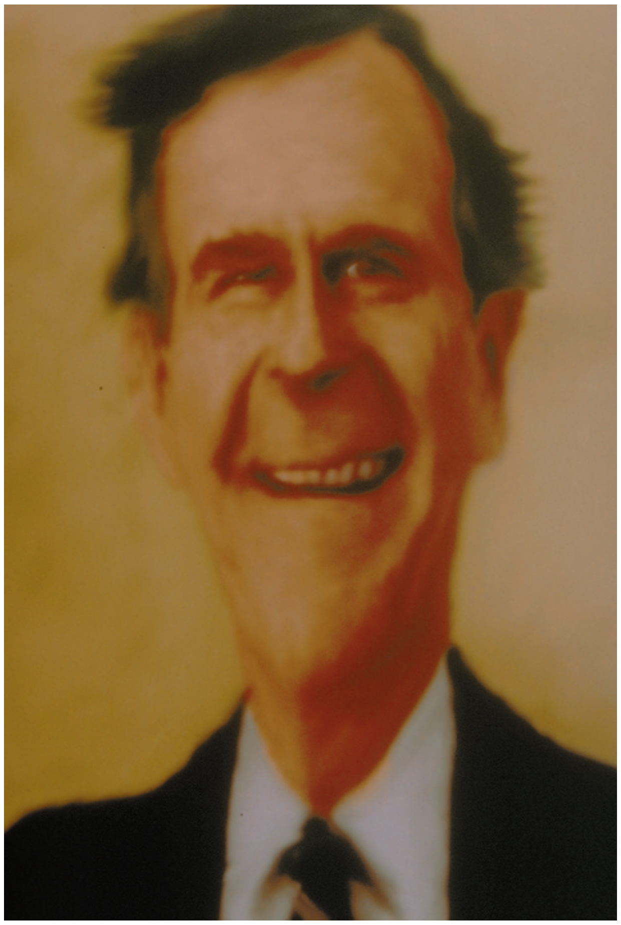
1 Use an extremely simple template. Thinking it will give them greater control, most people, when using morphing tools, tend to start with complicated templates. However, in this case less is more. The templates should be extremely simple and they should include only the essential features of the face: nose, eyes, mouth, and outline.

2 Exaggerate only one feature at a time. Concentrating on only one feature forces the caricaturist to understand its importance relative to the face.

3 If exaggeration creates a likeness, continue to exaggerate. If it does not create a likeness, make the exaggeration in the opposite direction. If neither direction gives a likeness, return the feature to its original position.

4 Start again with another feature until satisfied with the result.

In this work, I am proposing a simple procedure for making caricatures. I believe that anybody who can recognize a likeness can make caricatures by using this procedure. I made the caricatures of six presidents and many other people following this procedure. To further enhance the results, I created a painted look by smudging the images in Photoshop. The figure shows the caricature of President George Bush. The photograph I based this caricature on is a 417x460 greyscale image, which I obtained from the Presidential Portraits Web page of the Library of Congress.



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Visual Simulation of Waterfalls and Other Water Phenomena

Accurate physically based rendering of complex phenomena such as the flow of water is an unrealistic aim: computational fluid dynamics simulation is a compute-intensive task, even for simple flow regimes, and is far beyond current knowledge for complex flows such as waterfalls. Our goal here is to develop a simple yet flexible simulation system that models a rich variety of scenes and behaviors, and provides the basis for visually convincing rendering. The simulation system aims to provide a convenient set of facilities for an animator to construct a scene and control the flow of water in that scene.

Whereas other authors[1,2,3] have simulated flows such as rivers, we have concentrated on falling water. Our system draws on observations of a large number of real waterfalls. A standard collection of objects such as spheres, planes, and polygons is used to model terrain or other solid objects such as fountains. More elaborate terrain models as in[4,6] are intended, but the current focus is on behavior.

Falling water is modeled using a three-dimensional particle system[5]: sections of falling water consist of a collection of relatively small particles that obey gravity. Each particle contains data relating to position, velocity, and size (including mass). Drops may influence one another, depending on the outcome of a simple particle-particle intersection test. As two particles approach, their relative velocity is examined. If this is above a certain threshold, the particles bounce away from one another, but if they are moving slowly they coalesce into a single blob of water (Figure 1 shows a fountain with coalescing columns). Intersection tests between particles or particles and solid objects are evaluated efficiently because the velocity of the particles and the simulation time step enable a localization optimization to be employed. Where a particle collides with a solid object, reflection about the surface normal takes place, but the normal is perturbed by a random amount to simulate surface irregularities and roughness. The reflection velocity is dampened by a factor based on the incident angle: if the angle is near 0°, then minimum loss occurs, but if the angle is near 90° then almost all energy is lost in the collision, thus slowing down the particle. If the impact velocity exceeds a given threshold, the particle splits into two equally sized particles. Figure 2 is a typical example.

Whilst falling, water is influenced by a number of factors. It can slow down and spread out due to air resistance and have its position affected by wind, sometimes dramatically. In our system, when wind is encountered, the number of nearby particles in the plane of interest is counted. This value is used to dampen the effect of wind on the volume of water falling, on the principle that dense particles mask the effects of wind, whereas sparse particles are more susceptible to being blown around. Multiple winds from multiple directions are used.

Mist/water vapor surrounds any section of falling water, contributed to by collisions with objects, deceleration, splitting, and small droplets of vapor escaping from the main volume. For example, a particle moving above a given velocity emits much smaller mist particles. Figure 3 demonstrates this effect. The behavior of mist differs from water particles in that it is very light, so it does not fall at the same rate as a normal section of water due to air resistance. Mist is particularly susceptible to influence both from the main body of water and external effects such as wind and may rise as well as fall. Mist also expands, contracts, and is even less predictable than its liquid counterpart. Rendering the final image in our simulation is currently straightforward, as our goal is not realistic rendering but visualization of the dynamics of the simulation. Each particle is initially assigned a blue colour, and a vector is drawn at the end of each time step based on the distance travelled in that time step (i.e. we draw velocity vectors). On striking an object, the colour of the particle is changed. The sound that water makes is emulated by generating random noise when particles strike solid objects.

In our future work, we plan to explore the turbulent actions of the splash-down area of a waterfall. We will also apply the ideas developed in the study of falling water to other water phenomena such as rivers and puddles. The goal is to provide an animator system that allows the construction of water-based scenes and effects based on the ideas that evolve during this research.

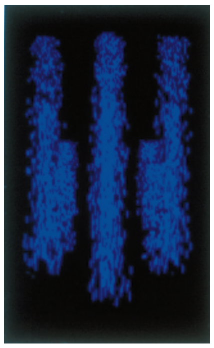
FIGURE 1 Fountain with coalescing columns (still)

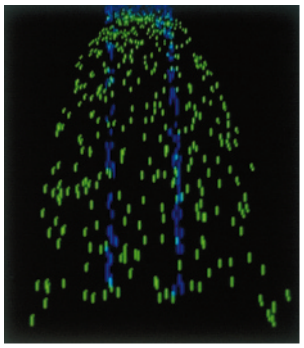
FIGURE 2 Water striking obstacle (still)

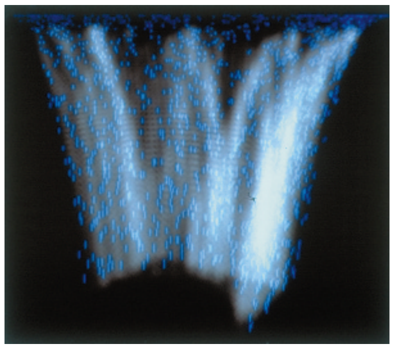
FIGURE 3 Horseshoe Falls with mist (still from video)

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Volumetric modeling is vital for realistic simulation of many natural phenomena, including water, clouds, gases, and fire[1]. Unlike traditional surface-based approaches[3], volumetric models allow you to capture the entire three-dimensionality of the phenomena. There are two general classes of techniques to simulate these natural phenoma: physically based simulation and non-physically based solutions. This sketch describes a new procedural technique for modeling and animating volumetric objects, which combines implicit function modeling, procedural turbulence simulations, and volume rendering to produce a powerful, easy-to-use, realistic volumetric modeling system for natural phenomena. The use of implicit functions (blobs, metaballs) as a modeling primitive allows the user to take advantage of smooth blending of primitives, sketetal modeling elements[4], and more natural animation control.

Volumetric procedural modeling (VPM) techniques have many advantages, including data amplification and parametric control[2]. However, the definition of overall volumetric shape through procedures can be a difficult task, especially for non-programmers. By combining implicit functions with VPMs, a natural, flexible, powerful animation and modeling system can be built. The advantages of both techniques can be harnessed to enhance the design and animation of volumetric objects.

An Example Procedural Volumetric Implicit Function

This new technique can be used to create realistic volumetric clouds that can be rendered with low-albedo and high-albedo physically based illumination and atmospheric attenuation. Figure 1 shows a cumulus cloud created by positioning nine implicit spheres with varying radii and blending amounts to define the overall shape of the cloud.

The turbulence-based[5] volumetric procedures add natural detail and allow control of the density and edge sharpness of the cloud. User-defined parameters control the blending of the implicit function density and the turbulence-based procedural density, the overall denseness of the cloud, and the sharpness of the density fall-off. The algorithm below describes the general cloud procedure:

```
cloud(pnt)
  perturb point using noise and turbulence
  density1 = implicit_function(perturbed_point)
  density2 = turbulence(pnt)
  blend = blend% * density1 + (1 - blend%) * density2
  returned density = power(blend*max_density, exponent)
end cloud
```

Cloud formation and evolution can be simulated by adding time as a parameter.

Conclusion

This sketch shows that implicit functions can be combined with procedural models to model and animate complex volumetric objects and phenomena. The addition of implicit functions provides natural blending of primitives, use of skeletal models, and ease of modeling and animation. More examples of this technique and resulting animations can be found at: http://www.cs.umbc.edu/~ebert/cloud

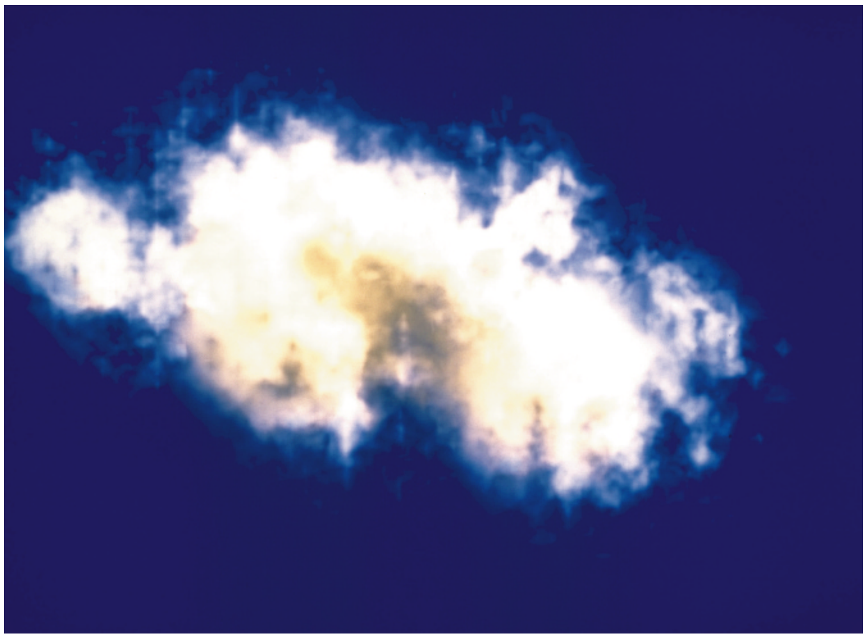

FIGURE 1 Procedural volumetric implicit turbulent cloud

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In 1992, Pat Hanrahan and Don Mitchell introduced[3] a new algorithm that allowed an exact computation of the reflected illumination from curved mirror surfaces onto other surfaces (see Figure 1). That superb work was based on Fermat's principle, which says that this computation is equivalent to finding extremal paths from the light source to the visible surface via the mirrors. Once pathways were found, irradiance was computed from the Gaussian curvature of the geometrical wavefront. Another approach is bi-directional ray tracing[4], but it has as a major drawback: the inherent high computational cost of ray tracing.

In this sketch, I present a high-speed scan-line based algorithm to achieve the same effect. The key ideas on which the whole work is based are:

- There is no light-reflecting mirror that is not "seen" by the light sources.
- We can think of the whole process as if each curved reflector that receives light acts as a secondary light, that is, transforms itself into a non-isotropic extended light source.
- We can perform Phong-like interpolation, within a certain error, of any quantity that can be pointwise obtained, such as the intensity (Gouraud Shading), the surface normal (Phong Shading) or even its curvature.

Armed with these three ideas, we can introduce our scan-line based solution. As we build the shadow maps, we store the reflected illumination info within the mirror (see below), and later, when performing the final rendering step, we treat it exactly as any other light source. To do so, we only need a data structure to hold the illumination information in an efficient and accurate way. But that structure was already developed. It's a modification of the Environment Map[1] called Z-Buffered Environment Map[5]. It is very similar to the Light Buffers[2], where, for each pixel in the map, a complete sorted list of all the surfaces seen through it is stored (Figure 2). However, instead of storing the surface ID, we store its distance from the map center, its material ID, and the light intensity accumulated on it. Given a reflection ray in the map coordinate system (given by the position on the reflector, W, and the reflection direction, R), we only need to search in the line given by the intersection of the Env. Map and the plane determined by the Center of Projection, W and R; checking only the lists stored in the pixels that are between W and R, in order to find the closest to the desired intersection point.

So, the first step of our algorithm proceeds as follows (see Figure 3): Firstly, compute the Z-buffered Env. Map for each reflector. Then, when computing the shadow buffer for each light source, scan-line the mirrors as usual, but linearly interpolating the curvatures (stored with their respective vertices) as we use to do with the color or the normal. For each point of the surface rendered, calculate the light ray to it from the source and reflect it. With the Z-Buffered Env. Map, compute the intersection of this new ray with the environment, leaving the intensity information (computed exactly as described in Hanrahan, P & Mitchell) in the corresponding entry of the map.

During the final rendering, we must transform any point to be shaded to all the light sources' spaces and to all the mirrored objects own spaces, too. With the second ones, it's just a matter of taking the illumination information from the corresponding entry from the right pixel and computing the illumination (see Figure 4). If the object being rendered is the mirror itself, I use the indirect illumination stored in the first entry, along with the position (and coordinates of the pixel) to get the direct component, treating the surface as a pure lambertian one.

If we take into account that the original images were rendered in an eight-processor Silicon Graphics Iris in about 10 hours and that a small image (200*200) only took 10 minutes in a 486DLC PC, we would see that scan-line algorithms are just as capable of generating sophisticated lighting effects as ray tracing, at noticeably lower computational costs.

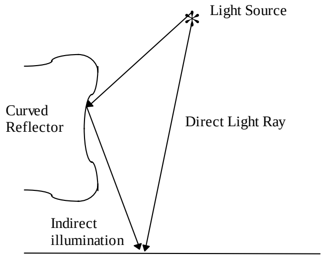

FIGURE 1
Direct and Indirect illumination to be computed at a surface.

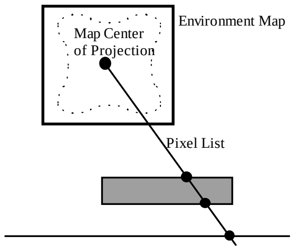

FIGURE 2
The Z-Buffered Environment Map geometry: A pixel list is shown with the three intersection points it contains marked as black dots.

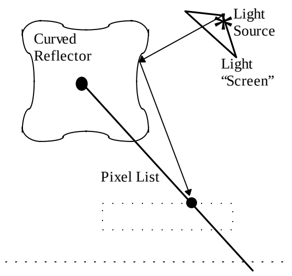

FIGURE 3
Storing the reflected illumination into the Environment Map. When computing the shadow buffer, each light ray that reaches the mirror surface is reflected and stored in its respective intersected list item.

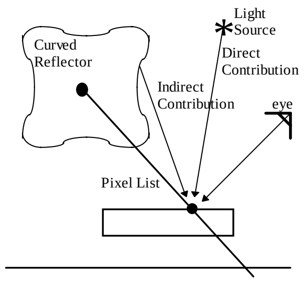

FIGURE 4
The final illumination step: the shading of the point seen by the observer is computed both from the light sources and from the curved reflector.

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We present a new method to compute the impulse response (IR) of a given virtual room based on hierarchical radiosity. Unlike previous work, our approach can treat complex geometries and is listening-position-independent. Moreover, complex phenomena such as sound diffraction are also taken into account.

The acoustical quality of a room may be evaluated from two points of view: objective criteria that can be measured and subjective appreciation by listening. These two ways, however, usually require knowledge of the room's impulse response at the listening position. The impulse response of a room may be seen as the pressure response of the room when the source emits an instantaneous impulse (Dirac signal). It is a digital filter that encodes all sound reflections through time from the source position to the listening position. By convolving this filter with a rough sound signal, the virtual sound field is made audible. This process is referred to as "auralisation".[2,3] Two standard methods for IR computation are ray/cone-tracing and image sources methods.[2,3] However, they quickly become impractical for complex geometries or high orders of reflection. They do not take into account complex phenomena such as diffraction by partial occluders. Moreover, they are listening-position-dependent, so the complete solution must be recomputed if the listener is moving, which can be limiting for virtual acoustics applications.[2,3]

We present a new approach to compute the IR of a virtual room based on a hierarchical-radiosity-like solution with general reflectance distributions.[1] We propagate energy from patch to patch as in the classic hierarchical radiosity method. Since sound propagation time cannot be neglected, we store an energy repartition through time for each surface corresponding to the list of echoes that reach the surface. This energy repartition through time (or echogram) is computed for various frequencies (generally octave bands), since reflection functions, source, and microphone directivities as well as propagation medium scattering are frequency dependent.

We approximate the attenuation factor due to diffraction by partial occluders by evaluating a frequential extended sound visibility term. This term is computed by counting the proportion of the first Fresnel ellipsoid, where most of the energy propagates, blocked by occluders. The first Fresnel ellipsoid is defined by $\{ M \in IR^3 / C_iM + MC_j = C_iC_j + {}^{l}\!/_{2} \}$ where C_i is the center of a patch P_i, C_j is the center of a linked patch P_j and l the wavelength of the sound wave. We use graphics hardware for fast calculations by evaluating occlusions using the Z-buffer (Figure 1).

Phase information is also essential in order to reconstruct the IR. Thus, we represent echoes as complex numbers corresponding to modulus and phase. Once the sound radiosity solution is computed, the IR can be evaluated by re-projecting each echo stored on each surface onto the listening point. A short sampled impulse response of a basic bandpass filter is associated with each complex echo. These short IRs are then delayed and summed to obtain the final IR.

Our new method allows for using the appropriate number of patches for each frequency band, thus leading to an "optimal" usage of the computing resources. Complex propagation phenomena are taken into account, and final rendering times of less than a second make our approach promising for virtual acoustics applications. Validation of our algorithm with measured IRs of existing concert halls and rooms is currently in progress.

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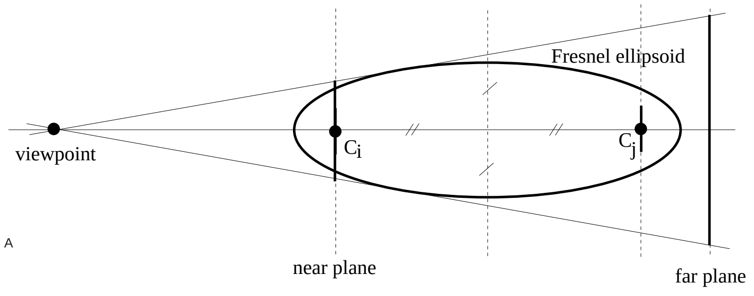

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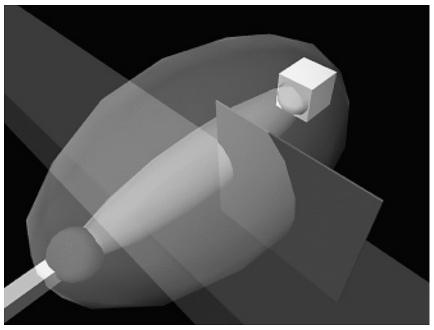

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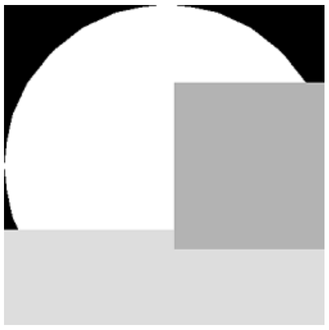

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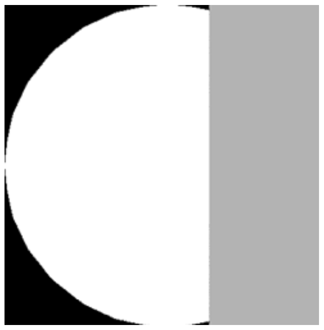


D

FIGURE 1 Using graphics hardware for sound visibility calculations
A Viewing frustum
B 3D view of microphone, source, occluders and Fresnel ellipsoids for 400 and 4000 Hz
C Visibility from microphone at 400 Hz
D Visibility from microphone at 4000 Hz
(Visibility term is the percentage of white pixels in the view)

Radial Basis Function Interpolation Surface On Space Mesh

The B-spline paradigm for modeling smooth surfaces is limited by the requirement that the control point mesh must be organized as a regular rectangular structure. Ignoring this requirement by collapsing control mesh edges leads to surfaces with ambiguous surface-normals and degenerated parameterizations. Many approximation approaches have been considered for modeling surfaces of arbitrary topological type by smoothly approximating an irregular control mesh. A limitation of the polishing method is that it does not satisfy the interpolation condition. Some local interpolation methods have been discussed for constructing piecewise interpolation smooth space surfaces. These methods are based on increasing free degrees of each surface patch by using increasing polynomial order or refinement of space mesh. Generally, surface degree is not less quartic. In applying these methods, surface shapes depend on determination of parameters and estimation of gradient. It is concluded that local polynomial interplant generally produces unsatisfactory shapes.

In this sketch, we consider construction of a smooth interpolation space surface. A radial basis function interpolation surface over space mesh is generated by combining both the subdivision method and the radial basis function interpolation method. The technique's advantages include using interpolation to generate generally nice shapes.

Radial Basis Function Interpolation Surface

The interpolation surface algorithm takes a space mesh as input. A spline surface is constructed by using a subdivision method with bi-quadratic Bezier patch representation and tangent plane continuity between these patches that are in the same space triangular patch surrounded by space triangular. Then, a radial basis function interpolation surface defined on the spline surface is introduced. Radial functions are chosen to be either inverse multiquadric case or Gauss case, depending on which case will guarantee a coefficient matrix of radial function parameter equation system that is positive definite.

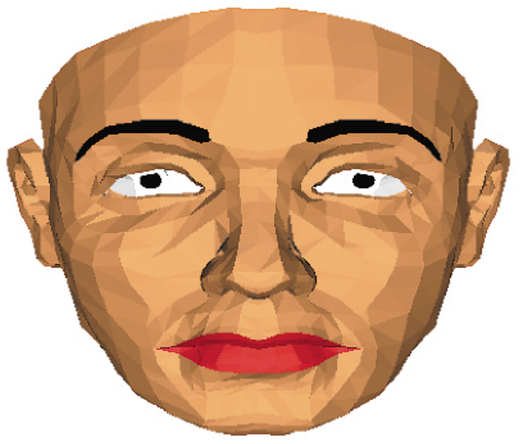
The radial basis function interpolation surface is constructed in two stages:

1 Construct bi-quadratic Bezier patches by subdivision algorithm.

2 Construct RBFIS defined on the collection of Bezier patches.

Input: irregular control mesh.
Output: radial basis function interpolation surface.

The purpose of using subdivision bi-quadratic Bezier patches is to isolate irregularities and smooth the entire surface shape. Any approximation surface is general enough to be used. The interpolation surface shape and smoothness order are dependent on the construction of the subdivision surface. A human face surface generated by using the algorithm is illustrated in Figure 1.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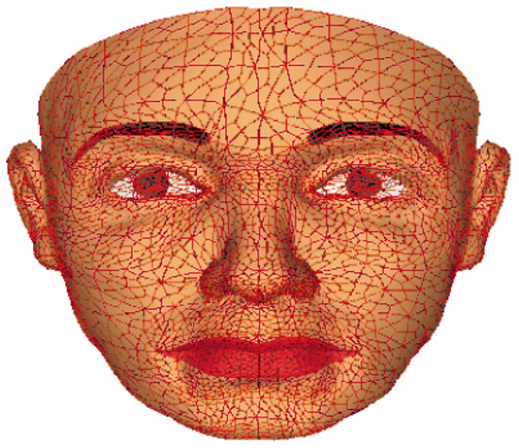
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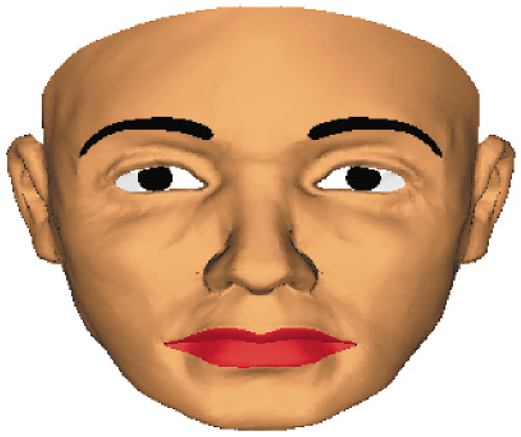
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FIGURE 1
A A human face triangulation control mesh
B Radial basis function interpolation surface. The radial basis function is chosen to be Gaussian case: e^{-r^2}
C Control point mesh of subdivision spline surface (red color lines, only eight boundary lines are drawn for each bi-quadric Bezier path) and resulting subdivision spline surface.

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A 3D model construction constrained by a set of polylines provides a simple and accurate result. In particular, we provide a boundary-based model without using an irregular tetrahedra mesh, which is guaranteed to generate the triangular facets to match the surface of the 3D model. Our algorithm to generate a 3D model does not need a fine discretization on the 3D surface. However, if the model needs to be finer, recursive subdivision on the triangulated meshes can be implemented after the shrink.

Reconstruction of a 3D complex model from interpreted seismic data has been an intriguing problem during the last decade. The main motivations for solving this problem come from applications such as the study of medical imaging or geological imaging for oil exploration. Data obtained by digitization of 3D objects can be triangulated in order to represent a 3D model. When the model has a simple shape, the triangulated meshes can be easily generated. However, if a set of digitized data corresponds to a multi-valued surface, no method relying on projection can be applied.

Edelsbrunner and Mucke[1] tried to define the geometrical data structure by the notion of "shape" for a set of points. Starting from the Delaunay triangulation, an alpha coefficient is associated with each point, edge, triangle, and tetrahedron. For alpha equals infinity, the shape of a 3D object is identical to the convex hull. However, as alpha decreases, the shape shrinks by gradually developing cavities. Unfortunately, based on our experience, it is difficult to define a continuous triangulated boundary from a set of points.

Boissonnat[2] proposed a volume-based approach to build a 3D object. The first step of this approach is to implement Delaunay triangulation on the scattered data points. The second step is to successively remove the triangles or tetrahedra from the convex hull to the objective boundary of the 3D model. In both methods described above, the generated 3D model will cause an error when the data points representing the surface are not dense. Given a set of constraints such as tetrahedra, triangles, or edges, we are unable to build the tetrahedra that can be filled with those tetrahedra or triangles, if the data to represent the 3D surface are not fine enough. Therefore, to tetrahedralize a geometric structure involving vertices, edges, and triangles, Steiner points must be added in the general case[3]. Their number can be very large, resulting in a far more complex tetrahedralization. Boissonnat proposed another surface-based approach to build a 3D model by means of a local procedure[3]. However, the proposed method does not guarantee a satisfactory triangulation of a 3D surface even if the discretization is fine enough.

We propose a method to circumvent this problem by applying constrained triangulation on a 3D surface. Rather than implementing 3D triangulation and removing the tetrahedra step by step, we implement 2D Delaunay triangulation to generate the convex hull. We then implement local triangulation, constrained by the given polylines, which guarantees an efficient and accurate result surface.

By providing a set of points in space, one can build a convex hull filled with triangulated meshes. At the beginning, four triangles are built as a single tetrahedron, which contains four vertices but not any three points on a line. For any point outside the existing polyhedron, we add and locally triangulate on the 3D surface. The triangulation scheme we use satisfies the Delaunay criterion (that is, there is no point in space defined by each circumscribing sphere associated with each triangle).

After all the points in 3D space have been checked and triangulated, we are able to generate a convex hull with all the points either inside or on the surface of the convex hull, as shown in Figure 1.

A polyline is generated if a set of points in 3D space is in a sequential order. We are able to use sequential points as a guide to ensure the proper triangulation in the 3D model. The first step is to compute the normal vector from the given polylines. For each point in 3D space, we assume the vector is orthogonal to the 3D object and intersected with a specific triangle on the convex hull. The normal vector gives us the direction to apply local triangulation. Note that the lines projected from a normal vector should not intersect with its polyline. Therefore, our algorithm relies on checking of the minimum distance of query point inside the convex hull. Each time, we select a point with the minimum distance to the convex hull, and locally triangulate to the 3D surface. Rather than building Delaunay triangulated surface, we implement 2D local triangulation, constrained by polylines. This is to ensure that the edges of triangular meshes are constrained by the polylines. Figures 2 and 3 show the procedures of shrunk processing. Finally. we are able to generate a 3D model after the implementation of local triangulation on all the hidden points inside the convex hull.

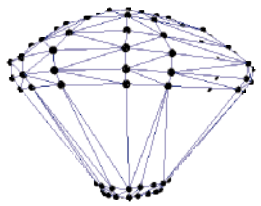
FIGURE 1

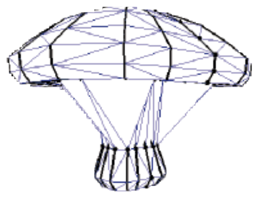
FIGURE 2

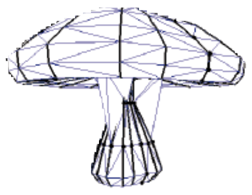
FIGURE 3

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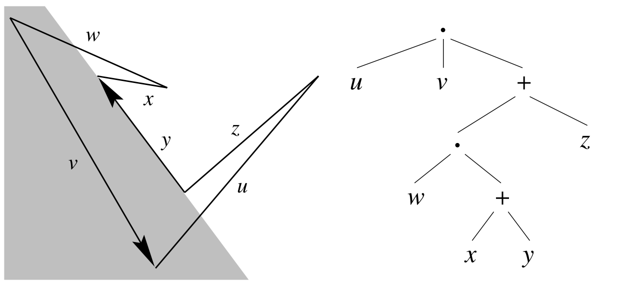
Using CSG Representations of Polygons for Practical Point-in-Polygon Tests

There have been many point-in-polygon test algorithms presented; Haines[1] gives a thorough comparative treatment of existing point-in-polygon algorithms, and the terminology that we use is based upon that work. The best of the current methods utilizing a preprocessing phase (the grid method[1]) requires a lot of extra storage in addition to the basic polygon information. We present a method based on constructive solid geometry (CSG) representations of polygons[2] requiring only two integers and three reals per edge plus an integer and two pointers per polygon (the original representation can be discarded). The only drawback to this method is that it does not support self-intersecting polygons.



An example polygon yielding the formula uv((w(x+y))+z) (the half-plane defined by the edge y is also shown) and its CSG representation.

A polygon may be represented via CSG as a monotone Boolean formula on the half-planes bounded by the edges of the polygon[2]. If we orient the edges of the polygon in a counter-clockwise fashion, the half-planes of interest lie to the left of the edges. These formulae may be represented as directed trees in which each edge of the polygon appears only once.

The point of interest is then tested against the leaves (edges) of the directed tree in left-to-right order to determine if it falls inside (TRUE) or outside (FALSE) the associated half-planes. Since an AND-node will not be satisfied if any of its children are FALSE, as soon as we determine that one of its children is FALSE, the remaining children need not be tested; the situation is analogous with OR-nodes. The idea is then to minimize the number of tests required for points on average for a given polygon; this may be done by altering the embedding of the directed tree by swapping any two children of a given node. As a simple first step, we chose to rearrange children beneath each node by size of subtree and secondarily by length of edge. We are developing more sophisticated heuristics based upon coverage of the target plane (or bounding box) by the defined half-planes.

We confine the construction of the tree and its rearrangement to a preprocessing phase. This reduces the actual test algorithm to a series of point-in-half-plane tests, each resulting in a predetermined decision as to which edge to test next.

	3	4	10	20	50	100
Crossings	6.8	7.1	11.4	19.3	41.2	77.1
Half-plane	2.4	3.8	11.3	23.7	59.0	117.8
Spackman	3.3	4.9	13.6	27.7	74.3	137.2
Grid 20 X 20	5.1	5.1	5.3	5.5	6.2	7.0
Grid 100 X 100	4.8	4.8	4.9	4.8	5.0	5.1
CSG w/sorting	3.0	3.9	7.6	11.3	20.5	32.4
CSG w/o sorting	3.4	4.3	7.8	12.7	24.4	41.5

Average times for point-in-polygon tests (in microseconds), number of vertices per polygon vs. method. For each of 50 random polygons, 50 random points were tested. Some tests were repeated to reduce inaccuracy; see Haines[1] for discussion.

Haines' implementation of existing point-in-polygon tests[1] was augmented with our CSG method both with and without the sorting heuristics described above. Tests were as described by Haines, save that, to ensure that the polygons were non-self-intersecting, an edge-swap algorithm was used to untangle them. The tests were run on a Silicon Graphics Indigo workstation.

The simply sorted CSG representation method is faster than the basic methods for all polygons save triangles. It uses significantly less memory than the grid method and is faster than the grid method for small polygons. This method may be extended to 3D ray intersection, via the use of Pluecker coordinates, without having first to resort to determining a plane for the polygon and intersecting the ray with this plane.

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Discrete models of elastic materials have many applications, particularly in computer graphics. The driving force for the research described in this sketch was the problem of modeling skin so that it would stretch and slide realistically over an underlying body of modeled muscles and bones. Particularly on animal skin with markings, the markings should shift realistically in response to underlying limb movements and changes in muscle shape.

In two dimensions, given a discretization of a membrane as an irregular triangle mesh, the standard finite element method analyzes each triangle approximately as a membrane with specified elastic properties, computing stresses and strains. An alternative is to regard each edge as a spring, assuming the springs are connected by "pin-joints" at the vertices of the discretization.

This alternative, called a "spring mesh," offers conceptual and computational simplicity compared to the first, but it is unclear under what conditions it produces the same results.

Spring meshes have been used by numerous researchers to model elastic material, with skin, textiles, and soft tissue being typical applications. However, given a specified set of elastic material properties, the question of whether a particular spring mesh accurately simulates those properties has been largely ignored in the literature, leaving the presumption that they are all equal. As we shall show experimentally, identical spring stiffness coefficients for all edges in the mesh may lead to noticeable distortions, while varying the coefficients according to the geometrically based formula presented here provides a more accurate simulation. Because the formula is local, it extends immediately to the case of non-uniform membranes. Extension to tetrahedral meshes in 3D is work in progress.

The relationship between stress and strain depends on two parameters of elasticity, called Young's stiffness modulus (E_2 for membranes) and the Poisson coefficient (v). Timoshenko and Goodier [1951] recommend using v=0.25 for "most materials."

Consider a triangle T, with edges and angles as shown in the accompanying image, top left, which is subjected to horizontal opposing stretching forces. First, suppose that the triangle consists of pin-connected springs. Then, clearly edge c will elongate, while edges a and b will not change length (black triangle, right). Now, suppose that the triangle is modeled as a membrane. The question is, for what family of internal stresses will the lengths of both a and b not change?

This question has an elegant geometrical answer, which is indicated in the top right part of the image. The key is to transform into the coordinate frame (u,v) such that the v-axis bisects the angle g. Now, *any* constant stress whose principal directions are the u and v axes will produce identical elongations in edges a and b, and in our case we want both to be *zero*. Applying the constraints and solving:

$$k_c = \frac{E_2}{(1-v^2)} \left(\frac{\sin a \ \sin b \ - \ v \cos a \ \cos b}{\sin g} \right)$$

For $v = 0$, this equation is equivalent to $k_c=2E_2\,area(\mathrm{T})/|\mathrm{c}|^2$. Corresponding formulas may be obtained for k_a and k_b. The coefficient derived, k_c applies for *one* triangle of which c is an edge, but normally, c is in *two* triangles, so the two individual coefficients are added to give the total stiffness coefficient for edge c in the overall spring mesh.

The method described has been implemented for some test meshes, where the correct behavior is known from the construction. For simplicity we used $v = 0$ throughout the tests. The accompanying image shows a hexagonal membrane subjected to a constant outward radial force at the six external vertices. A regularly triangulated membrane would expand uniformly.

The irregularly subdivided membrane in which all spring k's are equal undergoes distortion, as in the bottom left of the image. However, the same geometry expands correctly when the spring k's are calculated by the formula given here, as in bottom right. One supplemental movie animates this test. The second supplemental movie shows simulated tiger skin stretching. Notice the deformation of the skin stripes on the hindquarters.

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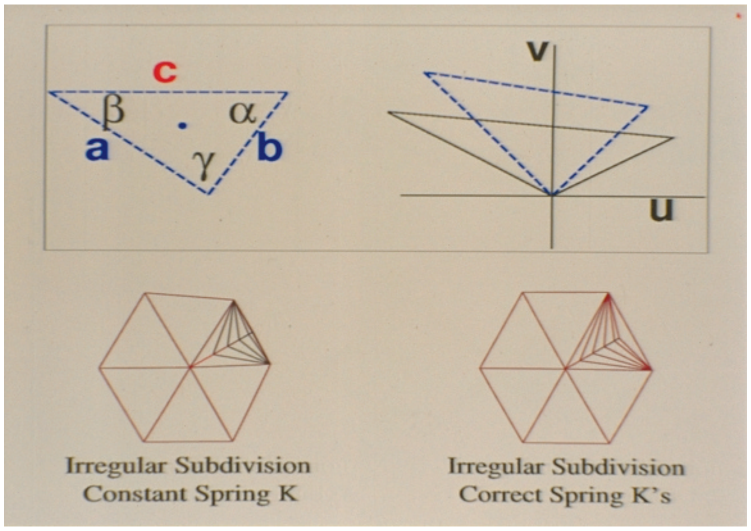


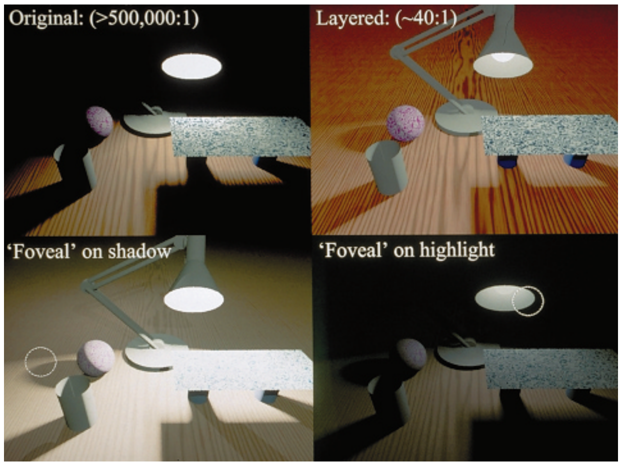
Display of High Contrast Images using Models of Visual Adaptation

High-contrast scenes and images are quite common. Scenes with dark shadows, specular highlights, or directly visible light sources may have contrasts (ratios of light intensities) of 100,000:1 or more. Images of these scenes are difficult to display accurately because their contrasts greatly exceed the range of most display devices (about 100:1). As a result, displayed image contrasts are often compressed by "gamma correction" or truncated by "clipping," which hides or destroys subtle textures and details. Unlike displays, the human eye can accommodate high-contrast scenes easily, *adapting* the visual response with no apparent loss of content or detail. This sketch presents two methods for display of high-contrast images that are based on some of these visual adaptation processes.

Layering

Humans see far more than just intensities when viewing a scene or image. We also sense shapes, textures, reflectances, transparencies, and illumination. Several researchers in disparate areas have suggested that an image is not perceived as a single entity, but as image *layers*, each of which describes an important scene quantity[1]. We propose segregating synthetic image intensities into three layers during rendering: diffuse surface reflectance R, diffuse illumination I, and image intensity due to specular reflection toward the eye, transparency, or self-luminous emission of the surface STE. Often STE is recursively subdivided into additional I, R, and STE layers to accommodate scenes containing partially transparent or mirrored surfaces.

Dividing the image into layers allows us to compress the layers independently to reduce the overall contrast in the image while preserving fine details and textures. Most of the detail is contained in the R layer, but the contrast of this layer is always small. The wide-ranging values of the I and STE layers are the cause of high image contrasts, and the layering method compresses and combines them with the unmodified R layer to create a displayable image.



High-contrast scene (>500,000:1) displayed using layering and foveal methods: a) Original loses highlight and shadow detail to clipping; b) "layering" reduces image contrast (estimated 40:1) but preserves visible scene details; c),d) "foveal" interactively adjusts entire image for best display of a small circled region near the cursor, compressing out-of-range values. Interactive viewing of a scene resembles the familiar dynamic behavior of an automatic-exposure camera.

This approach is supported by substantial experimental evidence that shows that the visual system acutely senses surface reflectance R, but tolerates wide variations in illumination. For example, humans are often unaware of artificial changes to illumination such as "fill" lighting, which lessens shadow contrasts but does not disrupt the boundaries or other primary features of the scene. Because specular highlights within a viewed scene are predominantly used to refine estimates of surface properties such as local curvature and smoothness, the shape and width of specular highlight boundaries may be far more important than the intensity. The compression of I and STE layers preserves boundaries well but reduces overall image contrast to the range of the display device.

Foveal

The human eye is highly directional, adaptable, and nonuniform. The 2-5 degree central region of the retina, or fovea, gathers almost all the fine image detail and color information we see, and the eye preferentially adapts to the available light in the small foveal region. This changeable and localized assessment is particularly useful for high contrast images, because small neighborhoods tend to have much lower contrasts than the entire image, suggesting that neither the eye nor the image display must accept all scene contrasts at once.

Our "foveal" display program mimics this process by using a small circular neighborhood around the mouse cursor as the "fovea" and adjusting the entire image for best display of this region. Out-of-range display values are asymptotically compressed towards black or white, reducing contrasts without truncating them. Interactive viewing of high-contrast images in this fashion relies on the remarkable ability of the human visual system to form a stable and seamless impression of the entire visual field from glances at interesting scene features.

Conclusions

These two simple, effective methods show that limited display contrasts do not prevent accurate depictions of visible scene content and suggest that more perceptually motivated methods should replace clipping. Van Allsburg[2] and other skilled artists can create detailed, artifact-free drawings of high-contrast scenes such as a rocket launch at midnight (>100,000:1) using low-contrast displays such as a pencil on paper (<30:1). Clearly, the 100:1 contrast range of CRT displays should be adequate for all synthetic scenes with the development of improved display methods.

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Human vision operates over about nine orders of magnitude, from starlight at 10^{-4} candelas/meter^2 to daylight at 10^5 cd/m^2. In any given scene, the eye can adapt comfortably over a smaller range of about four orders of magnitude. This still exceeds the dynamic range of conventional display devices and media, which at best cover a range of about 100:1 – only two orders of magnitude. The rest of the information, which would be perceived in the real world as detail in bright and dark regions, is lost above the maximum display value or below the black level. This limitation has serious ramifications for simulated imagery, especially when it is needed to evaluate visual performance or in virtual reality (VR) environments. Previous tone mapping work by Tumblin and Rushmeier[1], Ward[2], and Ferwerda et al[3] did not consider the question of local adaptation. Chiu et al[4] looked into this problem, but their solution resulted in reverse gradients and did not account for human visual response.

In this sketch, we present a new method for mapping scenes and images containing high dynamic range information to conventional (and VR) displays. The technique matches object visibility as its primary goal, meaning that objects visible in the real world will be visible on the display, and conversely, objects not visible in the real world will not be visible on the display. As a secondary goal, the method attempts to reproduce a viewer's subjective response, meaning that the impression of the displayed image should correlate well with memories of the actual scene.

The starting point of our method is a histogram of scene brightnesses, which we define as the log of luminances averaged over 1^o areas. These areas correspond to foveal adaptation levels for possible fixation points in a scene or image. We then apply a histogram adjustment procedure to remove portions of the brightness population that are under-represented in the scene, since they convey relatively little visible information. We compress this unused dynamic range so that important objects in bright and dark regions can be included within the usable dynamic range of the display. The eye tends not to notice the compressed information as missing, since human vision is designed to perceive object detail, not relative brightnesses.

Once we have solved the problem of making visible world objects also visible on the display, we need to consider human visual limitations, so that objects *not* visible in the real world are *not* visible on the display. First, we adjust our brightness histogram to match local human contrast sensitivity. Next, we add veiling luminance around bright areas (e.g., light sources) to simulate scattering in the eye. In dark scenes, we also model the loss of color sensitivity in accord with measurements of mesopic and scotopic response. Finally, in very dark regions, we may adjust image resolution locally to match limits in human visual acuity.

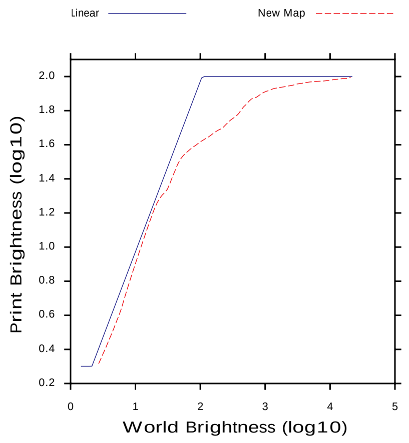

FIGURE 1 Plot of linear tone mapping used in Figure 2 versus new tone mapping used in Figure 3.

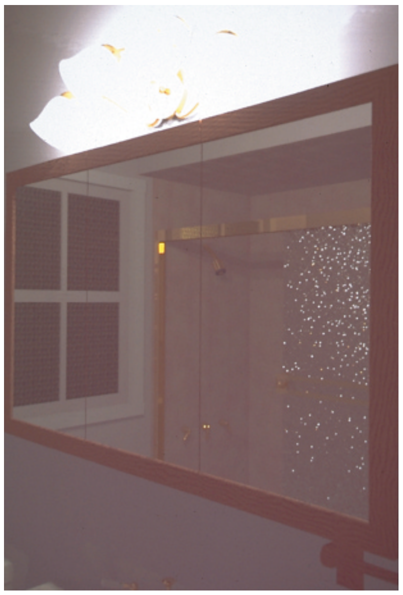

FIGURE 2 An unadjusted simulation of a bathroom scene mapped with a standard linear tone reproduction operator.

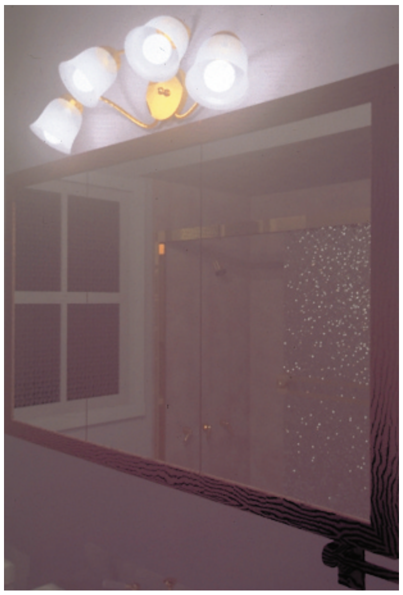

FIGURE3 The same simulation reproduced using the new tone mapping operator, which models human contrast sensitivity and disability glare.

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Validating Global Illumination Algorithms and Software

It is relatively easy to use photorealistic rendering techniques to create images that look great. It is much more difficult to perform physically based lighting simulation and create images that match the appearance of an actual space. A direct comparison of the virtual and real-world images is an effective way to validate rendering algorithms and discover their drawbacks. Unfortunately, such comparisons are almost never performed, even for very simple environments.

In this work, we simultaneously view synthetic images and photographic images, and we vary the parameters of our perception-based image rendering software to achieve the best visual match between the virtual and real-world images. This qualitative evaluation is complemented by a quantitative measurement of lighting simulation accuracy. We investigated two different lighting simulation techniques:

1 Deterministic cluster-based hierarchical progressive radiosity.

2 Stochastic Monte Carlo photon tracing (the core algorithms of the Inspirer system from Integra, Inc.).

As a case study, we chose an atrium at the University of Aizu (left below). While the direct lighting distribution within such an environment can be easily predicted analytically, calculating the results of indirect lighting is much more involved. In fact, analytic solutions exist only for extremely simple, symmetric environments. So for quantitative validation of the lighting simulation, we examined several simple cases. (See our Web site[1] for more details on the analytic derivation of illumination values for these simpler cases).

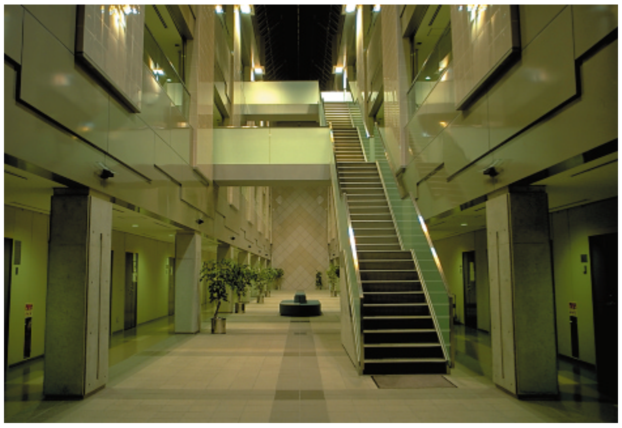
In our work on the atrium, we began by specifying the light sources and surfaces in our model according to information from luminaire manufacturers and architectural drawings. More adequate measurement data are needed (for example reflectance functions), but in practice, it is very difficult to obtain complete and reliable data.

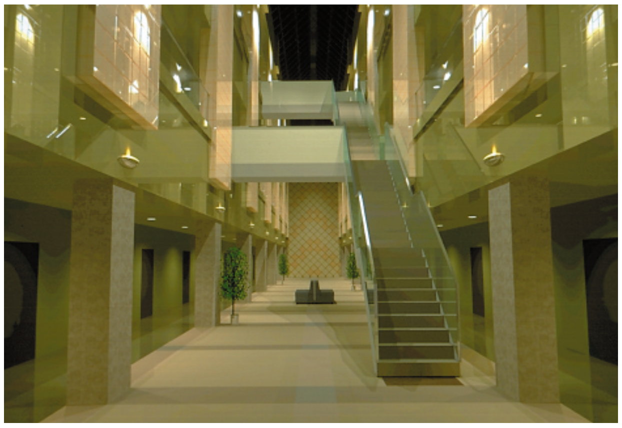
In the lighting simulation phase, we obtain luminance and chroma (maintained separately) values for every pixel of the final image. We then transform the stimulus luminance values to brightness values (perceived brightness predicted for the observer using Stevens' power law[2]). The brightness transformation is also performed for the range of luminances produced by the display device.

First, we confirm that we are able to present the photographic image under display conditions that give the best match between this image and the original environment. Next, we adjust the parameters of the brightness transformation until the appearance of the synthetic image (right below) best matches that of the photographic image (left below). Since we were unable to directly determine a given viewer's light adaptation level, this method allowed selection of the brightness function that worked best for that viewer under those viewing conditions.

While our atrium rendering is still far from perfect, first impressions were very favorable. In fact, many viewers who were quite familiar with the real atrium thought that they were viewing the actual photographic images when they first viewed the synthetic images. However, when the same viewers compared the synthetic images to the photographic images, they were able to find many differences and therefore were able to provide us very useful feedback.

We hope that the global illumination community will come to a more standardized approach to evaluating their algorithms and software. Toward this end, we have posted our atrium data in various formats[1]. We also provide a comprehensive description of our validation tests for lighting simulation with analytically derived luminance values.


Photograph


Rendering using the deterministic method

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2 Jack Tumblin and Holly E. Rushmeier. Tone Reproduction for Realistic Images, IEEE Computer Graphics and Applications, 13(6):42-48, 1993.

Many different lighting simulation techniques have been developed for computing illumination in a virtual environment. However, many of the techniques make different simplifying assumptions and thereby restrict the lighting effects they can simulate. Multi-pass methods try to combine the advantages of each of these techniques to yield better algorithms, but they have so far been limited to static combinations of the above techniques.

In the Lighting Network approach, each lighting algorithm is considered a lighting operator, taking illumination information as input and generating new illumination information as output after having computed a part of the global lighting simulation in the scene. By formalizing the representations of illumination taken as input and generated as output, different algorithms can be combined in a data-flow network. This flexible combination allows for obtaining special lighting effects that would be difficult to compute with single algorithms or a fixed combination thereof. Light paths computed by a Lighting Network can formally be described using extended regular expressions. This allows an automatic analysis of composite lighting simulation and guarantees completeness and redundant-free computations.

The ability to restrict Lighting Operators to certain parts of the scene allows for tailoring the simulation to the needs of a user. It allows the simulation to be restricted to a small subset of the scene, thereby making it usable for simulating costly lighting effects, even in complex scenes. This brings back the control that has been taken away from users by conventional global lighting simulations.

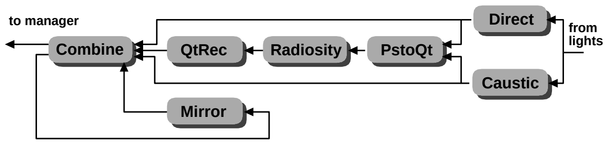

FIGURE 1 Lighting Networks: A simple example

Figure 1 shows a schematic view of the Lighting Network used for generating the images in Figure 2. The direct and caustic illumination (computed by ray tracing and photon maps, respectively) from a lamp with an internal reflector is used directly and as the input for computing indirect illumination with Radiosity. Additional lighting operators convert between and combine different illumination representations and account for perfect specular reflection and transmission.

This approach presents an open framework for composite lighting simulations, where advanced algorithms and new solution strategies can easily be integrated. While this makes Lighting Networks a versatile tool for research and development, its advantages are most useful to practitioners. Traditionally, global illumination algorithms have offered only little opportunity for configuration, tweaking, and creating special effects. With Lighting Networks, the user may select where and to which extent the features of automatic global lighting simulation are appropriate or necessary.

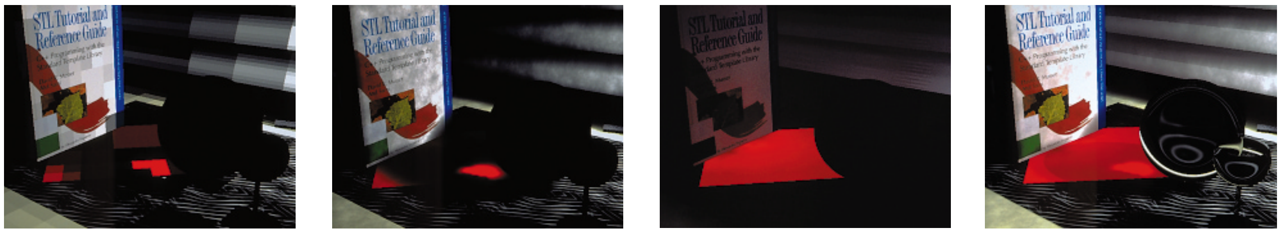

FIGURE 2 Partial results computed by the Lighting Network in Figure 1(from left: direct, caustic, indirect, and full illumination).

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Live Web Stationery: Virtual Paper Aging

We propose a method to visualize a World Wide Web page's life based on the metaphor of the page. Pages are made of paper, which, over time, shows the effects of time and use: it may fade, get dusty, get stained, smudged, creased, and torn. These changes provide us with clues about that piece of paper: its age, how often it was handled, where it was placed, and even something about the people who have handled it. The type of paper and how it has been handled also provide us with clues to its content. A long document or book, a personal letter, or a list are typically produced on differently sized and colored paper with different characteristics. Although Web pages share these characteristics of age, handling, and intent, this information is not systematically integrated with the presentation graphics of the page.

In fact, there is very little we can glean about a page on the Web, with perhaps the exception of a hit counter or date of last revision. Even this information does not tell us how the Internet community interacted with the page. The hit counter of a Web page with 100 hits from one user looks just like the hit counter on a site with one hit each from 100 different users. Similarly, hits are counted as the same whether the user stays on the page or immediately follows a link to another page. A richer set of information is available, some through the current mechanisms of the web (http), but most of it requires specialized data gathering mechanisms and analysis. This information can be mapped to the characteristics of a piece of paper. The system created by Hill, et. al. represented document usage through variations in the appearance of user interface elements such as their attribute-mapped scroll bars[1]. Instead, our system integrates the visual representation of time and usage with the document itself, relying on metaphors of real-world paper aging to provide instantaneous visual cues to the relative age and popularity of the documents in the system.

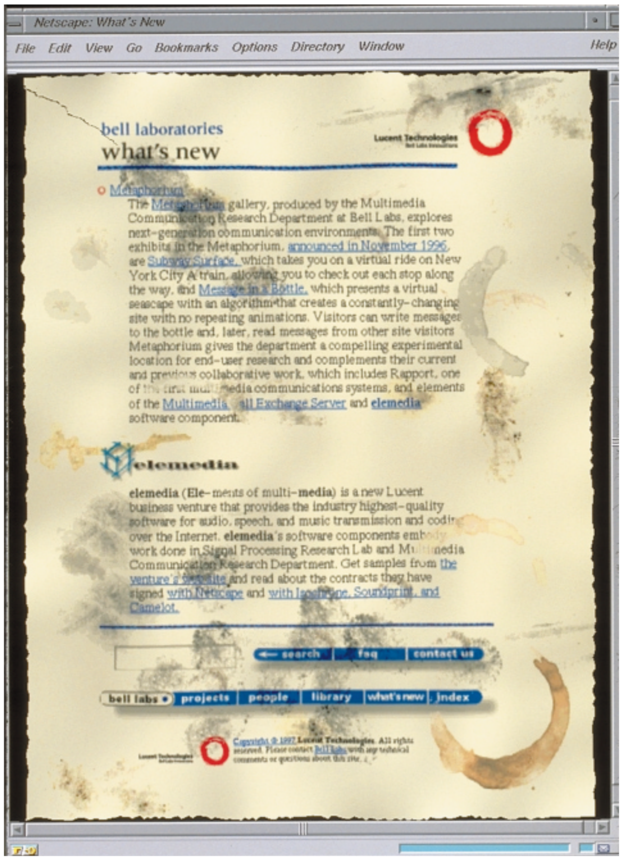
Problem and Proposed Solution

Our goal is to automatically generate image files representing pieces of paper to use as background images for HTML formatted pages. Hence, we favor approximate, but speedy methods over correct, but slow, methods in order to generate the images in real time, and minimize additional downloading delays. Some elements of wear and tear are mathematically modeled, while others are drawn from a library of textures created by Cati Laporte and parametrically combined to create the desired effect. The virtual paper generated by our system is a visualization of document usage, showing what links have been followed the most, time since last visit, etc. Some of this information can be provided by linking user interaction to a collection of human-caused effects: smudges, spilt coffee stains, creasing. Other information will be provided by showing wear and tear.

We model the paper, its environment, time, and human manipulation:

- Paper attributes: color, texture, weight, wear and tear.
- Environment attributes: storage, dust, dirt, light.
- Time: creation, modification, display.
- Human interaction: retrieval attributes (user, browser, originating link, bookmarking, site-mapping, etc.) and interaction types (clicking, editing, copying, printing, etc.).

Our example, shown in Figure 1, illustrates several of these techniques. The surface deformation and edge wear depicts handling. Coffee stains are used to indicate that the page has been read for long periods of time. Smudges and fingerprints are placed over links that have been followed frequently, with cumulative wear indicating the most frequently followed links. More general smudges and stains, as well as yellowing, provide further cues to the relative age and amount of handling received by this document.



Metaphorium

The Metaphorium gallery, produced by the Multimedia Communication Research Department at Bell Labs, explores next-generation communication environments. The first two exhibits in the Metaphorium, announced in November 1996, are Subway Surface, which takes you on a virtual ride on New York City A train, allowing you to check out each stop along the way, and Message in a Bottle, which presents a virtual seascape with an algorithm that creates a constantly-changing site with no repeating animations. Visitors can write messages to the bottle and, later, read messages from other site visitors Metaphorium gives the department a compelling experimental location for end-user research and complements their current and previous collaborative work, which includes Rapport, one of the first multimedia communications systems, and elements of the Multimedia, all Exchange Server and elemedia software component.

elemedia (Ele-ments of multi-**media**) is a new Lucent business venture that provides the industry highest-quality software for audio, speech, and music transmission and coding over the Internet. **elemedia**'s software components embody work done in Signal Processing Research Lab and Multimedia Communication Research Department. Get samples from the venture's web site and read about the contracts they have signed with Netscape and with [illegible], Soundprint, and Camelot.

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FIGURE 1

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In computer graphics, scan-converting (i.e., rastering) a straight line segment (or simply line) is the most basic operation. Many curves, wireframe objects, and complex scenes are composed of line segments. The speed of graphics rendering depends heavily on the speed of scan-converting a line. The ability to scan-convert a line quickly and efficiently is a very important factor in a graphical library. Bresenham's Midpoint algorithm (1965)[2] is the most important algorithm and has been widely used for line scan-conversion. In the past 30 years, many new methods have been proposed in the attempt to speed up the line scan-conversion process, and most of these new methods have been based on Bresenham's algorithm[1-7].

We observed that a scan-converted line may contain many identical pixel segments in their relative positions. We can prove that if any two points on a line repeat their relative positions in the raster grid field, the line can be cut into segments and the corresponding pixel arrangements of the scan-converted line segments will repeat also. In other words, if (x_0 , y_0) and (x_0+r, y_0+s) are on the line, where r and s are two arbitrary integers, then the corresponding scan-converted pixel arrangements from $x=[x_0]$ to $x=[x_0]+r$ will be the same as the pixel arrangements from $x=[x_0]+r$ to $x=[x_0]+2r$. Therefore, multiple segments (or pixels) of the line can be replicated, or scan-converted in parallel. Furthermore, as shown in Figure 1, the repeated points on a line (L) can be decided by its translation (L_0, L_1, or L_2), of which one end point is on the raster grid. Therefore, our algorithm will not require any of the two end points of the line on the raster grid. In fact, we don't even require the line to intersect any grid point. All existing well-known line scan-conversion algorithms require at least one end point on the grid, restricting the range of the applications.

Theoretically, we can speed up any existing line scan-converting algorithms m times, where m is the number of repeated line segments. On average, we can speed up all existing methods about three times. We have integrated the Midpoint algorithm and the Symmetry algorithm with our method to prove the idea.

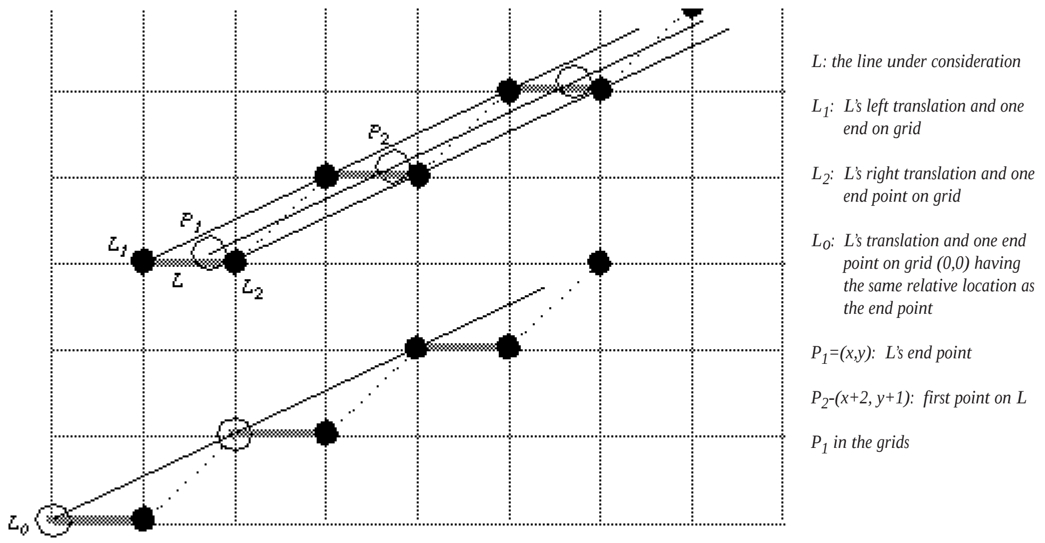
L_1
P_1
P_2
L
L_2
L_0
L: the line under consideration
L_1: L's left translation and one end on grid
L_2: L's right translation and one end point on grid
L_0: L's translation and one end point on grid (0,0) having the same relative location as the end point
$P_1=(x,y)$: L's end point
P_2-(x+2, y+1): first point on L
P_1 in the grids

FIGURE 1 Pixel segments having the same shape

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Text is an extremely important data type in computer graphics. Current font models are based on glyph outlines[2,8], resulting in two major deficiencies:

1 Design intent, which is expressed using high-level typographic features, is translated to a low-level outline representation and lost.

2 The functionalities provided to font users are only resolution independent scaling and outline interpolations or extrapolation[3,4].

We present LiveType, a new font model based on features, parameters, and constraints. LiveType consists of two tightly related glyph models. One is a designer model where font designers can losslessly express their designs in high-level terms corresponding to the way they think. The other is a compressed run-time model, which font users can create font instances in different variations along typographic, aesthetic, or other axes predefined by the font designer. Changes in glyphs can also be used in real time in order to create animated-like text.

The underlying geometry of a LiveType glyph includes both outline and supporting constructs. Features are defined on top of the geometry and organized in a feature hierarchy. They are mainly used to represent typographic elements such as stems, bars, and serifs, but any desired subset of the underlying geometry can be defined as a feature.

Geometric constraints, such as distance and ratio relationships between points, are associated with the geometry of features, either automatically, using a feature detection algorithm[10], or manually by the designer. The types of constraints have been chosen to enable an expressive language for design, along with an efficient constraint evaluation algorithm that guarantees finding a single solution to the constraints graph in real time. This is done by automatically transforming the constraint graph during design stage to a direct acyclic graph that can be solved constructively in linear time.

The numbers participating in the definition of a constraint can be regarded as parameters having meaningful names such as stem width or baseline distance. Parameters can be further grouped hierarchically inside a single glyph and across the font to form font axis parameters such as weight or spikeness. When parameters are modified, some points change their position. This triggers the constraint evaluation algorithm to compute new positions for all affected points, thereby modifying the outline of the glyph. Parameter modification can result in non-linear font variations that preserve the typographical nature of glyphs or follow any other designer intent. The model can be compressed for end-user systems by flattening the feature hierarchy and retaining only the constraint and parameters structure.

LiveType introduces advanced modeling techniques into font models. This allows designers of fonts a more intuitive navigation in design space, preserving their intent using constraints and parameters. LiveType fonts enable font users to modify parameters interactively and create richer, more flexible, and more vivid text.

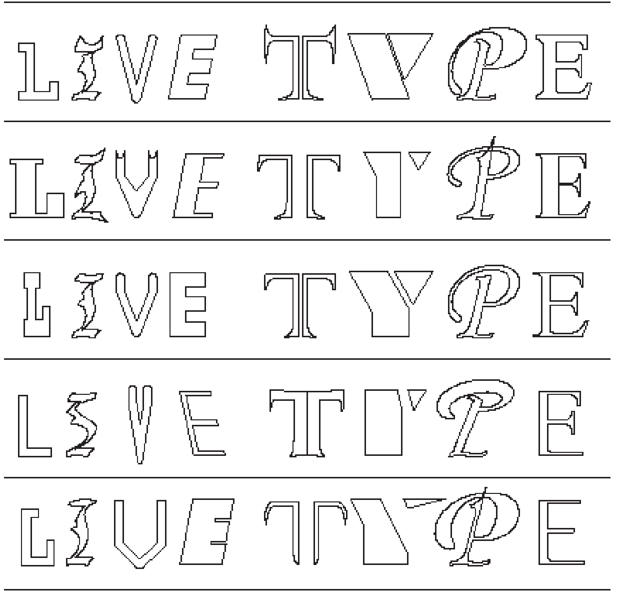
FIGURE 1

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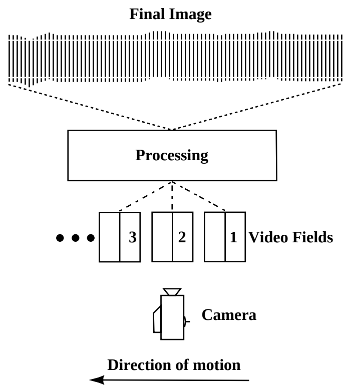
As a work in progress, the Texture Maps from Orthographic Video project is an attempt at enhancing virtual spaces with photographic-like texture maps from real-life environments. While traditional methods of generating such texture maps for virtual worlds rely heavily on photographic manipulation, the goal of this project is to produce seamless texture maps from recorded video. The project will particularly benefit virtual environments where texture maps orthogonal to the path of travel are used to enhance the user's experience, such as those used in driving, biking, running, and other similar simulators.

In its most literal interpretation, the process of producing a texture map from video might seem quite simple. Taking into account that a field of video is captured every 60th of a second (on traditional video cameras), one might assume that the center lines of each field are thus evenly spaced in time. By extracting the center lines from each field and piecing them together, the resulting image resembles a snapshot of the environment captured by the source video. However, it becomes quite obvious that this "snapshot" is not accurate enough, and a few adjustments must be added to the theory, including: controlled camera movement, averaging of several lines from each field to produce an equivalent center line of that field, adjustment for motion in the direction parallel to the lines of video, and expansion or compression of the resulting image in accordance with the speed at which the camera moves.

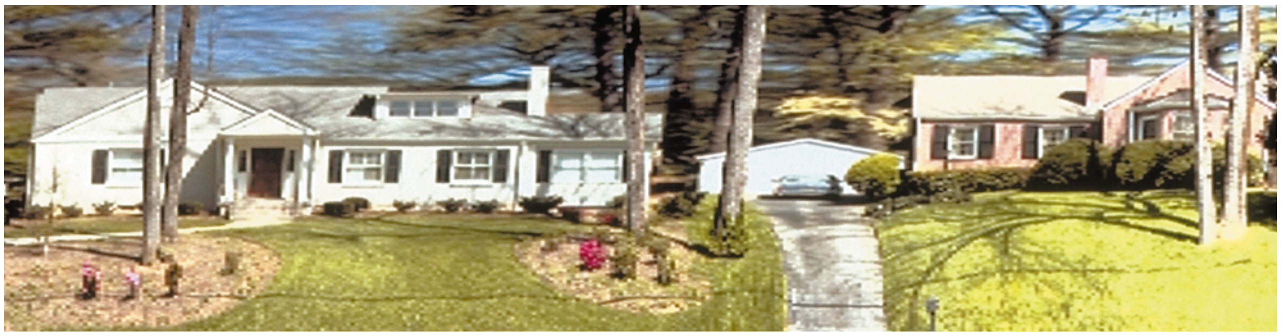
In order to produce a usable texture map from video, restrictions to camera orientation and motion apply. The camera movement must be parallel to the desired environment and oriented so that the lines of video are perpendicular to the path of motion. Since the overall requirement of the project is to produce an accurate image that one may texture map along some path, such as a road, a camera was mounted to an automobile so the lines of video were perpendicular to the road surface and orthogonal to the path of travel. The vehicle was then driven through a residential neighborhood, where the roads were fairly level, maintaining an average speed between five and 10 miles per hour.

Once the video had been captured, the video was digitized and then processed using a custom Visual C++ (PC) application. This application performs the composition of the final image from the fields of video by performing such operations as averaging the lines of each field and determining the optimum correlation between fields. In order to solve the problem of the time/space mismatch that occurs when only the center line of each field is used, the program employs a gaussian average across multiple lines of each field to approximate the true center line. Further computations that adjust for such problems as bumps in the road determine the point of the greatest correlation between successive fields. The resulting offset along the lines of video is then applied to the averaged center line from each field before being added to the final image.

The next step in the project's evolution will be to affix a bike tire with an optical encoder to the moving vehicle and produce a "click track" (an audio click per unit of distance traveled) that is synced to the video and embedded in the audio channel of the video tape. This "click track" will allow the application to stretch or compress the resulting image, depending on the speed at which the vehicle is moving. Thus, in theory, an accurate image should be produced. This image may then be texture mapped on a polygon to achieve a real-life feel in the 3D space. If additional dimensions are desired, objects may be extracted from this image and arranged in a 2.5D fashion where discrete depth layers are produced. Although other problems are sure to arise, this project has a promising future in the realm of 3D simulation.



Process used in creating texture maps from video captured using a camera mounted orthogonal to some path of travel (driving, pan, track, etc.) with scan lines perpendicular to travel surface.



Portion of image produced from video captured while driving between five and 10 mph, using camera mounted orthogonal to path of travel with scan lines perpendicular to road surface.

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Disparity Morphing for Automatic Generation of Stereo Panoramas for Image-Based VR

Stereo perception is important for a truly immersive virtual reality (VR) system. Recent improvements in computer and video technology have made stereoscopic display systems more prevalent than ever. While most panoramic imaging systems are capable of displaying photo-realistic VR worlds, they still have difficulties in automatic production of high-quality stereo panoramas.

The major difficulty comes from the fact that, when taking a stereo image sequence with a two-camera set having a horizontal stereo baseline, only one camera can have its lens center located on the vertical rotation axis. In our experiment, we let the rotation axis pass through the lens center of the left camera. Hence, the position of the lens center of the right camera will move along a circle (i.e., off the rotation axis) during the acquisition process, as shown in Figure 1. Consequently, the objects in the overlapping image area will not be of the same size, and the image locations of those objects will be inconsistent in two adjacent partially overlapping images, which will make the conventional image stitching techniques fail to produce high-quality stereo panoramas, especially when the objects are near to the camera. To automatically generate a high-quality panorama from a sequence of "off-the-rotation-axis" images, we propose a new method that utilizes the FOE (focus of expansion) and block matching techniques that are familiar in the field of computer vision.

Let O_1 and O_2 be the lens centers of the cameras located at two adjacent positions, as shown in Figure 1. The 3D line connecting O_1 and O_2 is referred to as the motion baseline. We first warp each image into a cylindrical image (e.q., I_1 and I_2 shown in Figure 2) as in the conventional stitching method. However, we then dewarp the cylindrical image into a flat image whose image plane is perpendicular to the motion baseline, as IF_1 and IF_2 shown in Figure 2. Notice that the intersection of the motion baseline with the flat image plane is the so-called focus of expansion (FOE), as illustrated in Figure 3, which can be determined by using the extracted image features and their between-image correspondence.

Consider Figure 3. Let p_1 and p_2 be the projection of an object point P onto IF_1 and IF_2, respectively. Let L_1 be the epipolar line passing through p_1 and FOE_1, and L_2 passing through p_2 and FOE_2. According to the epipolar geometry, all the 3D object points seen on L_1 must be also seen on L_2, if not occluded. Hence, given an image point p_1 in IF_1, one can find its corresponding point p_2 in IF_2 along the epipolar line L_2 by using the block matching techniques. Let $v=\overrightarrow{p_1 p_2}$ be the image disparity vector. Now, suppose a camera is moving from O_1 to O_2 and takes an image IF_s when its lens center stops at O_s, $s \in (0,1)$, as shown in Figure 3. However, IF_s is not really available, and we want to generate an approximation of it by using IF_1. What we have done is copy each pixel value at an image position, say p_1, of IF_1 to position p_s of IF_s, where $p_s = p_1 = s \cdot v$, and then interpolate the pixels not covered by any value.

Next, suppose there are K vertical scan lines in image IF_1, we can create K_1 images, IF_s where s ranges from $1/K$ to $(K-1)/K$ with increments of $1/K$. Then, a disparity morphed image, IF_{morph1}, can be generated by letting the k-th vertical line of IF_{morph1} equal to the k-th vertical line of $IF_{k/K}$. By using the same procedure with the camera moving from O_2 to O_1, we can generate IF_{morph2} from IF_2. Then, IF_{morph1} and IF_{morph2} can be used to generate the right-eye panorama by using the regular image-seaming and image-blending techniques.

Our experiments have shown that the above method can produce high-quality stereo panoramas from a sequence of stereo images by generating an off-the-rotation-axis panorama with smooth transitions and without manual trial-and-error.

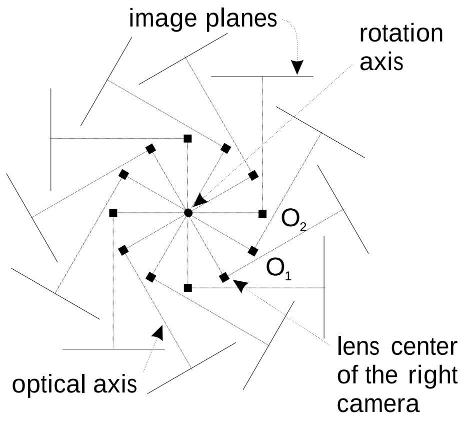

FIGURE 1

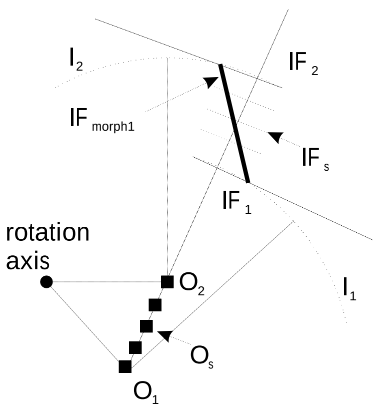

FIGURE 2

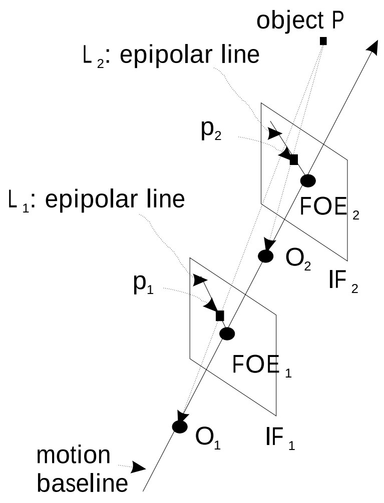

FIGURE 3

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Interactive Contour Modeling Applied to Image Querying

Query By Sketch for indexing into an image database involves presenting the machine with a sketch of the object to be found in the database. The sketch can be of the object shape or distinct contours on the image of the object. This sketch can be made from memory or can be refined interactively in response to what the database search returns at each iteration. We introduce a family of 2D curves for this purpose and an algorithm for generating a representation that passes within small distances of a set of control points specified by the user. Control points can be placed at arbitrary locations and in arbitrary order, and can be erased by the user at will, in order to arrive at the desired shape representation.

The geometric model that we use should facilitate the efficient indexing or querying of the database. Although B-splines can represent geometric structures accurately, their effectiveness in dealing with missing data, matching of "approximately" similar shapes, and unknown coordinate transformations, at low computational cost, has not been established. We use an implicit polynomial (IP) shape model instead (i.e., polynomial function $f(x,y) = S_{i,\, j\$\, 0,\, i+j\#\, n} a_{ij} x^i y^j = 0$ whose zero set represents shape).

To generate the IP model for a shape interactively, we use a linear programming (LP) approach and build the constraint matrix by choosing a number of control points and requiring the IP model to be close to these control points. Specifically, we fit a polynomial to represent a shape potential field (Figure 2, column 1) that is positive for points interior to S and negative for points exterior to S. For any control point, $p_k(x_k,y_k)$ selected by the user, impose the constraint:

$$f(x_k,y_k) = S_{i,\, j\$\, 0,\, i+j\#\, 4}\, a_{ij} x_k^i y_k^j > 0, \text{ if } p_k \text{ inside object,}$$

$$\text{and } f(x_k,y_k) < 0 \text{ if } p_k \text{ outside object.}$$

A set of control points provided by the user generates a set of linear constraints. The objective function of LP problem can be constant, quadratic, or other nonlinear functions.

Figure 1 illustrates the LP-based IP model fitting process. The user inputs a set of control points (close or far apart) on a sample image. The object shape boundary (black) is displayed with the control points (circles and squares) and the zero set of the fitted IP model (gray). The user starts with very few control points. The fitted IP model then may capture only part of the overall shape. As the user places more control points, the resulting IP model becomes closer to the object boundary and eventually captures the global structure. The degree of the polynomial is four, and constant objective function is used. The user can also function by placing a set of control points freehand, observe what is returned by the query, then modify the control points to refine the desired shape, and repeat.

Another example is illustrated in Figure 2, which shows objects automatically segmented and decomposed invariantly into parts from LADAR data. Now, given a new image, a user can interactively build models for one or more parts, and the system matches the joint geometries of the parts against those in the database to find the similar images.

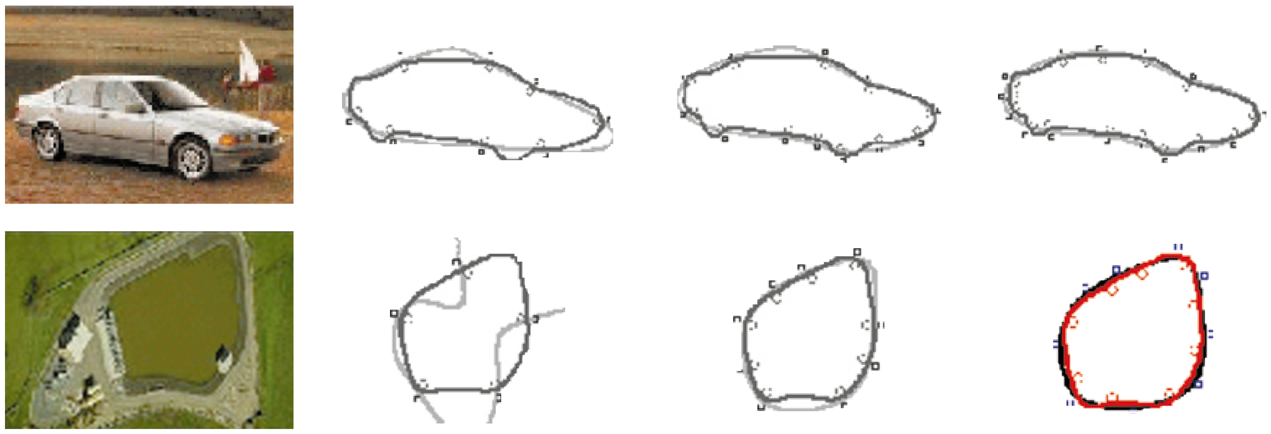

FIGURE 1 Interactive shape modeling examples

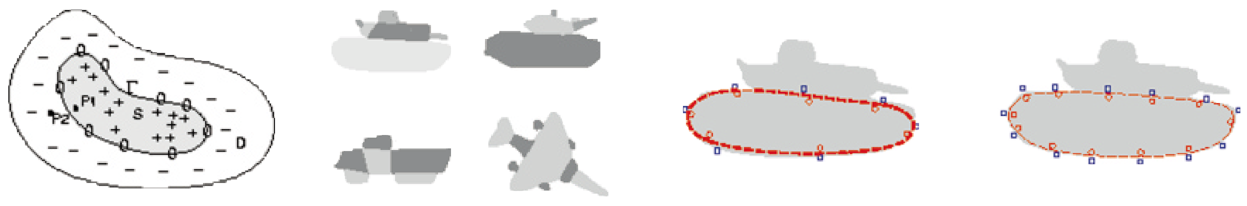

FIGURE 2 Parts database for object shapes and indexing based on the tank body part

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Curvelet Feature Extraction and Matching for Image Retrieval

We propose an approach to automatically extract prominent geometric shape structures – curvelet features (line segments, circular arcs, or high degree curve segments) from images and use them to compute the similarity values between images. A prototype (Figure 2A,2B), built upon curvelet feature extraction and the Java applet technology, is introduced that allows users to draw sketches and pose queries over the Web.

Color Image -> Edge Detection -> Hough Transform -> Line Extraction -> Grouping & Linking -> Curvelet Features

FIGURE 1 Prominent Curvelet Feature Extraction

The process contains several steps. The edge detection step first identifies perceptually significant edge pixels. Hough transform is then applied to the edge map to relate edge pixels that lie on the same straight line. The line segment extraction step subsequently discards line segments that are too short and thus may be noisy or ignored by the user. Finally, a higher-degree curve extraction phase groups and joins small line segments together and generates a set of prominent curvelet features.

Curvelet structures are modeled by implicit polynomials (i.e., polynomial function $f(x,y) = \mathrm{S}_{i,\, j\$\, 0,\, i+j\#\, n} a_{ij} x^i y^j = 0$ whose zero set represents shape. We use a line segment's tendency or preference of joining with its neighbors as the main factor in the grouping stage. Under the assumption that points on the line segments are actually generated according to a feature curvelet model M_j plus white noise, the probability that edge map $S=\{S_k\}$ is generated by a set of curvelets $M=\{M_j\}$ is:

$$P(S|M)=P(\cup_k S_k|\cup_j M_j)=\mathrm{P}_k P(S_k|M_{jk})=1/\mathrm{u}(S,\mathrm{s})\, e^{-\mathrm{S}_k \mathrm{S}_i (dist^2(p_i{}^k, M_{i\,k}))}$$

Here s is the standard deviation of noise model, $dist^2(p_i{}^k, M_{i\,k}))$ is the distance from a point p_i to the curvelet model M_j. The net result of the distance errors from all the data points measures the fitness of the model for the dataset, or how well a set of data points is represented by a given curvelet structure M.

The goal here is to generate a set of features (curvelets) that is the best or most probable representation of the original edge map. We adopt a neighborhood criterion and employ greedy searching algorithm to find the solution. Figure 2C shows the result of feature extraction algorithm applied to an airplane image. Although there are many small details in the original image, the number of final curvelet sets is small and captures the essence of the geometric structure. From the computational point of view, grouping actually reduces the total number of line segments and hence reduces the number of comparisons and the searching time.

A template-based partial matching method is proposed for calculating the similarity value between curvelets obtained from images. It uses the algebraic invariants of curvelet models, which capture the useful geometric structure information. To compensate for the erroneous or inconsistent grouping or linking exhibited in the curvelets, a windowed Mahalanobis distance is used to account for the partial matching of sub-structures. Figure 3 is an example of the query result for a bowl-shaped image. The query sketch is shown with the target image and a few other images that have similar structures. They are all within the 10 best results returned from a database of 137 candidate images.

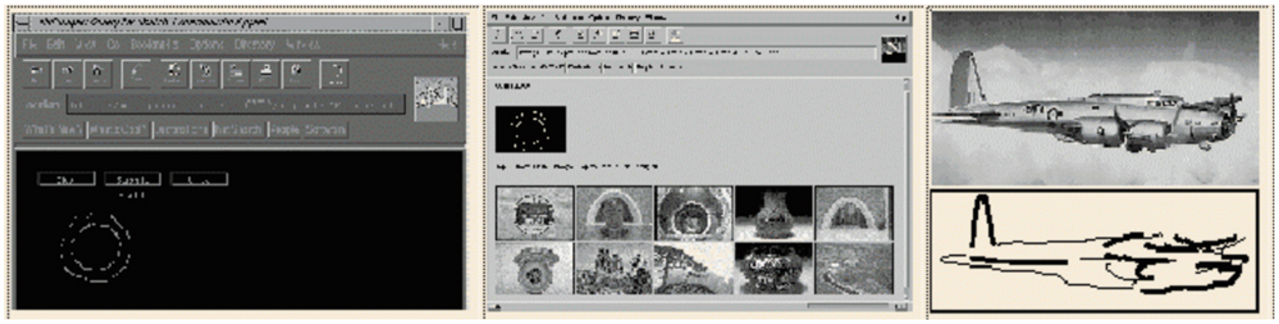

FIGURE 2A, 2B, 2C Prototype Query-by-Sketch system based on curvelets

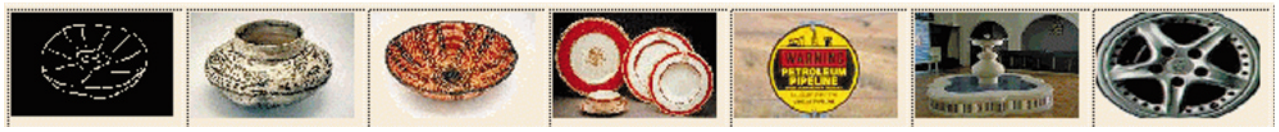

FIGURE 3 Query sketch and best matches returned using curvelet features

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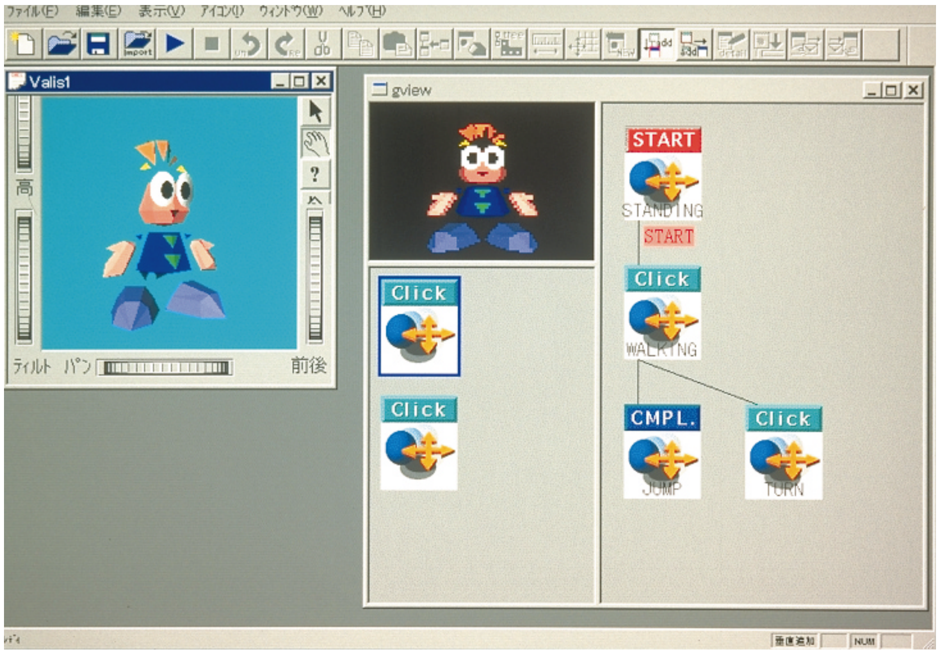
We present a VRML2.0 content authoring tool with an intuitive visual behavior programming interface. The main features of this tool are: a high-level visual programming editor that facilitates the action transition descriptions, and automatic Java script code generation from visual programs produced with the editor.

With the visual programming editor, a content author correlates 3D object actions to corresponding icons and specifies the events that will trigger the individual actions. The author connects the icons in the order in which the actions are to be executed. Branches and loops can also be used as sequence connections. After the visual behavior programs for objects are described, the script code generator scans the programs and converts both the data and the program-structure described in the programs into Java script codes individually.

The generator generates three types of function codes: “initialization,” “event handler,” and “action-methods,” which are taken together to comprise a script code. The “initialization” portion contains the declaration of the event path to the 3D world, a data array related to object actions, and event-action pairs describing program-structures. The “event handler” portion is a function that determines what action is to follow an event that has been sent in through the event path. The “action-methods” portion contains functions to execute object actions.

This tool enables a content author to manage object actions as individual graphical icons, greatly facilitating the authoring process. Further, since the actual execution of actions in 3D views are accompanied by synchronized indications of activated icons, tracing and debugging are also made much easier because they can be performed visually.



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Making Them Behave

For applications in computer game development and character animation, recent work in behavioral animation has taken impressive steps toward autonomous, self-animating characters. It remains difficult, however, to direct autonomous characters to perform specific tasks. We propose a new approach to high-level control in which the user gives the character a behavior outline, or "sketch plan."

The behavior outline specification language has syntax deliberately chosen to resemble that of a conventional imperative programming language. In terms of functionality, however, it is a strict superset. In particular, a behavior outline need not be deterministic. This added freedom allows many behaviors to be specified more naturally, more simply, more succinctly, and at a much higher level than would otherwise be possible. The character has complete autonomy to decide on how to fill in the necessary missing details. For example, with some basic background information we can ask a character to search for any path through a maze. That is, we do not initially have to give an explicit algorithm for how to find a particular path. Later, we may want to speed up the character's decision-making process by giving more detailed advice.

Although the underlying theory is completely hidden from the user, the success of our approach rests heavily on our use of a rigorous logical language, known as the situation calculus. The situation calculus is well-known, simple, and intuitive to understand. The basic idea is that a character views its world as a sequence of "snapshots" known as situations. An understanding of how the world can change from one situation to another can then be given to the character by describing what the effect of performing each given action would be. The character can use this knowledge to keep track of its world and to work out which actions to do next in order to attain its goals. The version of the situation calculus we use is inspired by new work in cognitive robotics[1]. By solving the well-known "frame problem," it allows us to avoid any combinatorial explosion in the number of action-effect rules. In addition, this new work incorporates knowledge-producing actions (like sensing), and allows regular programming constructs to be used to specify sketch plans. This has enabled us to propel our creatures out of the realm of background animation and into the world of character animation.

Duffy, the merman, in his undersea world
With nowhere to hide, Duffy is destined for a grizzly end!
But add some obstacles and ...
... Duffy is smart enough to escape from "Jaws" by hiding behind the rocks

We have developed a character design workbench (CDW) that is both convenient to use and results in executable behavioral specifications with clear semantics. We can use the system to control multiple characters in realistic, hard-to-predict, physics-based, dynamic worlds. Interaction takes place at a level that has many of the advantages of natural language but avoids the associated ambiguities. Meanwhile, the ability to omit details from our specifications makes it straightforward to build, reconfigure, or extend the behavior control system of the characters. By shifting more of the burden for generating behavior from the animator to the animated characters themselves, our system is ideal for rapid prototyping and producing one-off animations.

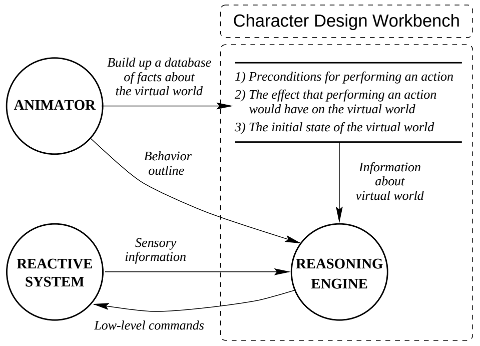
Character Design Workbench
ANIMATOR
Build up a database of facts about the virtual world
1) Preconditions for performing an action
2) The effect that performing an action would have on the virtual world
3) The initial state of the virtual world
Behavior outline
Information about virtual world
Sensory information
REACTIVE SYSTEM
REASONING ENGINE
Low-level commands

FIGURE 1 Interaction between CDW, the animator and the low-level reactive behavior system

The potential of our approach is demonstrated by some intriguing animations of physics-based "merpeople" characters engaged in pursuit and evasion behaviors. Using our system meant that without having to state exactly which one, the merpeople were able to pick any goal position that met some given specification. The animations were the result of elegantly incorporating the existing lower-level reactive behavior system, described in X. Tu and D. Terzopoulos, into CDW.

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2 X. Tu and D. Terzopoulos. Artificial Fishes: Physics, Locomotion, Perception, Behavior, In A. Glassner, editor, Proceedings of SIGGRAPH 94, Computer Graphics Proceedings, Annual Conference Series, pages 43-50. ACM SIGGRAPH, ACM Press, July 1994.

Animation through the numerical simulation of physics-based graphics models offers unsurpassed realism, but it can be computationally very demanding. This sketch demonstrates the viability of replacing the numerical simulation of model dynamics with a dramatically more efficient alternative. In particular, we propose a radically different approach to creating physically realistic animation that exploits fast emulators implemented as neural networks, which we call NeuroAnimators.

NeuroAnimators are automatically trained off-line to emulate the actions of physics-based models, by observing the models in action. We demonstrate NeuroAnimators that have learned the motion not only of simple passive and active dynamic models, but also of state-of-the-art. physics-based models reported in the literature, including mechanical models of a swimming dolphin and a running human. Depending on the model, our approach yields physically faithful animation one or two orders of magnitude faster than the conventional, numerical simulation technique.

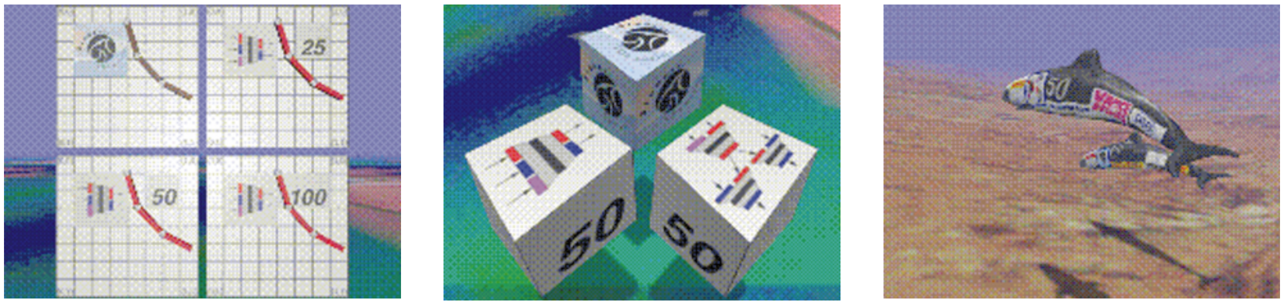

FIGURE 1 This plate illustrates the emulation of three different dynamical systems: a three-link pendulum, an elastic cube and a biomechanical dolphin. In each image the physical model is indicated byt he SIGGRAPH logo. In the third image the biomechanical dolphin[2] is in the background

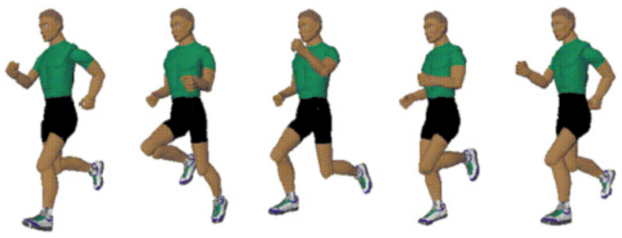

FIGURE 2 Emulated motion produced by training a NeuroAnimator on state transition data generated by the numerically simulated (by SD-Fast) Hodgins mechanical runner model.[3]

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Combining Active and Passive Simulations for Secondary Motion

The secondary motion of passive objects in the scene is essential for appealing and natural-looking animated characters[1], but because of the difficulty of controlling the motion of the primary character, most research in computer animation has largely ignored secondary motion. We use dynamic simulation to generate secondary motion. Simulation is an appropriate technique because secondary motion is passive, dictated only by forces from the environment or the primary actor and not from an internal source of energy in the object itself. Secondary motion does not lend itself easily to keyframing, procedural approaches, or motion capture because of the many degrees of freedom that must move in synchrony with the primary motion of the animated figure.

Passive simulations have been used with great success for many systems, including water, cloth, flags, and leaves blowing in the wind. Active simulations have been used to animate the motion of running, walking, jumping, diving, and vaulting human figures. We explore the interactions between passive and active simulations by coupling passive simulations of objects in the environment with active, rigid-body simulations of humans to compute secondary motion for animated figures. We describe several examples: a gymnast on a trampoline, a bungee jumper, a gymnast vaulting onto a mat, a girl swinging while wearing a skirt, and kites in the air.

The primary contribution of this work is an exploration of three different kinds of coupling between passive and active simulations: full, partial, and one-way. To clarify the differences between the forms of coupling, we use the interaction between a basketball (primary) and the net (secondary) as an example. If the coupling is one-way, the direction and velocity of the ball are not affected by the motion of the net, and the ball continues on a ballistic trajectory. If the two simulations are fully coupled, the rotational and linear velocity of the ball will be changed by the contact with the net, the deformation of the net will be less extreme, and the motion will more closely match that of an actual basketball net. In between these two solutions are a variety of partially coupled solutions. For example, a heuristic drag constant might be applied to the velocity of the ball when it is in contact with the net.

The physics of the particular situation and the fidelity of the required motion dictate how tightly the simulations must be coupled. In some situations, substantial computational savings can be achieved with little loss of realism, but in others tight coupling is essential. The gymnast jumping on the trampoline and the bungee jumper are examples of systems where the interaction forces must be applied to both the passive and the active simulations. In contrast, the girl on a swing is an example of a system where it is sufficient to have a one-way interaction: the active simulation of the swinger affects the passive simulation of the clothing, but the passive simulation does not influence the rigid body motion. A final set of problems is amenable to the use of a simplified passive model that is fully coupled to the rigid-body model and a more complete passive model that is driven by the motion from the rigid-body system. For example, the vaulter is fully coupled to a simple model of a mat with vertical springs, and the resulting motion of the feet is used to drive a more realistic simulation of a flexible mat.

The decision about the degree to which the systems are coupled is similar to the modeling decision about the level of detail required for a physical simulation. In the physical world, all interacting objects are coupled, and movement includes a remarkable amount of perceptible detail. Each decision to ignore a potential coupling or use a more approximate model will result in some loss of realism. In the case of the basketball and net, the motion of the ball in the fully coupled simulation much more closely matches the real world than the motion produced by one-way coupling. However, with appropriate selection of the simulation parameters, either motion might be appropriate for a background element in a scene.

Although we are often not consciously aware of secondary motions, they add greatly to the perceived realism of an animated scene. While we have simulated the secondary motion of some of the objects in the scene, many objects are still motionless. In some cases, it appears that modeling some of the moving and flexible objects emphasizes the lack of motion in the others. Like the progression in models from wireframe to polygonal models, this increase in the fidelity of the modeling may increase the viewer's expectations.

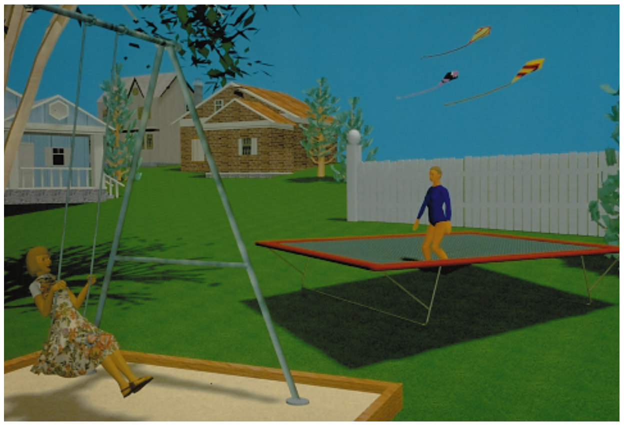
FIGURE 1 Image of a girl swinging while wearing a skirt, kites in the air, and a gymnast on a trampoline

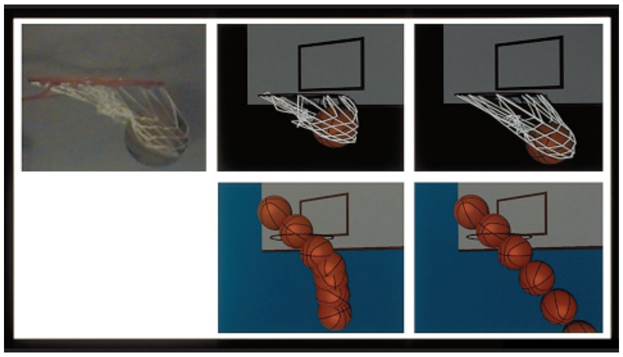
FIGURE 2 Images of a basketball and net with fully coupled interactions, one-way coupled, and an actual net and basketball for comparison (The bottom two images show the trajectory of the ball with fully coupled and one-way coupled interactions)

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In this sketch, we present a rendering meta-primitive called the paintstroke and develop a fast, view-adaptive method for rendering it using our implementation of the A-Buffer. Since the paintstroke's shape is that of a generalized cylinder, it is not a general-purpose tool for building arbitrary objects. At the expense of this generality, however, comes a highly optimized rendering algorithm that greatly improves over traditional methods for drawing the equivalent curved surfaces.

Paintstrokes serve as useful building blocks for a variety of finely detailed natural phenomena such as fur, hair, fine branches, wicker, and pine needles. By incorporating various view-dependent image effects into the rendering algorithm, paintstrokes can be further used for modeling streams of water, icicles, and wisps of smoke. Self-shadowing is simulated on a global scale, offering an alternative to shadow mapping.

Implementation

The standard way to render a curved surface is to tessellate it into a fixed set of three-dimensional polygons. Our algorithm tessellates the paintstroke dynamically, directly making use of the image-space projection of the generalized cylinder to obtain a desirable arrangement of polygons in screen coordinates. Capitalizing on important modeling and rendering efficiencies, the algorithm arranges the polygons so as to maximize their projected screen size, thereby minimizing their number. The resulting savings in vertex transformations, rasterization overhead, and A-Buffer fragment blending more than repay the cost of the dynamic tessellation.

After transforming the control points from world to viewing coordinates, we generate Hermite interpolants for the path and radius components, and linear interpolants for the others. The paintstroke is then subdivided along its length into segments, with a granularity that adapts to its screen-projected size and curvature. Each segment is subsequently tessellated into polygons such that the side of the paintstroke closestto the viewer is always completely covered by one, two, or four polygons, depending on the user-adjustable quality level. Quality-zero paintstrokes use a single polygon per segment and represent the most efficient tiling pattern, although they do not render correctly when viewed head-on, and the distribution of normals along their breadth, derived by linear interpolation across a single polygon, is somewhat inaccurate. Nevertheless, they are an excellent choice for fur, as shown in the bottom right figure.

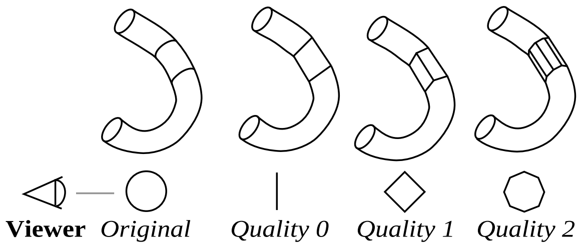


FIGURE 1 View-dependent tessellation meshes

Special Rendering Effects for Paintstrokes

The dynamic, view-dependent tessellation of paintstrokes allows for several useful rendering effects that would be difficult or impossible to achieve with a fixed polygonal model.

Lengthwise Opacity Variation

This feature simulates volume opacity, which varies according to the penetration of the light rays passing through a paintstroke segment. A simple formula involving the segment's path and the viewer's direction estimates the opacity, with a maximum value achieved when the viewing angle is along the path, and a minimum value when it is orthogonal to it.

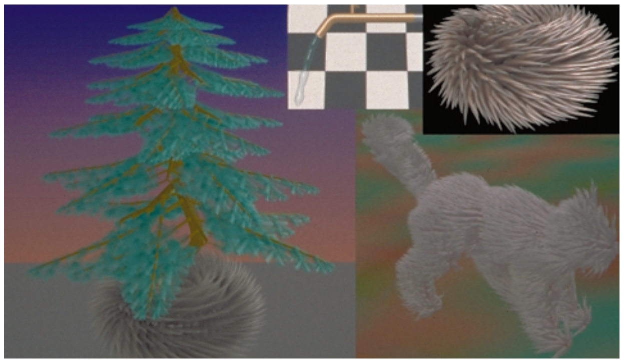
Breadthwise Opacity Variation

The opacity of the paintstroke can also vary across its breadth, allowing the user to specify distinct opacities for the centre and for the edges. Our view-dependent tesselation scheme makes this effect particularly easy to implement. It can be used to produce fuzzy paintstrokes or to simulate the Fresnel effect for transparent fluids, as shown in the top middle figure.

Global Lighting Algorithm

This algorithm works well when a large number of control points are fairly uniformly distributed over a convex volume. Each control point of a paintstroke contains a user-specified global normal and depth value. The former indicates the normal of the global shape to which the control point belongs, and the latter the relative depth from the surface. The estimated amount of light penetration at each control point is computed using the depth, global normal, and average light direction. The control point's reflectance is then scaled accordingly. The left and top right figures are good examples of this effect's efficacy.

Thanks to Michiel van de Panne for the original idea and motivation for this research, and for the many useful discussions about it.



Animal (bottom right) modeled by Nick Torkos using approximately 12,000 quality-zero paintstrokes and as many polygons, rendered at 640x480 resolution in six minutes on a 250MHz R4400. Torus (top right) modeled using 1,250 hybrid quality (level zero / one) paintstrokes, rendered at 256x192 in 15 seconds on a 200MHz 604e. Water (top middle) modeled with four paintstrokes (three for tap, one for stream), rendered at 256x192 in four seconds on a 200MHz 604e.

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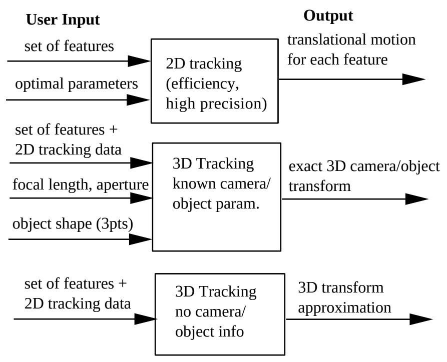
Motion Tracking for Special Effects in the Film Industry

The concept of motion tracking has attracted a lot of academic and industrial attention in the last few years, and it is gradually being applied to special effects in the film industry. Tracking is already used in nearly all special effects shots for camera stabilization and smoothing of object motion. It is also necessary when composing multiple layers of images taken from different positions, when adding new computer-generated objects to the scene, and when mapping textures or reflections onto moving objects. Most of the existing 2D and 3D tracking algorithms are designed and tested to work with video-resolution data, and are too slow and imprecise for film resolution sequences. The reasons for this are: a significantly larger number of pixels in film production, the huge physical size of pixels on the film screen (higher precision requirements), and film grain (high noise level).

We propose an advantageous architecture for tracking and describe novel algorithms for fast and accurate camera/object 2D/3D transform recovery. These algorithms cover most tracking needs in the industry. Some of the techniques are improved versions of existing ones and some are completely new. The proposed algorithms could be successfully used on video sequences, providing a significant improvement in precision and efficiency.

Architecture (see figure below)

- Optic flow calculation is expensive and noisy for film sequences. Tracking of high-frequency features is preferable.
- 2D and 3D tracking is separated so the user can choose the best features for 2D tracking, define an optimal set of parameters (gamma correction, color transformations, reference of tracking), check the results, and repeat the process if necessary.
- The accuracy of 2D tracking is crucial. A high-precision sub-pixel algorithm is required.
- The 2D results from the set of features are used to calculate the 3D transformation. The main factor for choosing 3D tracking algorithms is the ability to work with precise but limited data.
- Two different methods of 3D tracking are used. When the camera parameters are known, and some information on the tracked object is available, precise frame-to-frame 3D transformation can be recovered. When no pre-measurements on the object can be done, a different transform recovery method should be used. In this case, tracking is known to be extremely sensitive to noise, and object/camera translation is defined only up to a scale factor. Therefore, the motion will be only approximated.


User Input
Output
set of features
optimal parameters
2D tracking (efficiency, high precision)
translational motion for each feature
set of features + 2D tracking data
focal length, aperture
object shape (3pts)
3D Tracking known camera/ object param.
exact 3D camera/object transform
set of features + 2D tracking data
3D Tracking no camera/ object info
3D transform approximation

Description of Algorithms

2D tracking module. The following combination of techniques provides the high-precision and efficiency that are necessary for film industry applications. We subsequently perform a small radius multi-resolution search on the Gaussian Pyramid. The Sum of Square Differences (SSD) algorithm is used on each pyramid level to find the best match. For each pair of frames, the translation from the previous pair is used as an initial motion guess. High-precision sub-pixel data is then obtained by fitting a paraboloid to the best SSD results and calculating the minimum of this function.

3D tracking with known camera and object parameters. The standard 3D transformation has 12 (9+3) unknowns that could be computed by a least-square technique with six data points. We are limiting the number of points to only three by assuming small frame-to-frame rotations and using an antisymmetric matrix to represent rotation[1]. After each step, the matrix is converted[2] into the standard rotational matrix that is used to define object depth. Initial object/camera position is obtained by iterating this process and rotating the relative features position according to the transformation until the algorithm converges. This technique allows a precise reconstruction of the camera/object transformation using only the minimum possible number of features.

3D tracking with no camera/object information. Two main standard approaches exist for this type of 3D tracking: epipolar and bilinear constraints. Both of them are extremely unstable for a small number of points, especially for small motions. We propose a new algorithm, created on the basis of a three-frame-based technique recently introduced by Shashua and Avidan[3]. This technique is more simple and robust than others, and has no degenerate cases. The proposed method has been shown to give accurate results with as few as five features, a significant improvement over existing algorithms.

Our tracking module has been successfully used to track objects as complicated as clouds, to achieve excellent stabilization results, and to precisely recover complex transformations using only a few object points.

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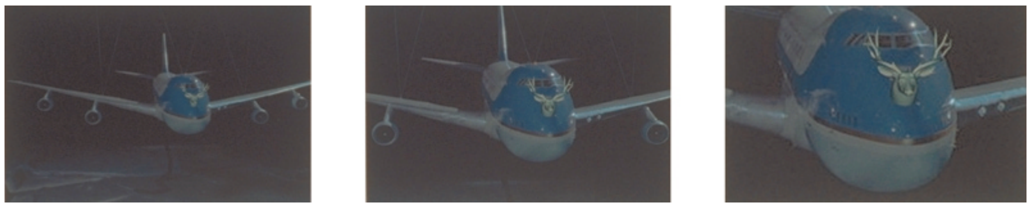


FIGURE 1 Demonstration of the synthesis (according to the recovered motion) of a computer-generated object in a film sequence.

In designing or examining free-form surfaces or polygonal objects, there is often a need to display linear dimensions of the object, especially when the object must fit with other objects, as in the case of mechanical or industrial design. The standard technique of underlaying axis-aligned grids for measurement is convenient only in an orthographic view. In a perspective scene, a shadow of the object can be orthographically projected onto surrounding walls that contain a grid[1]. One measurement at a time can also be provided by an inquiry function, where the user temporarily attaches a measurement widget to the desired objects, but the widget will obscure the objects. For general angle measurement, almost the only choice is a three-point measurement widget that will obscure part of the scene while reading out the angle.

The approach suggested in this sketch is simply to mark the surface directly with texture-mapped measurement tools.

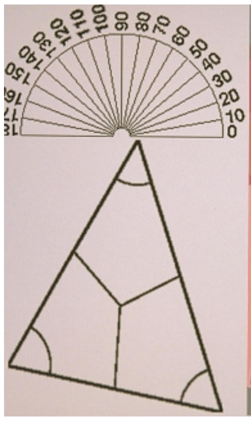
In a similar technique, Silicon Graphics has a demo that maps a regular grid texture onto a bicubic patch to show its (u,v) parameter space. The main advantage with this approach is that input clutter is eliminated, because there are no widgets to avoid clicking. Instead, the surface is painted with measurements that can be turned on or off as a rendering attribute. Output clutter is also reduced because the measurements occupy the identical space as the object being measured, meaning that the measurements cannot occlude other objects in the scene. Because images are textured onto the surface, potentially hundreds or thousands of measurements are available simultaneously to the user, who simply has to look at the points of interest to learn the dimension of interest.

To measure the edge lengths of polygon P, a bilevel ruler texture is applied to each edge. An inner inscribed polygon is generated in the plane of P, and for each edge a four-sided ruler quad is generated to hold the texture.For example, a triangle would be divided into an inscribed triangle and three ruler quads.

For angle measurement, the bilevel arc texture map is used, which is essentially a protractor with heavy tickmarks at 10-degree intervals (Figure 1). For each angle of the polygon to be measured, the axis of this protractor image (at the center of the bottom edge) is placed at the vertex, with the line marked 0 located along the edge lying counter-clockwise from the vertex. To apply the arc at each vertex, the polygon must be cut into subpolygons with the arc texture applied to each, as shown schematically in Figure 1. For a triangle, each subpolygon is a quadrilateral that is made up of the main triangle's vertex, the midpoint of each incident edge, and the centroid of the main triangle. Both arcs and rulers can be displayed at the same time, in which case the texturing occurs using the inscribed vertex values for the edge and centroid calculations.

This new scheme of textured annotations on the surface of objects is quite effective at providing users with ready access to salient metrics on the surface. In an experiment that required subjects to build a simple object to precise dimensions, subjects were readily able to visually access linear measurements provided by the texture-mapped rulers. Subjects could quickly tell that they had reached the correct length.

In a surface with hundreds or thousands of quads in the mesh, each quad can be textured with rulers and arcs, making the linear dimensions of each quad visually available simultaneously without cluttering the scene with auxiliary measurement dialogs. This new texturing method eliminates input clutter and reduces output clutter.



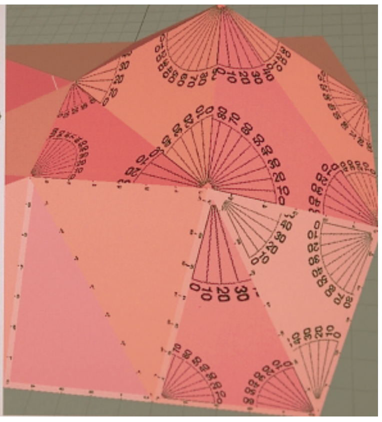


FIGURE 1

TOP LEFT Protractor texture applied at the vertex of each triangle

BOTTOM LEFT Subdivision of a triangle into 3 subpolygons so that the arc texture can be drawn at each vertex

RIGHT An example surface CLOCKWISE FROM TOP LEFT Two quads with arcs applied to each vertex of each component triangle, a quad with rulers and arcs, and a quad with just rulers.

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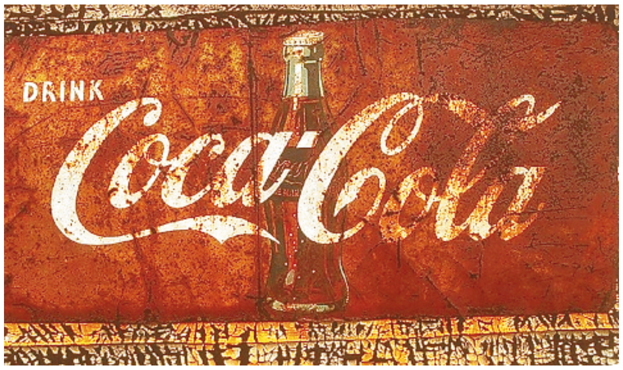
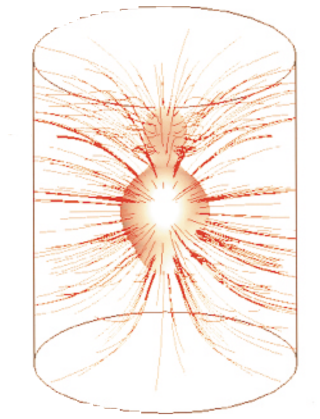
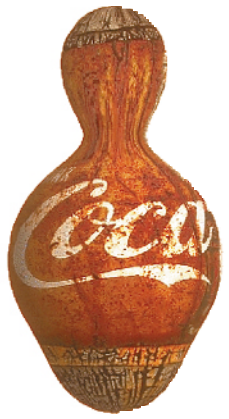
Texturing Implicit Surfaces with Particle Systems

We describe an intuitive yet effective method to apply bidimensional textures onto implicit surfaces. The main idea is to simulate the motion of particles starting on the surface and moving along the gradient vector field until the particles reach a support surface, where a texture is defined. This approach is a good alternative to the use of solid texture, allowing effective application of arbitrary 2D image textures onto implicit surfaces. Moreover, our method is enhanced by a set of tools for controlling how the texture is mapped.







The Method

The method is based on inherent properties of implicit models. Let S be an implicit surface defined by a function F:$\mathrm{R}^3 \rightarrow \mathrm{R}$, i.e., $S=F^{-1}(0)$. We interpret the gradient vector field $=F$ as a force field defined in the ambient space, and we use it to guide the particles that are initially at rest on S. The motion of a particle is governed by the differential equation $d^2x/dt^2 + \mathrm{g}dx/dt + =F = 0$ where g is a viscosity constant. This particle system establishes a correspondence between points on the implicit surface and points on a support surface T, where the texture is defined: the texture attribute for each point on the surface is "read" at the intersection of the corresponding particle trajectory with T. The support surface T should be simple enough so that it is very easy to define texture coordinates on it (e.g. cylinder, sphere etc.).

Computation

We start the simulation with particles placed at the vertices of a simplicial approximation of the implicit surface. Next, particle trajectories are generated by numeric integration of the motion equation. At each integration step, we test whether a particle trajectory has crossed the support surface. If it has, then we obtain the texture coordinate for the corresponding point on the implicit surface from the intersection point on the support surface. Once the simulation is over, texture coordinates are available for each vertex of the polyhedron approximating the surface. Linear interpolation of texture coordinates on each face then completes the texturing of the implicit surface.

Control

The dynamic behavior of a particle system allows us to create a set of tools for controlling the placement of the texture onto the surface. Global control is done by positioning the implicit and support surfaces relative to each other. Local control is achieved by introducing external forces in the system, such as attractive and repulsive point, curve, or surface sources.

Example

The figures below demonstrate how the method accurately applies an image onto a blobby surface. A cylinder is chosen as a support surface for the texture, and the particle system is generated from a blend of the blobby and support surfaces gradient vector fields. More examples, including animations, can be seen at:
http://www.visgraf.impa.br/Projects/dtexture

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We present a new data structure and algorithm for fast, flexible computation of static levels of detail. Our algorithm extends previous work by Jarek Rossignac and Paul Borrel[1].

Vertex clustering is a fast, robust technique for generating static levels of detail. However, the results can be crude and unpredictable. The user has very little control over the properties of the output simplifications (e.g. number of triangles, size of triangles, topology, surface properties, preservation of features). Furthermore, the existing algorithms compute only isolated simplifications, rather than the continuous range of simplifications needed for many network applications today.

A quick review of basic vertex-cluster simplification is in order. Cluster the v vertices of an object and choose a representative vertex in each cluster. Translate each facet of the object to a facet of the simplification by mapping its old vertices to new ones. Eliminate degenerate and redundant facets by comparing the new vertex indices. This process can be accomplished in $O(v \log v)$ time, and various enhancements can be made without increasing the cost. Note that the translation and elimination steps are independent of the clustering algorithm. This observation is the key to our new method.

We present a new data structure called a vertex cluster tree from which a particular vertex clustering can be extracted quickly and adaptively. The tree can be used to simplify to a desired number of triangles or to optimize a wide variety of other geometric and topological properties.

In general, the tree is built by defining a hierarchy of clustering functions C_i, one for each level i of the tree. C_i must be hierarchical: if two vertices are in the same cluster at level i, then they must be in the same cluster at level i+1; and an upper bound on the number of possible clusters should decrease by a constant factor at each level. For example, let C_0 be a spatial binning into a regular grid of cells with 2^kcells, k=[log v]m, along each dimension of the grid. Let C_i,0 < i <= k, be a similar binning using a grid 2^{k-1} cells wide. In this example, the same type of clustering is used at each level, but this need not be the case.

To build the tree, we cluster the vertices at each level of tree, up to a single cluster at the root. If a vertex is assigned to a cluster at level i in time $O(T_i)$, the number of clusters generated at level i is c_i, and the tree has d levels, then the entire tree is built in time $O(vT_0 + \mathrm{S}^{d}_{i=i}\, c_{i-1} T_i)$. With the regular spatial binning described above, for which $T_i = O(1)$ and $d=k=[\log v]$, this reduces to $O(\mathrm{S}^{k}_{i=0} \min(v, 2^{3(k-i)})) = O(v \log v)$.

We grade the importance of each cluster in the tree by propagating value up from the leaves. The properties we use to grade the tree will determine the properties we can optimize in our simplifications. For example, if we want to use the tree to simplify to a target number of triangles, we can grade each cluster with the number of triangles of the original object that would collapse if all of the vertices in the cluster were collapsed into a single vertex. This grading can be accomplished in time $O(td\mathrm{S}^{v}_{i=1} G(i)$, where t is the number of triangles and $G(i)$ is the complexity of the local grading function. Note that in the case of spatial binning, the tree can be built and graded in time $O(v \log v)$.

By selecting a set of nodes that cover every path from the root to the leaves, we define a clustering of the vertices. For any interesting criteria, choosing the optimum clustering is a complex problem, but we have found that a greedy approach gives good results in practical cases. Initialize the clustering to the root and repeatedly choose the child of a node in the current clustering that increases the desired property by the largest amount. Stop when the target is reached. This step can be accomplished in $O(\log v\mathrm{S}^{d}_{i=1}\, c_i) = O(v \log v)$.

Note that we can record a vertex clustering at any point in the last stage of the algorithm, and use it immediately for translation and elimination to produce a simplified object. Thus, we can very quickly extract many levels of detail with a single pass through the tree. In particular, we can generate a hierarchy of levels of detail using spatial binning in $O(v \log v)$ total time.

To consider more complicated properties of the object, we modify the algorithms for grading the tree and choosing clusterings. Essentially any local property of the data can be incorporated into these stages of the algorithm. Cluster grading could be based on topological complexity (to control topology and identity of separate objects), triangle size (to refine relative to the amount of detail in the object), angles between facets (to preserve features), importance of vertices (to maintain silhouettes), or any geometric or surface property.

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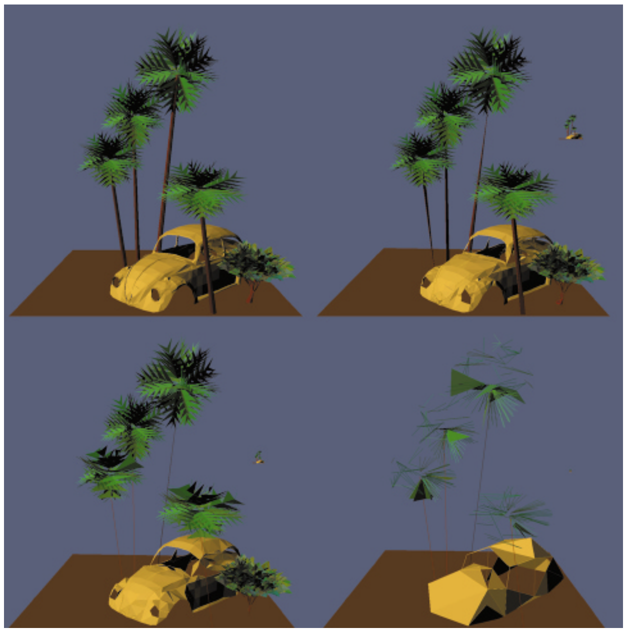
Model Simplification Using Directional Clustering

We are developing a clustering algorithm whose simplification metric minimizes changes to the final image rather than changes to the input model topology. This allows significant simplification of difficult models such as trees and plants, and it allows inter-model simplification for collections of objects. Most simplification algorithms attempt to produce compressed models that closely approximate the topology of the original model. Our algorithm takes advantage of recorded geometry compression generated in an off-line precalculation routine that runs on the order of minutes while the real-time object generation routine adapts to motion parameters and the demands of different graphics system hardware to ensure the fastest balance between rendering and simplification. This enables the algorithm to be used for a number of applications, including games, motion previews, and large-scale virtual environments.

The Approach

Many of the methods that have been used to reduce the complexity of object geometry perform reduction or re-triangulation of an input mesh based on some criteria, usually progress towards simplification and minimization of changes in the topology of the original mesh. Our approach is inspired by a clustering algorithm[1], in which any two vertices can be merged whether or not they share an edge or polygon. This allows the algorithm to introduce significant topological changes during simplification.

We introduce a metric for selection of mesh simplification steps based on their impact on the final image. The metric estimates the eventual screen distance of pairs of vertices and the color and normal differences of adjoining polygons. In Schaufler & Sturzlinger[1], the set of merges can be pre-calculated and used as geometry compression. However, in the course of an animation, a metric based strongly on eventual screen position can wildly change the order of compression and the underlying simplification data structure. Our method uses a hybrid of precalculated non-directional simplification and real-time simplification using our image-dependent measure.



The algorithm takes as much advantage of pre-calculated non-directional clustering as possible. This minimizes the amount of directional clustering in any given frame. For any frame, initial work is derived from the pre-recorded clusters, while a smaller set of easily changeable directional clusters are subsequent. Directional clusters are determined from a weighted average of global and screen distance in order to avoid pathological merges. The weight is determined from the rotation speed of the object. The ratio between a system's rendering speed and processor speed is also used to determine the profitability of (and thus determine how much effort to expend on) directional clustering. Animations with relatively static scene segments run on machines with a low ratio will spend more effort in eliminating polygons, while a wildly spinning scene calculated on a powerful graphics station gracefully degrades to the simplest version of geometry playback using the original metric and an algorithm similar to geometry compression.

A key feature of our new algorithm is the ability to control the amount of topological modification. Coarse models (which can be smoothly interpolated if needed) can be generated for motion previews and polygon-limited systems. Topological changes can be limited to sub-pixel merges for accurate renderings or turned off altogether so that the algorithm can still be used to eliminate redundant data from laser range data.

The advantages of directional clustering include near-back side surface removal and profitable results for distant slow moving objects like trees, terrain, and buildings. Results thus far show that in combination with a static, precalculated simplification hierarchy, our new approach is very effective in further reducing the cost of image synthesis without a significant loss of quality. Our scheme dynamically adapts to changes in viewing characteristics and automatically adapts to various display architectures.

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We study the use of wavelet compression of a volumetric representation of polyhedral surfaces. The surface is first represented by the zero set of a distance function. We apply wavelet multiresolution analysis to this function. This allows us to represent a polyhedral object of arbitrary topology to a variable level of detail. By reducing the number of detail coefficients, we can achieve very high compression ratios of the geometry data with little loss in image quality[1]. Secondly, this method allows change of the genus of the object as level of detail is decreased. Most current methods of surface simplification[2] (and many others) do not allow variations of genus as resolution is lowered. This is a significant drawback when used for the purpose of low resolution approximations of object for rapid rendering. Indeed, if we are given a grid of n intersecting cylinders, the number of triangles necessary for a genus-preserving representation is necessarily greater than n^2. The method of J Rossignac, P. Borrel and T.He, et al. are an exception. In the former, simplification is done by merging surface vertices. Our method uses a volumetric representation, as in T.He, et al. where a low-pass filtering method is used on a different representation.

We combine several techniques, and proceed as follows. Given a polyhedral surface S, we define a distance function $d(x,y,z)$ on 3D space such that S is the zero set of d. The function d will be the distance from the point (x,y,z) to the surface for points outside the object, and the negative of the distance for points inside. This function is piecewise linear and discontinuities occur at the faces, edges, and vertices of the Voronoi diagram of the polygonal object surface.

We sample this function at a regular 3D grid (the sample interval is a function of curvature and triangle size), and perform three-dimensional wavelet analysis[4] using an orthogonal filter bank. See below for the type of wavelet used. We now have a multiresolution representation of the distance function: a series of wavelet coefficients. Next, we apply wavelet compression: the number of largest wavelet coefficients we keep depends on the desired level of detail and accuracy. At this point, the object has a very compact representation which can be efficiently stored or transmitted.

To reconstruct the surface, the distance function is approximated by wavelet reconstruction using a synthesis filter bank. The next step is to reconstruct the polygonal surface. This is accomplished by using the classical marching cubes algorithm. Using the function d instead of the classical “volume inside voxel” function reduces the blockyness of the reconstructed surface.[3] The final step involves simplifying the resulting surface. We employ a triangle decimation method. An alternative to our last two steps is to use the methods of R. Shekhar, et al., which produces an already simplified triangular mesh.

In Figure 1, we give an example of the results obtainable by our method. We used Daubechies wavelets for their ability to approximate piecewise linear functions. The original object is shown in Figure 1a. In b., keeping 0.5% of coefficients yields a compression of 36:1 without much loss of image quality. In c., we show an intermediate resolution, and in d., we use Haar wavelets, keep 0.1% of coefficients, and obtain a reduction of genus.

In summary, we achieve high compression ratios of polyhedral surfaces. Other advantages of our method are that it allows simplifying and possibly merging several objects. In addition, this method can be used for progressive transmission of surfaces. We plan to continue the study of this type of object representation including using different distance functions, studying different types of wavelets, and comparing to other simplification algorithms.

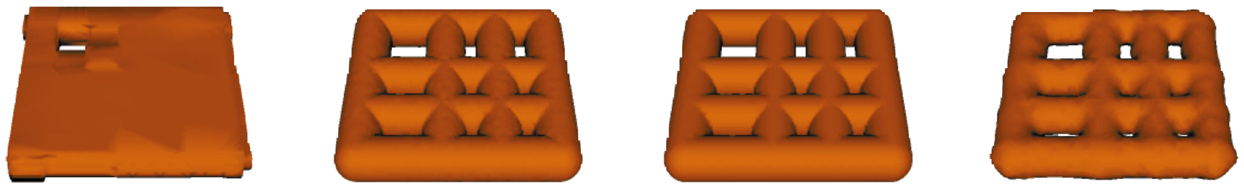
FIGURE 1a, 1b, 1c, 1d

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Intelligent Transmission of 3D Polygonal Models

Several authors have recently described novel approaches to the problem of generating multiresolution representations of 3D models[1,2,4,5]. This sketch presents a flexible and simple framework that can utilize such representations to offer improved Level of Detail (LOD) management in VRML. The framework can accelerate the rendering of VRML scenes by progressively transmitting and rendering selectively refined models of every object in the scene. Such models are constructed from small fragments of polygonal approximations to the objects, and hence the resolution of rendered meshes can be varied on a per-facet basis. When combined with our method for specifying the resolution required in a displayed scene, this gives an extremely flexible and accurate approach to the problem of polygonal LOD management.

Key Components of the Framework

Resolution Control Function: The RCF is an "oracle" which, when passed a facet, assesses whether the facet meets user-specified resolution criteria. These criteria can depend on client-side parameters (e.g. view frustum extent and object- and screen-based Areas of Interest). By using an inverted form of Cohen's "simplification envelopes"[3], the geometric precision required in the displayed surfaces can be specified simply by indicating volumes within which the surfaces' resolution must be enhanced.

Continuous Resolution Model Representation: A pre-processing step produces a representation of a VRML model from which selectively refined versions can be obtained. The CRMR consists of a base mesh together with a history of the refinements required to improve the base mesh with respect to some object-space resolution metric.[1,2,5] An RCF-classified object-space measure is associated with each refinement fragment. Our CRMR can be generated from many existing approximation techniques, such as Hoppe's Progressive Mesh approach.[4]

Algorithms: Selection of the regions to be transmitted and reconstruction of the selectively refined surface is performed as described in.[2] These routines identify the refinements that must be passed to the client in order to satisfy the RCF and produce a complete surface from a consistent set of such fragments.

It is necessary to geomorph[2,4] between displayed selectively refined surfaces in order to prevent "popping" artifacts. This can be performed efficiently with minimal alterations to the surface using the algorithm in.[2]

Advantages

During transmission, progressively better approximations to each object in a scene can be rendered on the client. In addition, the amount of scene information transmitted and rendered is directly proportional to the perceived quality of the displayed image.

Results

Figure 1 illustrates the structure of our selective refinement framework together with its application to a Progressive Mesh representation[4] of Viewpoint Datalabs' Cessna model. The resolution of the model displayed on the client has been reduced in the background of the view (i.e. the plane's tail and the wing on the left) such that the rendered polygon count is approximately 50 percent of the original VRML model.

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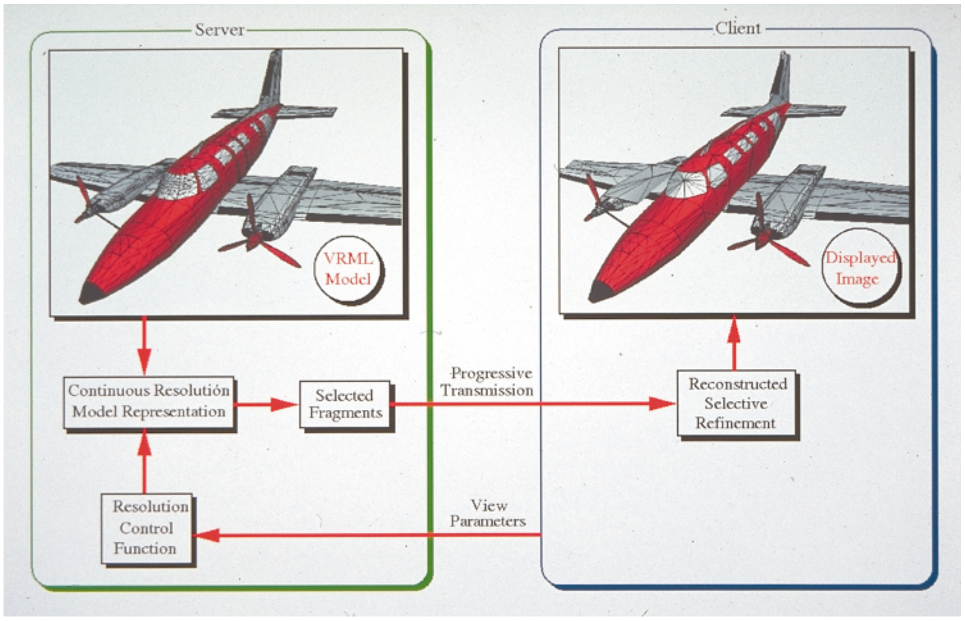
Server
Client
VRML Model
Displayed Image
Continuous Resolution Model Representation
Selected Fragments
Progressive Transmission
Reconstructed Selective Refinement
Resolution Control Function
View Parameters

The goal of the Talisman program is to dramatically improve the graphics and multimedia capabilities of a Windows PC. Talisman introduces both innovative hardware and an innovative merging of DirectDraw and Direct3D APIs to deliver multimedia performance and quality equal to or better than workstations that cost much more.

A key element of the Talisman architecture is scaleability – the ability to implement Talisman-consistent versions of hardware for motherboards to high-end, add-in cards for the PC. Microsoft has defined two implementation concepts that span the scaleability range for Talisman. This sketch discusses specific elements of a version called Wizard, which is specified to meet the requirements for volume PC applications of the Talisman architecture. Development of products based upon this version of Talisman was made possible beginning in January 1997, when the Talisman Technology license was commercially offered by Microsoft. Specific concepts for scaling the Talisman architecture to enable cost-effective Talisman 3D solutions for the motherboard and ~ $200 add-in card are presented.

In the Talisman reference design, the graphical functions are distributed across four ASIC chips with a targeted PCI add-in card BOM exceeding $200. The goal of the Wizard program is to provide Talisman quality at a motherboard or add-in card equivalent BOM cost of less than $100. This is only possible by increasing integration and lowering the chip count of the implementation. This sketch describes the results of on-going design work that demonstrates how this can be accomplished and delivered in real products in 1998.

The fundamental design goal for the Wizard version of Talisman was that it be fully architecturally compliant with the original Talisman concept. This means that the implementation had to include composited image layers, image compression, chunking, and multi-pass rendering. High-quality features such as anisotropic filtering, shadows and reflections, alpha blended transparency, and anti-aliasing must be supported.

The approach taken was to construct a super engine capable of performing the functions of both the Polygon Object Processor and Image Layer Compositor of the original reference design. In the reference design, these two chips were characterized by duplicated processing engines running independently and in parallel. The Wizard approach features time domain multiplexing of a common super-set engine. The Wizard is further designed to operate with a host CPU providing front end pipeline calculations in lieu of a DSP. However, the Wizard does include a setup engine to offload the processor and increased overall polygon throughput. The Compositing DAC of the reference design is eliminated by the addition of an external buffer and compositing directly into the on-chip color buffer. The LUT/DAC functions and a VGA/2D core are both integrated into the design as well. In order to accommodate both motherboard and add-in card designs, the chip interface supports both AGP and PCI interfaces.

The results of this sketch clearly demonstrate the viability of the Talisman architecture for volume PC applications and project a promising view of the quality of 3D that will arrive soon on the desktops of virtually all PC users.

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Practical SIMD

Sun's VIS instruction set has been integrated into all UltraSPARC processors shipped since December, 1995. SIMD extensions accelerate algorithms by partitioning a 64-bit register into smaller registers and executing a single instruction against each value simultaneously.

Documented Accelerations

APPLICATION AREA	ALGORITHM	SPEEDUP
Medical Imaging	Maximum intensity projection (MIP) Multiplanar reformatting (MPR)	4X
Video Encoding	Distance between vectors	4.6X
Image Processing	16-bit 1K x 1K convolution	1.7X
Audio Processing	FIR and IIR filters	2.8X and 1.4X
Printer	Color conversion look-up table	6X
Networking	Fletcher1s checksum (0.5 and 4 kB packets	4.3X and 5.9X
Mass Storage	XOR 64 kB blocks	3.75 X
Genome Sequencing	Sequence comparison	2X
Cryptography	Bit matrix multiplication	11 to 14X

VIS Summary

- 30 three-operand RISC-instructions, additions, subtractions, multiplications, and comparisons on four pairs of 16-bit values, or two pairs of 32-bit values at a time.
- Pdist (pixel distance), for motion estimation and cross correlation, compares eight pairs of 8-bit values at once, using a sum of absolute values of differences. Can provide a 20-50X performance boost for the inner loop for MPEG decompression or decode.
- Single-instruction commands move 64 bytes of data directly between eight 64-bit registers and system memory, bypassing cache.
- 3D data blocking for efficient handling of volumetric data. A 3blocked byte2 addressing scheme loads cache with cubes of data, rather than lines of data.

SIMD Impacts Coding, Requires Libraries

SIMD code, while faster-executing, is generally longer and more complex than a pure C code implementation of the same function, so libraries are essential. Examples:

	STRAIGHT C	VIS SIMD	LIBRARY
7 by 7 convolution	386 lines	4,984 lines	mlib_ImageConv7x7()
Image addition	177 lines	903 lines	mlib_ImageAdd()
RGB-HSV color space conversion	360 lines	565 lines	mlib_ImageColorRGB2HSV()

Sun's mediaLib Application Library

At the time this sketch is being written (Spring, 1997), Sun appears to have the first low-level application library for its SIMD extensions. (Intel has ported some existing libraries to MMX, but all libraries we have seen are coded in assembly language. Higher level MMX tools are available from Microsoft.) Sun developed its mediaLib library functions at the lowest possible level, to be inserted into the inner loops of the most demanding applications. The library consists of two sets of functions. One is VIS-accelerated, for the UltraSPARC platform, the other consists of highly tuned C functions that can be compiled on any platform. Portability enables developers to write to a common, low-level interface and run their applications on several high-performance platforms. Both versions provide access to the functions from C, C++, or Java.

mediaLib Functions

Imaging: Data format conversion, spatial operations, image generation and copying, arithmetic and logical operations, color space conversion, geometric and radiometric operations, image statistics, Fourier domain processing, volumetric data processing, and volumetric visualization.

Linear Algebra: Vector and matrix algebra.

Audio/Video: Digital signal filtering, signal generation, transformations, and the basic elements for JPEG and MPEG processing.

Graphics: 2D and 3D primitives, rendering and texturing

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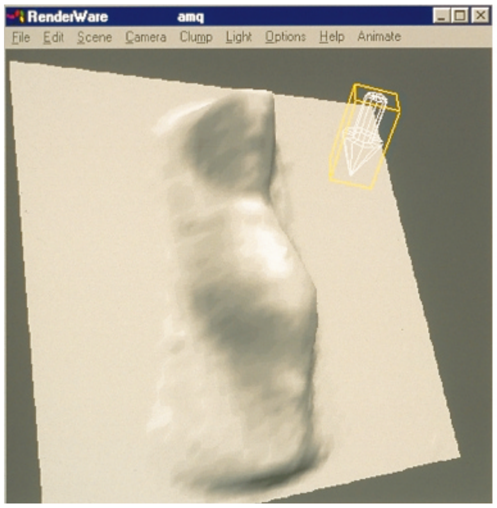
We have developed a low-cost hardware and software device to enable the real-time visualization of the haptic sense of pressure. The device and supporting PC-based software enable the visualization and documentation of certain forms of tactile input for applications such as robotic end-effectors, medical palpation, 3D digitizer, and a novel 3D input device resembling clay.

The sensor is actually a low-resolution 3D surface digitizer. It consists of an easily compressible elastomer bounded on one side by an opaque white deformable membrane and on the other side by a clear rigid face plate. An intrinsically clear elastomer is evenly colored throughout its volume during manufacture by an optically attenuating with low dispersion gray dye, imparting an optical neutral density. Pressing a 3D object against the white membrane while observing it through the elastomer, one sees a black and white image representing a 3D range map of the applied surface. The gray value at each 2D image location represents a monotonic function of the distance from the membrane to the face plate. The closer the white membrane is pressed to the face plate, the less gray elastomer the light has to pass through, the less attenuation to the image of the white membrane, and hence, the lighter that part will appear.

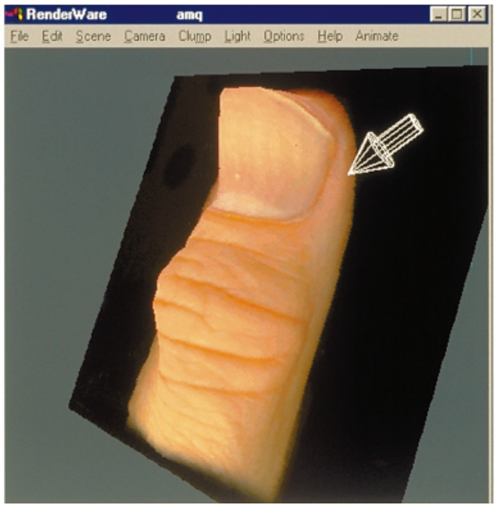
Using a video camera (a Connectix digital camera was used) and even illumination, a real-time digitized range image representing the 3D surface in contact with the membrane is produced. This is then converted to a real-time rendered 3D surface with special software. A function relating the Z-value of the membrane deformation [Z_def(x,y)] returns an approximate (and relative) compliant force at that location [Z_force(x,y)]. Multiple Z_force(x,y). iImages, taken at different average forces, can be used to generate a "modulus map" of an object exhibiting varying material densities, such as a body part. Thus, tissue density contrasts (difference between skin and bone, for example) can be characterized, documented, and visualized.

Initial problems encountered were minor but can be eventually overcome for real applications. The first device built consisted of an optically dense fluid instead of the elastomer. Even though this was less useful in a final product (potential fluid leaks), it facilitated sensing of the average internal vessel pressure through a connected pressure transducer. This pressure value is added to the 3D spatially modulated pressure to yield the absolute restoring force at any x,y location on the membrane, resulting in absolute and repeatable data. Accuracy of the range image is dependent on eveness of illumination, color and clarity of the fluid or elastomer, and color of the membrane. Also, reflections from the on-axis illumination source must be reduced so as not to corrupt the image. Cross-polarized filters were used to reduce these reflections. The focal length of field of view of the camera lens also affects the range image, particularly off the optic axis.

Applications include haptic sensors for robotics, medical palpation, telemedicine, a 3D "digital clay" input device, and a low-cost 3D digitizer, among others. For the palpation application, a physician can objectively document the size, shape, area, modulus, and volume of a skin-level anomaly (such as a sub-cutaneous cyst), tracking its evolution over time. By superimposing a color texture map of the object over the 3D surface, one can produce a 3D computer model of the original object as shown in the picture.



Real-time 3D Surface Visualizer (thumb pressed into haptic lens)



Real-time 3D Surface Visualizer (color texture map added)

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A Low-Cost Digital Panoramic Camera

Panoramic photography has become a popular medium since the advent of the Internet and software presentation technology such as Apple's QuickTime Virtual Reality (QTVR). The combination of a well-commercialized and low-cost digital scanner with some simple modifications can net a high quality digital panoramic camera.

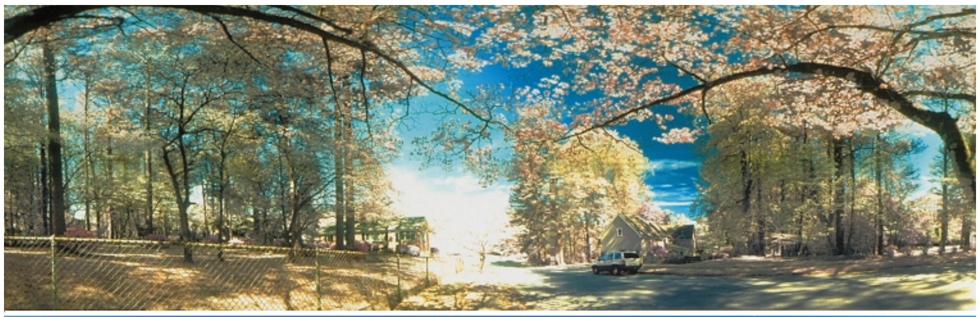
The immersive qualities on observers of wrap-around video and the compelling nature of the ability to interactively pan around in a fixed-eyepoint environment are well known. Unfortunately, production of these images is presently either very tedious or the camera is very expensive. If film is the original medium, it must then be digitized for computer use.

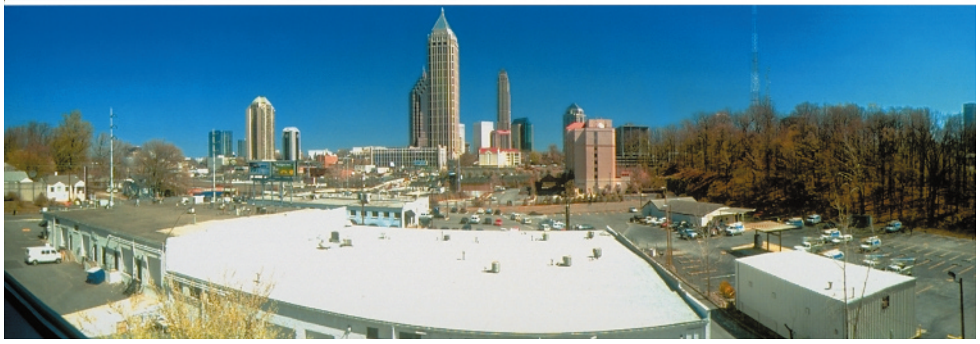
Enter the digital hand scanner, a relatively low-cost collection of lens, mirrors, linear color CCD sensor, electronics, mechanics, and software. In its off-the-shelf form, it is intended to connect to a special input card or to the PC's parallel port and allow users to carefully drag it across a piece of paper or artwork and transfer the image digitally to the computer. Though not as useful as a flatbed scanner for normal scanning, the hand scanner's portability and small size makes it a natural for use as a camera. Through modification (some call it butchering) with a knife, file, saw, and some electronics, it becomes a 360-degree digital panoramic color camera capable of producing remarkable images exceeding 27 Mbytes, which are directly importable into presentation technologies such as QTVR.

The unit chosen for modification is a Logitech Scanman2000 hand scanner because of its low cost, parallel port connectivity, and availability. The initial modification consists of focusing the lens at infinity, disconnecting the fluorescent lamp, cutting the circuit trace to the internal encoder, and wiring the encoder input to an external scan pulse source. A geared stepper motor with a battery-operated driver provides the external pulse source and a constant speed panning function of approximately 0.5 rev/minute with 6,000 motor steps per revolution. The camera is completed by mounting the modified scanner vertically on the geared motor output shaft and adjusting the motor speed so as not to exceed the data acceptance rate of the computer. While panning through one revolution (with this setup, it takes about two minutes, so a tripod is a must), it produces a 27 Mbyte image or approximately 1500 x 6000 x 3 RGB pixels. The scanner lens provides approximately 90 degrees of vertical field of view. Using Apple's PANOTOOL, one can produce a QTVR source image in just a couple of minutes.

Additional modifications consist of relocating the internal RGB adjustments to the outside, moving the bow-tie aperture closer to the lens, removing all mirrors, and adding two counter-rotating polarization filters. The adjustments on the outside facilitate exposure and color correction: moving the bow-tie aperture reduces vignetting when the lens is re-focused, and the polarization filters function as a variable neutral density for further exposure control (the lens has no adjustable aperture).

There are some problems with this technique, most of which can be eventually overcome. The eight-bit dynamic range of most scanners is not usually sufficient for normal outdoor images without some form of exposure compression. You lose detail in shadows and/or highlight areas. Also, the hand scanner's CCD color filters, fluorescent lamp, and software combination were made for a particular color temperature, not necessarily daylight. With low-cost, single-CCD sensor scanners, there may also be color banding problems, though this appears to be minimal. The images indicate some of these problems, mainly the lack of dynamic range. The white areas are generally caused by the saturation of the RGB sensor and analog-to-digital converter range limitation. But... for an investment of approximately $250, there seems little reason to complain.





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To digitize curved, especially organic shapes, current systems require that the user trace very dense and regular meshes on the surface. Such work is tedious and time-consuming. Our system allows the user to casually specify the most important features and let the computer fill in the regular gaps. The system can also automatically infer features such as creases and corners.

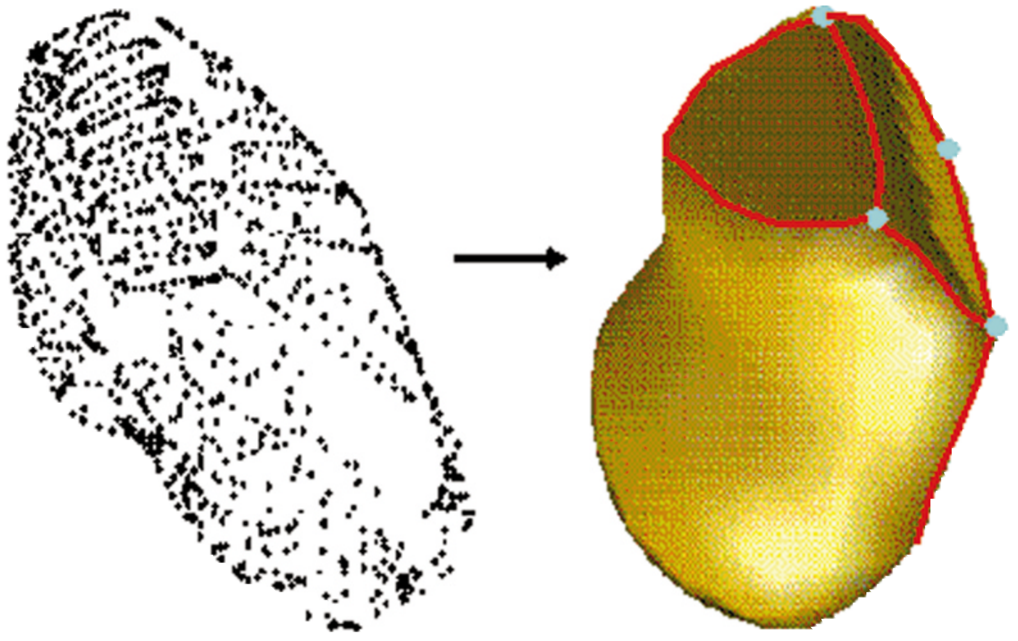
Prototyper: Boxing-Up and Outlining the Shape
We implemented an efficient volumetric clay modeling scheme (or metaballs, soft objects, blobby models). Gesture recognition is used for fast modeling without clicking the menus or icons. If more than three strokes are sketched, an ellipsoid is generated; if two strokes, the closed (or almost closed) stroke is taken as cross-section and classified into a square or an ellipse in 3D space, and the other stroke is used as the sweeping direction for the cross-section.

Refiner: Adding Details to the Prototype
The user needs to improve the surface by adding more detail strokes. In our system, the user randomly sketches over a region where corrections are needed, and the surface adapts to the new strokes to yield a better shape. The user can also trace the crease edges and mark corners on the object for the model to align with. Finally, a smooth surface with preserved and aligned creases and corners will be obtained.

Since the clay parts are solid models (blobs, plates, sticks) and lack local details, we treat the prototype as a surface model for local refinement by adjusting the positions of control points. The triangle mesh is upgraded to a quadratic triangular Bezier surface then to a triangular B-spline surface. Each datapoint contributes a negative spherical potential field that decays with distance, and thus three potential fields are generated by surface points, crease points, and corner points, respectively. Energy minimization is performed to deform the surface and align its edges and corners. Using potential fields makes surface fitting fast enough for interactive modeling. In some previous work, the distances from datapoints to the triangle mesh are computed many times during the iterations, and the program runs for hours. By contrast, the potential field is only computed once for each datapoint, and is incrementally updated with new sketching strokes.

autoTracer: Automatic Inference of Creases and Corners
The autoTracer module can automatically infer creases and corners from random strokes over smooth regions, and the user does not need to manually trace the edges or mark the corners. Then the Refiner module is called to perform the energy minimization that deforms the smooth surface and better aligns the inferred creases and corners. Drawing smooth surfaces is easy, but the singular points and boundaries are problematic. The autoTracer module reduces such difficulty.

Mathematically, each datapoint contributes a vector field in a 3D volume (grid), and we compute at each voxel a 3x3 covariance matrix (or second-order moments, or scatter matrix) of all accumulated vectors, and the three eigenvectors defining the major, medium, and minor axes of an ellipsoid. In other words, we build a dense structured tensor field from the sparse unstructured stroke data, and thus, surfaces, edges, and corners can be inferred from the shape of the ellipsoid. A stick-like shape indicates a surface passing through this position. A large plate-like shape has two salient directions, indicating an intersection of two surfaces. And a ball-like shape indicates a corner due to three salient directions.



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Feature Based Haptic Rendering: Architecture, Protocol, and Application

3D I/O devices, long awaited in computer-aided design (CAD) systems, are finally available as force feedback devices such as PHANToM (SensAble Devices, Inc.). This paper presents Feature Based Haptic Rendering (FBR), which provides haptic feedback of a more accurate shape required by the haptic man-machine interface for surface CAD than intermediate representation (IR).[1,2]

Figure 1 shows the FBR architecture. The virtual surface modeling process is connected to a haptic rendering loop using a single asynchronous TCP/IP socket stream. As Mark et al[2] state, decoupling the haptic rendering process is indispensable to obtaining high haptic fidelity that requires device control latency of ~kHz, since shape modelling (e.g. NURBS knot insertion) may take time. IR is data exchanged between decoupled processes, which actually is a plane in Adach & Ogino[1] and to which Mark et al[2] added a few more primitives. Because only received IR is used in haptic rendering, the haptic process does not need a geometry database. The database coherency problem that arises with such architecture, in that each process has its own geometry database copy, can thus be avoided.

FBR generalizes the idea of IR to a feature, which is the unit of communication and can be categorized into two groups: data and commands. The data feature includes local haptic properties of virtual objects, such as shape (Figure 2), texture, stiffness, and position. Command feature is used to control other processes (e. g., switching interpolation strategies of received shape features in the haptic rendering loop). FBR provides a communication protocol to exchange features. A feature is split into one or more fixed-length packets from which the receiver reconstructs the original feature. The haptic renderer has force feedback calculation algorithms and interpolation strategies for features.

FBR can be used by any point-contact type force feedback device as IR and can be easily extended to multiple-contact type devices by introducing an object momentum feature. Haptic volume rendering is also easy: shape features can be constructed as local iso-surfaces by the Marching Cube algorithm,[3] for example. Physically correct haptic rendering of a thin, elastic object is then possible, which is important for surgical simulation but is difficult with the voxel density field algorithm.[4] A virtual surface modeler with force feedback has been implemented with FBR, whose modelling and graphic rendering run on a SGI Indigo2 Elan (200 MHz R4400), and the haptic display is PHANToM (6 DOF input and 3 DOF force output) on a PC (200 MHz Pentium Pro). The user can touch, trace, and deform a B-Spline and a triangular surface directly[5] with virtual tools catching haptic feedback (Figure 3). Rich shape features display the surface shape accurately. A 5-10 kHz device control latency has been achieved with 20-30 Hz communication and graphics refresh rate. Quantitative and qualitative evaluation of FBR using psychophysical methods is underway.

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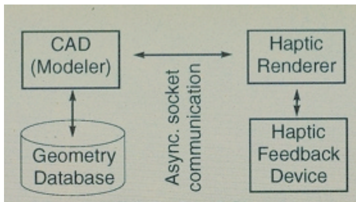

Fig. 1 FBR Architecture

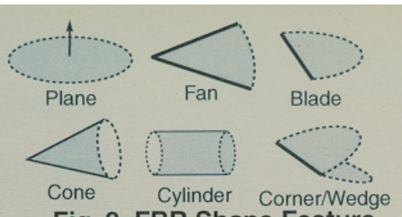

Fig. 2 FBR Shape Feature Examples

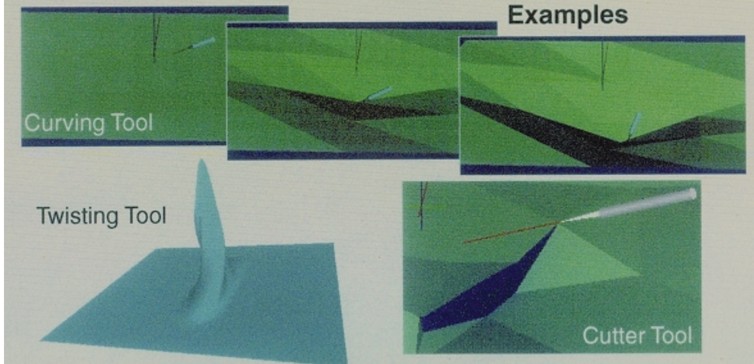

Fig. 3 Virtual Surface Modelling with FBR

The three-dimensional models used for computer graphics display are becoming so large and complex that they cannot be rendered at interactive speeds. As a solution to this problem, researchers have introduced the concept of level of detail (LOD). With this approach, model complexity is varied to ensure that interactive display speeds are maintained, instituting a tradeoff between LOD and interactivity. Two complementary lines of LOD research exist. The first, object simplification, introduces methods that allow variation in LOD, and has been the focus of much recent research effort. The second, LOD management, introduces methods for managing the LOD vs. display speed tradeoff. This sketch describes such an LOD management method.

The human visual system perceives the world at a high LOD in the center of its field of view, and a low LOD in the periphery of its field of view (FOV). This suggests an LOD management technique that mimics this characteristic of the visual system, and reduces LOD in the periphery of displays with relatively large (60 degrees or more horizontal) FOVs. We call this technique peripheral degradation. Previous experiments[1] have shown that this technique can work well, allowing reductions in detail that do not harm user performance on search tasks. With the increases in display speed that accompany these detail reductions, user performance should improve.

Use of peripheral degradation requires knowledge of user gaze direction, including both head and eye movements. Head tracking hardware is widely available and is used in many existing systems. However, there are a number of reasons to avoid eye tracking. Eye tracking technology can be expensive and often requires calibration for each new user. It is unwieldy and often unpleasant to use. Finally, sampling the eye tracker with each iteration of the rendering loop can actually reduce interactivity. We did not use eye tracking in our implementation of peripheral degradation.

Psychophysical research[2] shows that when the head can move freely, eye motion relative to the head is almost always restricted to a 15-degree central horizontal band. This suggests that LOD in a head-tracked display (without eye tracking) need only be high within this band. We performed an experiment to verify this hypothesis and to see if a similar detail degradation could be introduced in the vertical dimension. Eight participants performed a complex search task using head-mounted displays with varying degrees of horizontal and vertical peripheral degradation (Figure 1), or with no degradation at all. Search space was four times larger than total display FOV. Peripheral detail was degraded by using pixels roughly two degrees x two degrees in size.

Results, presented in Table 1, confirmed the hypothesized 15-degree horizontal detail constraint and indicated that a vertical 15-degree constraint could also be introduced. Displays with at least 30 horizontal and vertical degrees of central high detail did not differ from an undegraded display. This indicates that designers of head-tracked interactive graphics need only maintain high levels of detail within a 30 degrees x 30 degrees central display area. In CAVE systems that may have a 270 degrees x 270 degrees FOV, this high detail area may occupy only 1.25 percent of the display area. In our continuing research, we are attempting to isolate an appropriate LOD for the degraded periphery.

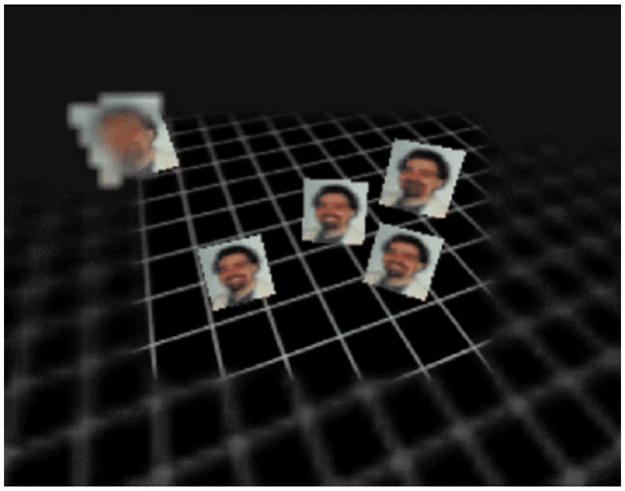
FIGURE 1 View with a degraded display with a 40 degrees x 30 degrees central detail area. Subjects located the face with its mouth closed.

	10^o	20^o	30^o	40^o
10^o	4.147	4.150	4.058	3.538
20^o	3.721	3.552	3.398	3.448
30^o	3.601	3.451	2.876	3.147
40^o	3.808	3.105	3.281	3.061

TABLE 1
Mean search times in seconds for differently sized high-detail areas. Rows have the same horizontal extent, columns the same vertical extent. Mean search time for the undegraded 75 degrees x 58 degrees display was 2.85 seconds.

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Virtual Backdrops

Large and complex 3D models are required for architectural walk-throughs, flight simulators, and other applications of virtual environments. It is not possible to render all the geometry of these arbitrarily complex scenes at highly interactive rates, even with high-end computer graphics systems. This has led to extensive work in 3D model simplification methods.

We have been investigating dynamically replacing portions of 3D models with textures. This approach is similar to the old stage-trick of draping cloth backgrounds in order to generate the illusion of presence in a scene too complex to actually construct on stage. A texture (or backdrop) once created, can be rendered in time independent of the geometric complexity it represents. Consequently, significant frame rate increases can be achieved at the expense of memory and image quality. Properly handling these last two tradeoffs is crucial to a successful texture-based simplification algorithm.

Previous work has approached these tradeoffs by requiring a large number of texture samples in order to guarantee a maximum per-pixel error. While for some ranges of applications and models this provides a good solution, we have found that in our domain (architectural models, CAD models, and other indoor models) the simplification benefits are overwhelmed by the large number of textures that need to be precomputed or dynamically rendered.

A successful algorithm for dynamically replacing geometry with textures must provide solutions for the following three major problems:

1 Geometric Continuity: a texture contains an image of a portion of the model. The image is only perspectively correct when viewed from the same viewpoint used to create it. Thus, when the eye moves from the texture's original viewpoint, the geometry adjacent to the texture appears discontinuous with the image of the texture. Previous systems addressed this issue by either allowing a small discontinuity or restricting the texture locations to fully contain entire "objects."

2 Temporal Continuity: when the eye approaches a texture (or recedes far enough from a subset of the model), we need to switch the texture to geometry (or vice versa). During this motion, the viewpoint will not be at the same position from where the texture was created. This sudden transition will cause an effect commonly known as "popping."

3 Automatic Placement: the texture-based simplification system will need to choose where in the model to place textures in order to achieve the desired speedup and image quality.

Solutions have been proposed[1] for the geometric and temporal continuity problems (see Figure 1). We have been focusing on the automatic placement aspect. For our purposes, we can loosely classify indoor models into two categories:

1 Single-Room Models: models where most of the geometric complexity is visible from the typical viewing locations (few large occluders are present).

2 Multiple-Room Models: this category fits well with the cells and portals framework used by some visibility culling algorithms.

The special characteristics of the cells and portals framework were used to solve the automatic placement problem for cell-partitioned models (see Figure 2)[2]. We are currently exploring solutions for the texture placement problem in general 3D models.

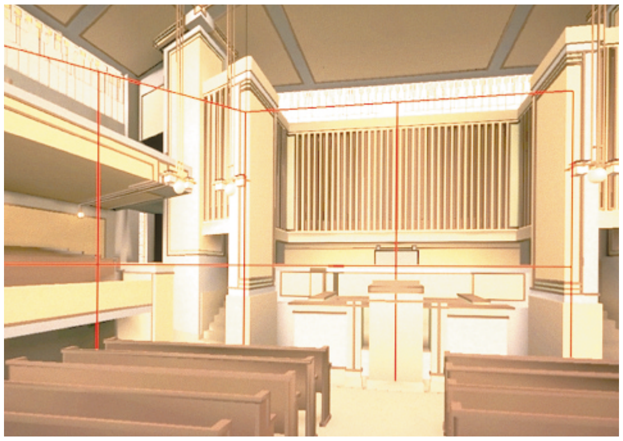
FIGURE 1 Geometric Continuity Two textures outlined in red (adjacent geometry warped to match the textures)

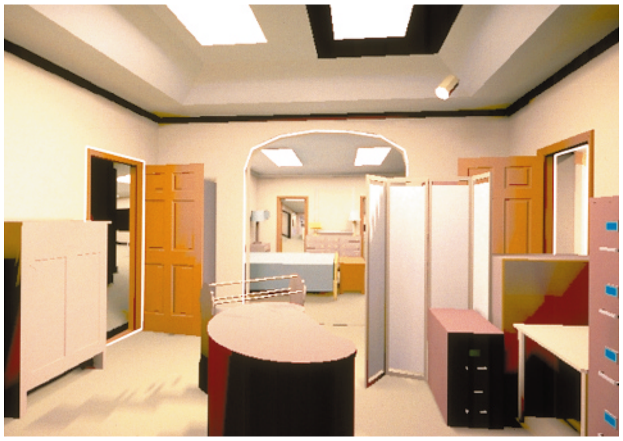
FIGURE 2 Portal Textures The portals have been replaced with textures

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The use of lines of contour to depict 3D surfaces has a centuries-old tradition in printmaking, reaching its peak in the technical virtuosity of the Italian Renaissance engravers (see Kemp[1]). Their techniques, being essentially manual, relied upon skill, experience, and intuition acquired through long years of apprenticeship. Since that period, several painters have also employed contouring, but with the addition of colour.[2,3] Current understanding of our perceptual mechanisms confirms that one of the most immediate and important depth cues is object surface contour information.[4]

Dissatisfied with existing methods of rendering 2D images of (projected) 3D computer models, some researchers have lately turned their attention to non-photorealistic (NPR) rendering techniques, in which the drawn line or mark replaces the pixel as the basic unit of depiction. Winkenbach and Salesin[5], for example, have developed sophisticated programs to generate monochromatic line-hatchings, modulated in weight and density, for rendering surfaces in a way that conveys spatial as well as tonal information. (A comprehensive review of NPR to 1995 is given by Schofield and Lansdown.[6])

To overcome the limitations of monochromatic contouring, the author has devised a specialized form of colour contouring using a restricted colour palette to facilitate transcription to fine art printmaking media, especially screenprinting. This method arises from his earlier work with techniques of optical colour mixing using dots and intersticed lines, and offers the creative artist new opportunities for control and intervention in making this type of "divisionistic" image.

An original 3D composition comprising an arcaded structure from a Sassetta painting housing a range of curved solids (including a greatly enlarged eye from Michelangelo's David) was used as the testbed for successive versions of the contouring procedure, designed and implemented by the author in AutoLISP (the LISP language extension to AutoCAD). Under user control, the procedure traces sets of lines across selected surface meshes. The contour lines are formed by contiguous "platelets" of cyan, magenta, yellow, or black whose relative widths, overlaid combinations, and spacing are computed to give the required balance of colour.

On each triangular facet, three bands of contours are constructed, one band for each of the (user-specified) HSV parameters: hue, saturation, and tone or value. The method depends upon the phenomenon of optical colour mixing, and since the colour of each surface region is set interactively, the colour composition of the resulting image is entirely under the (intuitive) control of the artist/user, who may use a conventional rendering of the same scene and/or direct observation as reference. Contour direction is generally chosen to be sympathetic to the underlying object structure, although line direction and width can also be used to introduce textural variation and contrast. In this way occlusion effects, for example, can be accentuated.

Each contour line thus produced is assigned by colour to one of four AutoCAD layers, facilitating the production of separations for imagesetting or plotting onto polyester drafting film at any size. Using a drafting pen to add or erase as required, the artist enjoys an additional level of control, which again differentiates this method from conventional photomechanical processes. Separations are transferred to screens using normal photostencil methods, ready for (manual) editioning using high quality process colours. A detail of a completed four-colour screenprint is shown.

Initial results demonstrate how this kind of contoured 2D representation conveys considerably more spatial information than a conventional colour rendering. The viewer also experiences various optical phenomena depending on proximity to the image surface.

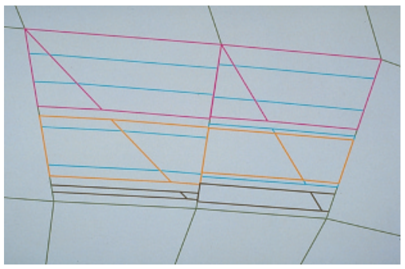
FIGURE 1 Surface contour lines built from coloured "platelets"

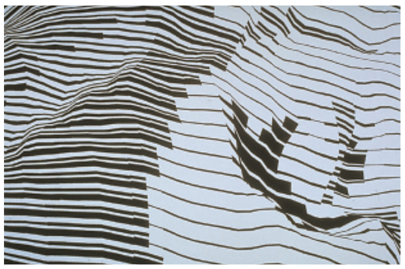
FIGURE 2 Plotted cyan separation (detail)

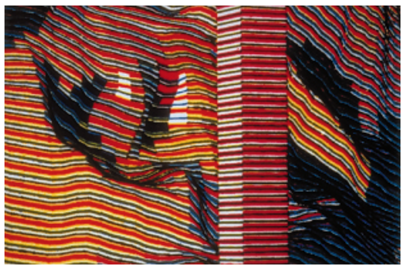
FIGURE 3 Four-colour screenprint (detail)

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Integrating Digital Media and Autographic Fine Art Printmaking

As a painter-printmaker – a maker of art objects – my concern is integrating digital technologies with traditional processes such that formal and material concerns are not denied the fine art printmaker who uses digital processes. Some recent and current work includes the following objectives:

1 Independence of printed colour from the computer and the constraints of both the CMYK and standard custom colour sets.

2 Using overprinted layers of inks, not dots in close proximity, allowing real physical planes of colours to create complex visual spaces. Wresting colour creation and manipulation from the "device," back to the printmaker, to be modified as the process develops in response to earlier stages.

3 Independence from the limitations imposed by the halftone dot.

4 Finding a durable image creation process that utilizes the computer's capacity for exploration and manipulation but which is susceptible to intervention by the hand of the artist at any point during the process, not simply during the process of compositing in non-real space.

5 Making a cheap, accessible method for artists and students, so they can work at manageable resolutions without high-end equipment.

6 Development of a process into which drawing (and / or other non-digital manipulation) can be re-integrated at any point without the work suffering a sense of intrusion.

Images to be transferred to photolitho plate are created from grayscale scans. Using alpha channels as selections and transparency masks, the image is made across a number of visual layers. Actual layers could be used in Photoshop 3.x and later to composite the entire image before committing parts to their destination channels, but this is not essential. Alpha channels can give an indication of the overprinted inks, if not their precise mixing requirements. Colours may be assigned to channels to simulate the eventual print, but, on RGB monitors, this is restricted and inaccurate. With suitable gamma settings and understanding of printmaking inks, this can be minimized. Outputting split channels using diffusion dither allows image scaling without succumbing to screen angles and rulings.

Colours may be mixed by the printmaker, using traditional inks, tested directly on the papers, and, significantly, may be modified in response to previous plates as the work proceeds. The printing of such works is thus time-based, the artist being free to leave the fixing of colours to the last conceivable moment. Given other processes, such as direct work on the plate, a great degree of flexibility and adaptation after output from the computer is still possible. The image can be almost infinitely variable and may be overworked right up until the artist decides to fix the process. These are all attributes of an autographic process.

Source scans are grayscale, as they need only work on alpha channels. The only expensive equipment used in my prints was a Novajet large format inkjet printer, but all other equipment would certainly be available in any art school's print workshops. The most recent pieces use five channels per image. Work is continuing on prints using up to 12, with direct physical intervention and / or drawing re-introduced at the stage of plate-making.

The images are details from offset litho prints on Fabriano Artistico Ivory 200gsm, using five plates rolled in hand-mixed printmaking inks.

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Why colored pencil drawings?

In general, traditional synthetic images tend to cause eye fatigue for the viewer, since all of the points are in focus, which gives the impression that they were painted uniformly. As a solution to this problem from an artistic point of view, "colored pencil drawings" (CPDs) should attract more attention also from the CG community, because of their intrinsic ability to produce a gentle appearance for human eyes. One of the salient features of CPDs is that high-level depiction and controllability can be achieved by a proper choice of papers and pencil holding, sharpening, and movement.[1] Therefore, it is becoming commonly acknowledged that CPD has become an artform in its own right, and is considered to be a challenging theme of advanced CG modeling in the area of digital painting. CPDs could be emulated on screen by combining various functions provided by existing commercially-available digital paint systems. At present, however, there exists no system that directly supports the CPD techniques.

Modeling Paper Microstructure

As the appearance of CPDs stems primarily from the "texture" of papers, faithful modeling of the papers' 3D microstructure is crucial. Papers are generally composed of multiple layers of globally-oriented, but locally random sparse fiber nets, whose spaces are filled partially with talc for surface smoothness. A fiber net is modeled geometrically by instantiating defaced, napped, and constricted cylinders. On the other hand, a constrained blobby approach is taken to model the distribution of talc. Such a microstructure of papers is then 3D-scan converted into a thin volume model, whose field value indicates the density of a paper component or pigment. The resulting paper volume is volumetrically ray traced to simulate paper semitransparency and subsurface scattering. A volume visualization and graphics software system called VolVis ver. 2.0[2] is used for the purpose of test rendering.

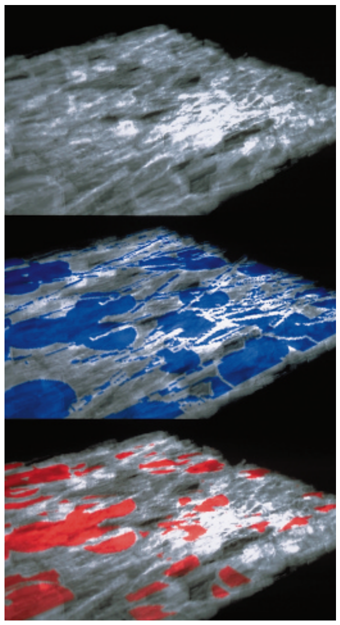
Modeling Pigment Distribution

Pigment distribution is modeled based on the paper microstructure model described above. Many chinks left in the layered structure of papers are the most dominant factor in governing how pigment is distributed. The offset distance accessibility (ODA)[3] is calculated to approximately locate the chinks in the paper volume, where fractions of pigment can be distributed, by accounting for the pencil point's shape, pressure, and stroke as well as pigment fragility. Here again, the geometry of pigment peeled off from a pencil and deposited into the paper volume is modeled by the collision-detected blobby model, and then 3D-scan converted into the paper volume.

Figure 1 shows three perspective views of the microstructure of a square piece of paper: drawing without pigment (top); virtual effect of graphitizer (middle); and drawing with a single color of pigment (bottom) The graphitizer is a well-known tool commonly used in paper science for evaluating the texture of papers by press coating a special kind of pigment uniformly on pieces of paper. It can be seen also from the middle and bottom images respectively that the virtual graphitizer reveals the fiber nets more clearly, while in the regular drawing, most of the pigment is accumulated in the concave regions lying on the fore side of fibers with locally maximal height with respect to the pencil stroke direction. Furthermore, in both cases, it is revealed that pigment is more likely to be attached onto surface areas covered with talc, because these relatively flat areas possess lower ODA values, and talc has a relatively high pigment-adsorption rate. Such pigment distribution patterns qualitatively coincide with physically observed ones. An example of a macroscopic view of the resultant CPD is shown in Figure 2.

Modeling Pigment Redistribution with Water

Currently, our interest is drawn also to yet another principal CPD operation: redistributing pigment with water. Using water-soluble colored pencils, spreading and blending of pigment with water can yield a sense of smooth color fading and blending, and hence play a key role in depicting objects in a precise and natural manner.



A
Drawing: without pigment

B
Graphitizer

C
Drawing: with single color of pigment

FIGURE 1 Microscopic images of paper microstructure.

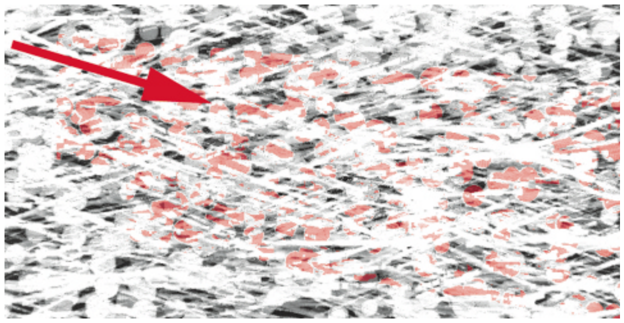


FIGURE 2 Macroscopic image of paper microstructure. Arrow depicts the primary direction of pencil stroke.

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Line drawing provides an excellent medium for communicating ideas. Unfortunately, because line density determines tone and line curvature conveys form, computing lines is simultaneously a two- and three-dimensional problem, making algorithms to create convincing computer-generated drawings difficult to design.

As in previous approaches, we simplify this problem by converting the three-dimensional model into two-dimensional data before calculating hatching. The resulting data include several vector fields generated by projecting the surface hatching direction of each object onto the image plane. In our system, the vector field streamlines are then calculated and converted into hatching by simply distorting them in a sketchy fashion.

Figure 1 depicts the complete process of generating a streamline drawing. Four types of two-dimensional data are extracted from the model. Some or all of the visible lines are sketchily distorted and added to the image.

Several vector fields are calculated for varying surface hatching directions, one or more of which are applied to each object (Figures 2 & 3). A global illumination image is referenced as a tone map to control the hatching density. Any tones captured in the tone map, including soft shadows and specular effects, are reproduced in the drawing. An ID map facilitates assigning custom hatching attributes to objects.

A simple one-pass algorithm was developed to calculate streamline direction and density. The algorithm employs an image mask to track the completed portions of the drawing. When all of the tonal areas are hatched, the algorithm terminates.

Because this technique avoids calculating hatching in three dimensions, it is not plagued by the robustness issues common to three-dimensional modelers and non-photorealistic rendering systems.

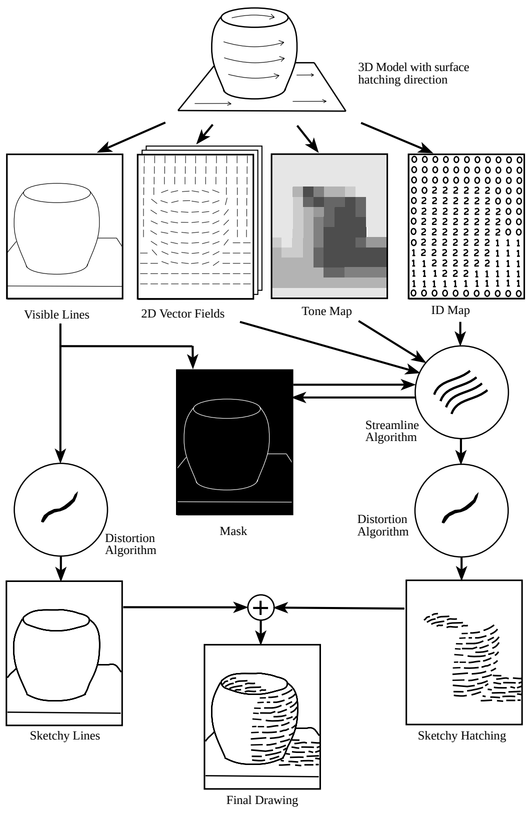

FIGURE 1 Process for creating a streamline drawing from a model.

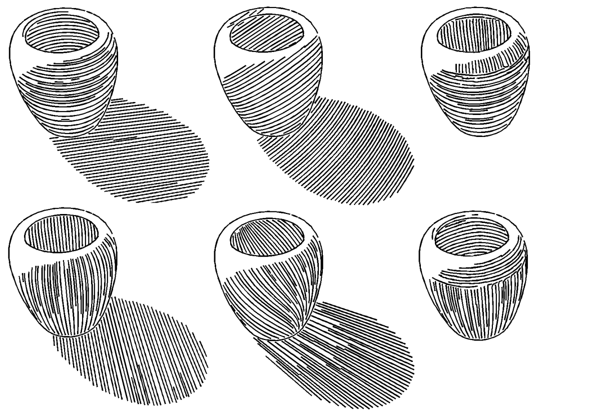

FIGURE 2 Various hatching orientations. They are, from left to right, (1) oriented with respect to the major axis, (2) oriented with respect to the light source, and (3) oriented along the principal curvature directions. Note that the surface shadow is not depicted for the principle curvature directions because principle curvature is not defined for flat surfaces.

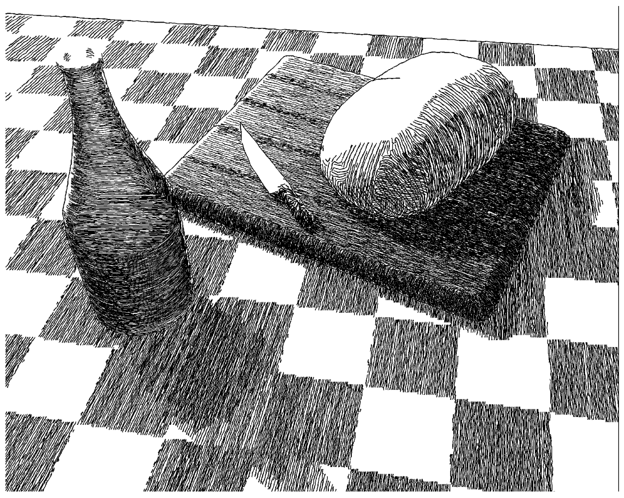

FIGURE 3 Streamline drawing depicting the shadows, texture mapping, and transparency captured from the ray-traced tone map. The only texture map in the scene is the table cloth. The wood texture of the cutting board is suggested by using the streamlines oriented along the length of the wood and applying the appropriate waviness parameters when converting to hatching.

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Realistic image generation in computer graphics is greatly facilitated by either using texture mapping of real images or writing shaders, programs that procedurally describe textures. Using texture mapping (e.g. scanning a photograph) is rarely adequate, as the photograph may capture information about the lighting direction and may cause aliasing problems. Another problem with a scanned texture image is that it has a finite size and resolution, and tiling the texture across a surface may cause unnatural periodicity. Writing shaders might seem to be a powerful approach, but in practice it is often very difficult to achieve the desired look.

This sketch presents a system that generates procedural textures or shaders using genetic algorithm techniques. The system operates in both artist-directed and automatic texture matching modes. In interactive artist directed mode, aesthetic evaluation and selection are controlled by the user. In automatic mode, the system compares rendered images of generated shaders to images of target textures, using texture matching techniques.

Representation

In our system, a shader is a hierarchical directed acylic graph of nodes, where each node represents a predefined function or texture.

Initial Selection

An initial population of shaders is obtained by searching through a predefined library of shaders, testing these images from the shaders against the target texture and scoring the images. The system selects the initial population from those receiving the best scores. Selection in the interactive mode is similar but based on the users' aesthetic judgment.

Breeding and Ongoing Evaluation

"Parent" shaders are selected and bred to create new children for the ongoing population. When breeding two hierarchies of shaders, the breeding procedure selects a random node in each hierarchy and swaps the subtrees under these nodes. The system evaluates images of generated shaders in automatic mode, while in interactive mode users assign scores to images of shaders based on their aesthetic judgment.

The new population of shaders is determined based on this fitness evaluation. A genetic algorithm procedure is used to determine which shaders will survive and reproduce and which will die, based on this fitness. Shaders are shuffled, and each pair of shaders is selected to breed. After a new population is generated, using the interactive mode users repeat previous steps to generate a new population and so on until they are satisfied with the result. In the automatic mode, the generation continues until a generated shader is sufficiently close to the target texture or a maximum number of generations has been reached.

Mutation

Random mutation is used to introduce diversity into the population. After breeding, the hierarchy is traversed, leaf node input variables are randomly selected, and depending on the mutation rate, changed to other valid values.

User Interface and Operation

The figure shows the system as it appears to the user and a collection of generated shaders. The top row of the interface contains generation parameters, while the middle three rows contain rendered images of the current population of shaders. On the bottom row are images of temporarily stored shaders.

The interactive mode has been used to generate a variety of complex shaders including both surface and displacement shaders, such as those shown in the figure. When running in interactive mode, the user selects two parents for breeding, and the top two images on the interface show the currently selected parents. On the other hand, in automatic mode, the top two images show the target texture, and the middle three rows show images of shaders that are attempts to match the target shader. In this case, parent selection and breeding takes place automatically.

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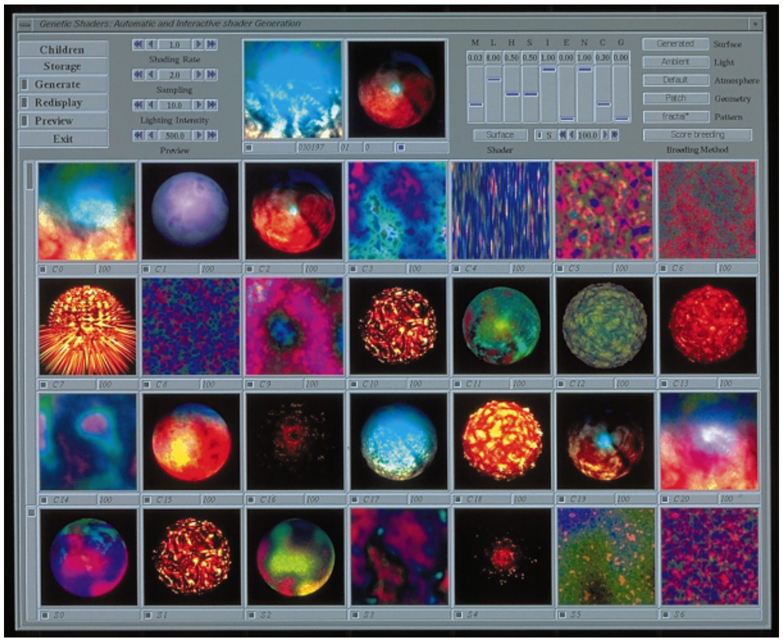


While procedural shaders provide an interface for evaluating the shader function at a single point, it is not easily possible to obtain an average value of the shader together with accurate error bounds over a finite area. Yet the ability to compute such error bounds is crucial for several interesting applications, most notably hierarchical area sampling for global illumination using a finite element approach and for the generation of textures used in interactive computer graphics.

Using affine arithmetic (AA) for evaluating the shader over a finite area yields tight, conservative error bounds for the shader function. Compilers can automatically generate code for utilizing AA from within shaders implemented in a dedicated language, such as the RenderMan shading language.

Affine Arithmetic

Affine arithmetic (AA), first introduced in J. L. D. Comba and J. Stolfi, is an improvement of interval arithmetic. Like interval arithmetic, AA can be used to manipulate imprecise values and to evaluate functions over intervals. In addition to keeping track of the interval, AA also maintains dependencies between sources of error during the computation, and thus manages to generate tighter error bounds. Prior studies[1,2] show that the bounds generated by AA are typically significantly tighter, even for much simpler functions than procedural shaders. The more complicated functions get, and the more dependencies between the sources of error exist, the bigger the advantage of AA.

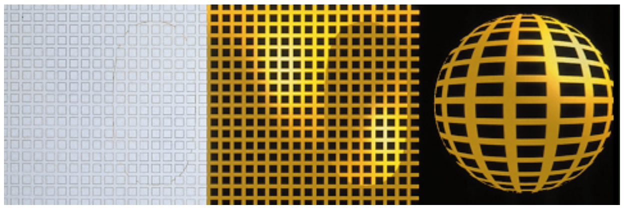
Application to Procedural Shaders

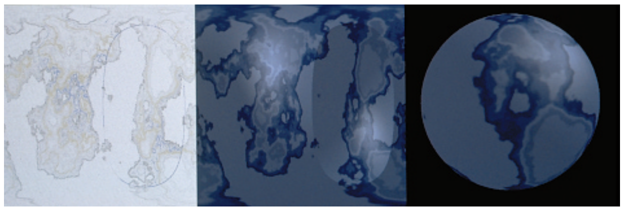
In order to use AA for obtaining conservative error bounds for area samples of procedural shaders, the shader code simply has to be evaluated using AA instead of normal floating point arithmetic. For this purpose, the complete feature set of the shading language (in our case the RenderMan shading language) has to be implemented in AA. In addition to the functionality found in normal mathematical libraries, shading languages offer a series of domain specific features, most importantly control structures, splines, noise, and derivatives of arbitrary expressions. All these features can be implemented in AA,[3] and yield tight, conservative error bounds when executed.

Results and Future Work

We have implemented a hierarchical subdivision scheme for procedural RenderMan shaders using AA. Given a tolerance value, the algorithm recursively subdivides the parameter domain of the shader, until the area samples for all subdivision cells are within the tolerance, or a maximum recursion level is reached. Experiments show that, using AA, conservative error bounds for an area sample can be computed in roughly the time it takes to compute 7-10 point samples.

Using this subdivision scheme, it is possible to adaptively precompute textures from shaders with an unknown amount of detail information. These textures can then be used, for example in an OpenGL renderer. We are currently working on integrating the subdivision scheme into our rendering system in order to improve finite-element-based global illumination.


Screen shader sampled using AA, together with color coded error bounds.


Blue marble shader.

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Open Inventor is an object-oriented 3D graphics toolkit. Because Open Inventor is written in C++, typical user code development consists of a program / compile / debug iteration cycle. In this sketch, we introduce InvenTcl, an interpretive version of Open Inventor that uses Tcl, (Tool Command Language)[4] and its object oriented extension (incr Tcl)[3] for the conversion. The advantages of InvenTcl include: scriptable and direct manipulation of objects in an Open Inventor scene, easy prototyping of 3D graphics and animation, and low-bandwidth communication of 3D scenes and animations (using scripts).

There are three command types provided by InvenTcl, which correspond to the main functions available in Open Inventor: object creation commands, object interaction commands, and animation commands. For object creation, there are command names for instantiating objects. These commands have the same names as the class names in Open Inventor. For interaction, InvenTcl has binding mechanisms to allow Tcl procedures to be called when objects in the 3D scene are selected. For animation commands, InvenTcl provides access to animation functions found in Open Inventor (i.e. engines and sensors). To illustrate creation commands with an example, the following code shows how a simple scene graph is created interpretively:

```
SoSeparator >root>separator1
SoMaterial >root>separator1>material1
SoCube > >root>separator1>myCube
```

This series of commands adds a SoSeparator node separator[1] to the root node, a SoMaterial node to separator[1], and a “SoCube” node to separator.[1] Notice that we use the ‘>’ notation to specify parent / child relationships. This is consistent with how the most common toolkit used with Tcl, Tk,[4] works.

There are four main technical problems to overcome to make Open Inventor interpretive:

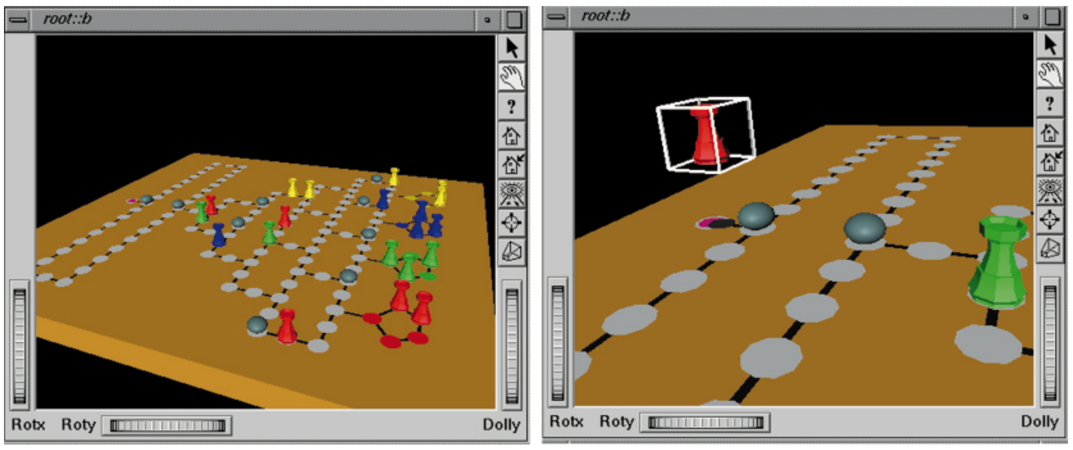
1 Accessing Open Inventor’s object functions and the object’s public methods and variables from the Tcl interpreter.

2 Open Inventor event management within Tcl / Tk.

3 Binding Open Inventor objects to Tcl procedures and interaction modes.

4 Synchronization of Open Inventor and Tcl processing.

A utility called Itcl++[2] is used to convert Open Inventor objects’ methods into [incr Tcl] classes. Event management is done using a handler callback mechanism available in Tcl. Implementation of event management within Tcl does cause some performance penalty. Object binding is accomplished using callback mechanisms and Open Inventor selection utilities. Object binding is an important feature of InvenTcl. By using bindings, it is possible for Tcl procedures to be called as a result of interaction with Open Inventor objects. Not only does this allow for fast prototyping of direct manipulation interfaces with 3D objects, but it also allows designers to easily create novel 3D interfaces for controlling other systems using the “glue-language” properties of Tcl. Synchronization is performed using a semaphore. Implementation for accessing Inventor objects’ public variables has not been done in a generalized fashion yet. Further, making Open Inventor interpretive has come as an offshoot of another project;[1] hence, we still have some commands that are tailored to our application.



These scenes show some 3D graphics created and being manipulated with InvenTcl

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The Contour Spectrum

In this sketch, we introduce the contour spectrum[1], a user interface component for improving user interaction and quantification in visualization of isocontours.[2] The contour spectrum is a signature consisting of a variety of scalar data and contour attributes computed over the range of function values. Each attribute is presented as a 1D plot, giving the user a quantitative measure of the function to assist in selecting relevant isovalues for informative visualization. For time-varying data, properties can be computed over time and displayed in 2D interface, giving the user a global overview of the time-varying function and allowing interaction in both isovalue and time.

Exploratory visualization is an iterative process, with many visualization parameters to control. Without effective user-interface tools, the user must rely on a-priori knowledge about the data of interest in choosing effective parameters. Informative and effective visualizations often mask the amount of time and effort required to create such a successful visualization. Recent approaches in user interfaces for controlling visualization parameters have aspired to provide the user with the tools to more rapidly choose parameters that result in an effective visualization.

In isocontouring, a common technique is to select a set of isovalues that are evenly spaced throughout the range of the function. It is clear that such a technique is prone to miss features that may be considered important. The ability to manipulate the isovalue in real time allows the user to browse the function for interesting features. However, in the absence of additional guidance, users may only use their prior knowledge of what they expect to see in the data and query for isocontours through a trial-and-error process.

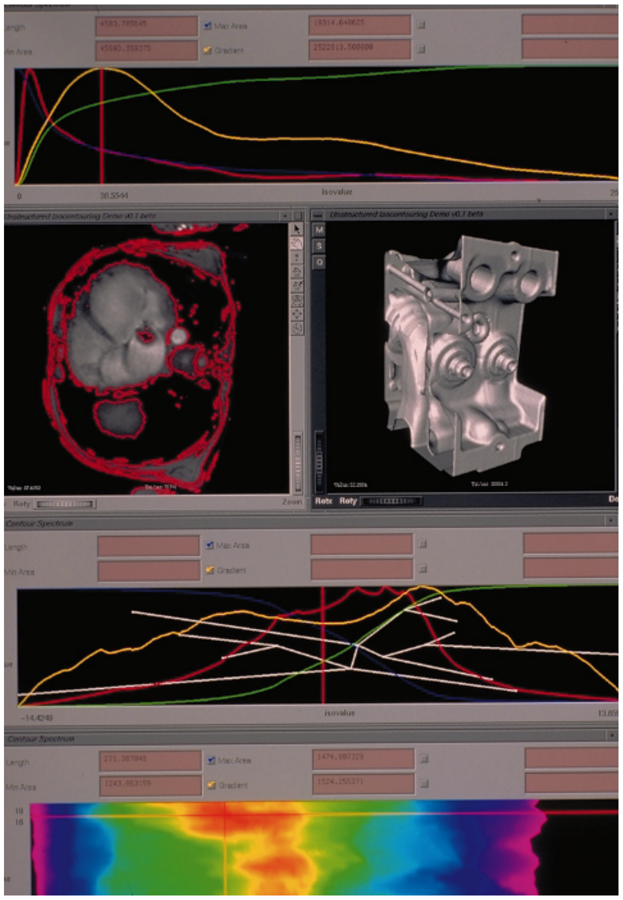
Each attribute of the contour spectrum – such as surface area, volume, and gradient integral – is presented as a 1D plot providing the user a quantitative measure of the corresponding function to assist in selection of relevant isovalues for informative visualization. The computation of each property can be performed exactly, as it corresponds to a spline-shaped function in each cell of the mesh where scalar field is evaluated. The sum over all cells may be expressed as a single spline function for each scalar field attribute. For time-varying data, properties can be computed over time and displayed in a 2D interface, giving the user an overview of the time-varying function, and allowing interaction in both isovalue and time step.

The left of the figure shows a MRI scan of a heart. The maximum of the gradient (yellow function plot of the spectrum on top) corresponds to the isocontour (red contour) bounding the relevant portion of the data.

The right of the figure shows the scalar field obtained from a CT scan of an engine. The main component of the engine can be easily determined by selecting the maximum of the gradient integral. Of course, this remains simply an aid in the interactive querying stage of the dataset, as the concept of "interesting" feature of a scalar field remains highly dependent on the domain of the dataset we are dealing with.

To enhance the understanding of the scalar field structure, a contour tree[3] can be superimposed on the spectrum as displayed in the middle spectrum of the figure. For each edge in the contour tree, there is a connected component of an isocontour in the scalar field. If, while varying the isovalue, two contour components merge together, we have in the contour tree two edges that join. Similarly, if an isocontour splits in two or more components, we will have in the contour tree an edge that splits in two or more edges. Moreover, the comparison between the contour tree and the spectrum may aid in the selection of "interesting" contours. Typically, an isovalue that has a contour tree with many edges but a relatively small overall contour length/area corresponds to a noisy region. Symmetrically, a single component of large length/area corresponds to a well-defined feature of the scalar field.

For time-varying data, we selectively display one function at a time by pseudocoloring of the function values over a 2D grid, as shown in the bottom spectrum of the figure. The value of the selected property is mapped to a colormap, while the vertical direction of the 2D spectrum represents the time evolution of the dataset.



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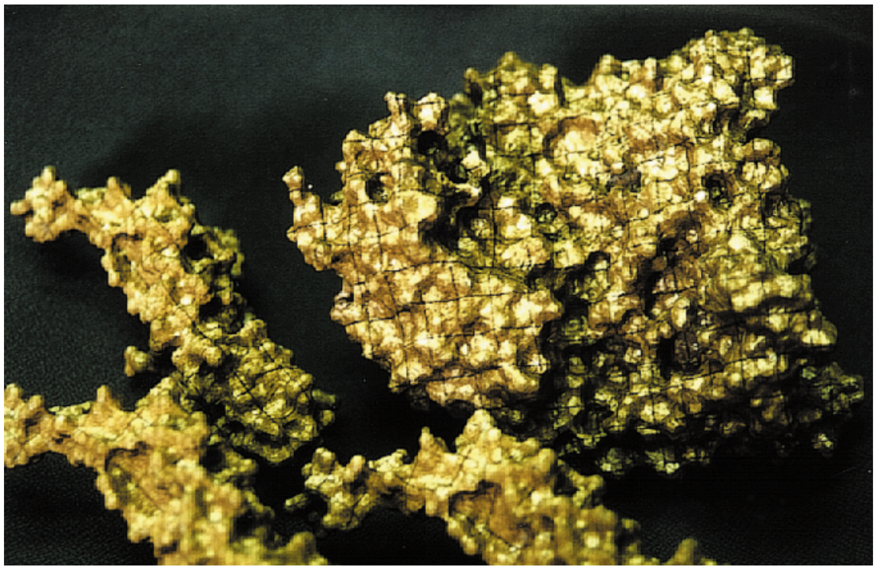
The University of California at San Diego/San Diego Supercomputer Center TeleManufacturing Facility (TMF) project has integrated a solid freeform fabrication (SFF) capability with the Internet to make production of prototype parts easy and convenient. As a result, manufacturing "amateurs," such as biologists, chemists, ecologists, geologists, and mathematicians are able to produce 3D solid models to better visualize their work.

The TMF uses a Laminated Object Manufacturing (LOM) machine from Helisys, Inc. In the LOM process, the 3D object is made from layers of paper or plastic. New paper or plastic is spooled into place and laminated to the layers beneath it with a hot roller. A laser cuts the part outlines at this level. The outlines are essentially the contour lines for this height on the 3D object. The process continues until the 3D part is completed.

The goal of this project is to make the use of physical model-making an everyday aspect of scientific and engineering visualization. Fabrication methods for visualization must not require any manufacturing knowledge, or they will not be used. The use of this type of visualization display must require no previous manufacturing experience in order to be successful.

To make access to this technology familiar to all users, the TMF project is using the World Wide Web as an interface. Users can submit their geometry files from their favorite browser, have those files automatically checked for geometric and topological consistency, have a corrected STL file returned, or have the file queued for fabrication. When the part is being fabricated, the Web page can also be used to get feedback on the manufacturing process, including video images from cameras surrounding the machine.

This sketch discusses how the hardware and software have been integrated with the WWW, and the computational geometry aspects of the project that allow many geometric and topological flaws to be automatically corrected. Finally, we show some examples of the visualizations with which the project has been involved and talk about the perceptual differences between having a real model in your hands versus having a virtual model on a graphics screen. The presentation includes real solid models so that attendees can hold them and experience their perceptual advantages first-hand.



Light Harvesting I Proteins and Photosynthetic Reaction Center.

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Hardware-Assisted Volume Rendering for Oil and Gas Exploration

The search for oil in the earth's subsurface begins with acquisition of terabytes of data, the result of measuring the return of sound waves sent into the earth's crust. These data are processed to form 3D volumes of seismic data, known in the industry as surveys. Very small surveys are in the 60Mbyte range, and typical surveys now approach the 1Gbyte range or higher.

Seismic data are relatively noisy, and determining oil reserves requires the ability to distinguish between subtle features from the noisy data. Because of numerous classification difficulties, interpreters use various color maps and opacity settings, often with very sharp transitions, combined with spatial and color space animation, to highlight different attributes and determine the extent of a given surface. The interpreter will often "roll" the color map, looking for breaks in the data, or interactively change the alpha transfer function to filter noise and determine edges and fades in the surfaces to interpret the connectivity of a given rock boundary.

Fast post-interpolation color lookups are needed to ensure that the application of transfer functions does not become the bottleneck in achieving the desired frame rate. In order to maintain data integrity, color transfer functions cannot be applied directly to the voxel data. They can be used only after all interpolation and compositing has been completed for the rendered scene. If the transfer functions are applied to the voxels using pre-interpolation color lookups, then interpolation essentially happens in color space. Color space interpolation tends to blur the already poorly defined transitions between rock layers. In addition, post-interpolation lookups are necessary to reduce the computational complexity of rendering large data volumes.

Rendering a survey must take into consideration the other data types that an interpreter uses when classifying an unknown survey. Typical data types are either measured geophysical data (well bores, well logs, etc.) or interpreted polygonal surfaces selected from the data (faults, horizons, event markers, etc.). These data items are embedded in the survey as either opaque or partially transparent objects. The interpreter uses multiple data types to tie the interpretations back to the original data and to ensure that the interpretation is valid in all cases. Proper 3D interpolation of data for both volumetric rendering and textured polygonal surfaces is critical to the interpreter.

One approach that can be used to both volume render a survey and map survey data onto embedded surfaces is to use 3D textures. Given the natural mapping of 3D textures to volumetric data, hardware 3D texturing for volume rendering is a natural progression from massively parallel software volume renderers. Volume rendering a seismic survey using 3D texturing starts with creating a 3D texture directly from the survey volume data. The rendering process traverses texture space back-to-front relative to the eye point and intersects the texture with polygon slices that are orthogonal to the eye. Aliasing artifacts are controlled by adjusting the number of slice planes that cut through texture space. Embedded textured opaque geometries can be rendered using a two-pass algorithm with the same 3D texture used for both passes. Rendering transparent geometries can be handled by only rendering the portion of each surface that intersects each pair of polygonal slices during the volume rendering process. When alpha channel transfer functions are used for volume rendering, and surfaces are rendered within the same volume, interpreters are able to, for the first time, view and correlate their interpretations with respect to actual data in 3D.

Over the past two years commercial 3D oil and gas exploration packages have become available for use by the exploration geophysicist. These packages, using hardware 3D texturing and post-interpolation texture lookup tables, have enabled a paradigm shift away from 2D slice-by-slice interpretation to fully 3D interactive interpretation.

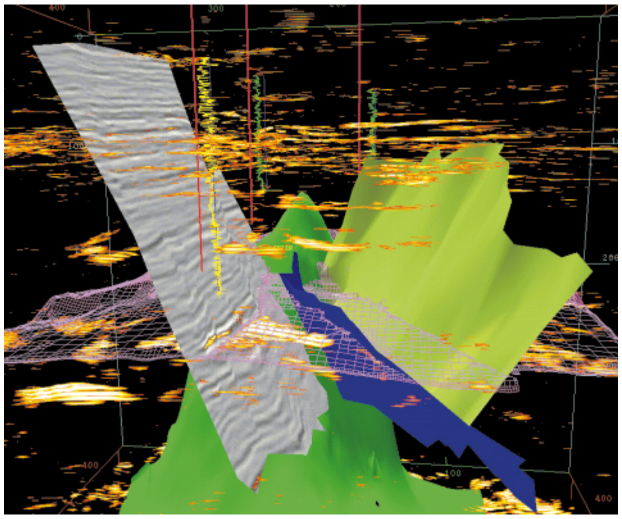
Image courtesy of Landmark Graphics

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Many scientific experiments result in data that are difficult to visualize using traditional techniques. A typical laboratory experiment, for example, will set up several experimental systems in each of two or more groups (for example, a “control” group and various “treatment” groups). The investigator will then measure various parameters for each system over time (sometimes dozens to hundreds of parameters). The investigator then tries to discern the contrast in evolution of the groups: what is it that is different between the control and treatment groups?

Field monitoring of polluted and unpolluted sites results in the same kinds of data, and the same difficulties in visualization. Plotting multiple lines on a single 2D plot quickly gets confusing, and the dynamic interactions are not readily visible. Graphical 3D scientific visualization can solve some of these problems, by taking advantage of the human visual system to enable qualitative inferences about data that would otherwise be invisible.

We have developed a 3D plotting technique, called “WormPlots,” for visualizing these kinds of data. To see how they work, consider first a 2D plot of, say, 24 samples, six from each of four groups, on two axes (measured parameters). We summarize the response of each treatment group (six points) with a 2D shape (for example, a circle centered at their mean and with radius proportional to their variance). This 2D picture represents the groups at a single moment in time. To visualize the evolving dynamics of the systems, we connect these circular time slices with conic sections, giving us “spacetime worms” that can be displayed graphically.

When colorized and displayed on an interactive terminal, the display looks like Figure 1. This figure shows the data from a controlled laboratory toxicology experiment on aquatic microcosms. Over a period of two months, the aquatic populations of some 20 species in 24 microcosms (six microcosms in each of four treatment groups) were sampled on 16 dates. In the figure, time moves out of the page, toward the viewer. The axis pointing to the left shows an algae species (Scenedesmus) combined with a detritivore species (Ostracod), while the vertical axis shows an algae consumer (Daphnia). The four doses of the toxin (low to high) are shown by the coloring of the worms: blue, green, yellow, and red.

Early in the experiment, you can see a classic “predator-prey” situation between Daphnia and Scenedesmus. In the green worm, the Daphnia consume all the algae and their population grows, while Scenedesmus does not. In the red worm, the Daphnia have been depleted by the toxin, and the algae population grows first, with the Daphnia population’s growth delayed. Later on, the Daphnia start to recover, and their upswing is matched by a simultaneous downswing in the population of algae. The typical corkscrew shape of the worm illustrates this interaction, and the strength of the effect, from low dose to high dose, is readily apparent in the four worms. By the end of the experiment, both the Daphnia and the algae have diminished to small numbers, and the primary effects of the toxin in the system have disappeared.

Toward the bottom of the figure, however, secondary effects of the toxin can be seen. Ostracods, a species that eats detritus and which is present only in low numbers throughout the early part of the experiment, have now begun to increase. Further, their increase is directly related to the strength of the toxic dose. Evidently, the differing population dynamics of the systems during the early weeks of the experiment have conditioned the detritus (food) for the Ostracods, with the most favorable situation being found in the lowest-dosed systems. This secondary effect in microcosms had not been noticed in previous experiments.

We believe that our visualization prototype solves some particularly thorny problems in visualizing multivariate time series from grouped data and can play an important part in laboratory experiments and field monitoring data analysis.

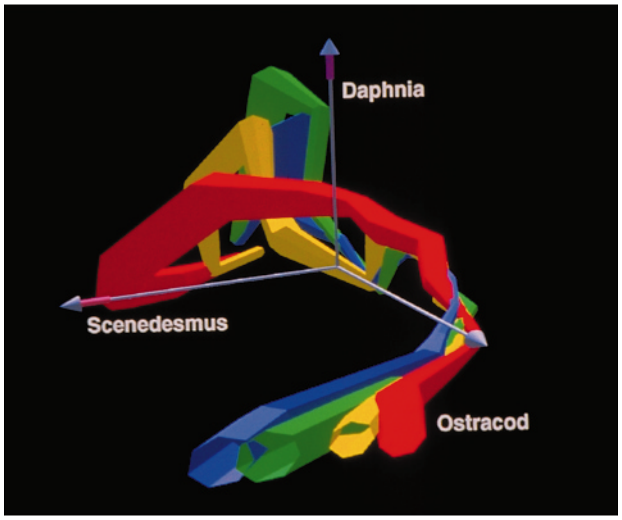

FIGURE 1

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A Visualization of Music

The most popular method of visualizing music is music notation. However, most listeners are unfamiliar or uncomfortable with the complex nature of music notation. The goal of this project is to present an alternate method of visualizing music.

In *A Visualization of Music*, music data are mapped into three-dimensional graphical representations. The data, which are captured from input MIDI data files, are transformed with a mapping function. This function maps musical tones to spheres of various size and color within a three-dimensional rectangular volume.

The first step in mapping music data is to map the individual tone data. Each tone can be characterized by its pitch, volume, and timbre. Variations in pitch are mapped to locations along the y-axis. Differences in volume are depicted as spheres of different sizes in the visualization. Tones produced by instruments with similar timbre are represented by spheres of the same color.

The second step of the mapping function involves mapping instrument data. In a musical composition, individual instruments play sequences of tones with specified rhythms. Tones produced by a specific instrument are mapped to locations along the x-axis. Starting times and durations of tones determine spacing along the z-axis.

Information relevant to the music itself is displayed in a legend located on the right-hand side of the visualization. This information includes static data such as title, composer, instrument group color key, and axes color key. Dynamic information such as the current tempo, current time signature, and the current metronome beat is also displayed in the legend.

A record of the tones that have already played is also shown in the visualization. This “note history” is represented by spheres that are smaller in size and lighter in color than the original tones.

In the accompanying video, arrangements of the first movement of Franz Schubert’s “Octet in F Major, Op. 166 (D. 803) for Strings and Winds” and Carl Orff’s “Tanz, Uf Dem Anger” from “Carmina Burana” are used to demonstrate the results of this method.

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Imagine combining the proven entertainment value of professional broadcast television with the enduring appeal of audience chat and participation, and you have a vision of "Inhabited TV." *The Mirror*, an early experiment in Inhabited TV, involved 2,000 viewers of the BBC2 multimedia magazine series "The Net." A research project created by BT, Sony, the BBC and Illuminations, *The Mirror* comprised six multi-user VRML2.0 worlds built on the themes of the broadcast material. The worlds were launched on 13 January 1997 with the broadcast of the first program, and they closed after seven weeks at an "End of the World" party, complete with online dance floor and beer tent.

Goals
The aim of the project was to explore the concepts of fully interactive TV, allowing professional developers to build a content framework within which their audience was free to explore, extend, and script their own program extensions.

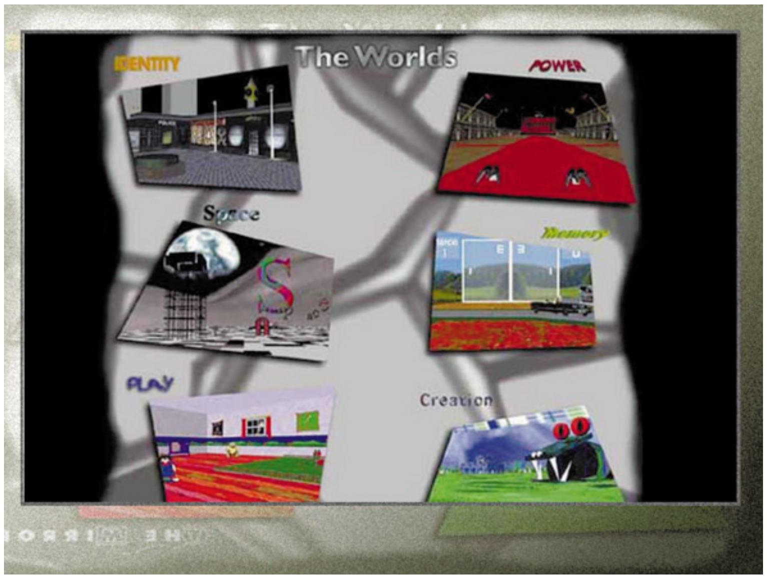
Implementation
Use of the Sony Community Place multi-user 3D spaces software allowed the worlds to contain extensive shared state and interaction. Elements of the content were specifically designed to encourage group cooperation and rivalry between visitors. Features included a rocket that required three people to launch, a shuffleboard with a persistent scoreboard to foster competition, and a bouncy castle whose features changed as more people joined.

Scheduled "special events" were also an important aspect of *The Mirror*. These included online debates with a real-time voting facility, game shows with audience participation, and an art exhibition. A debate between science fiction author Douglas Adams and BT's head of research Peter Cochrane attracted an audience of 45, who rejected the idea that "The book is dead."

Results
The Mirror was introduced to the half million viewers of The Net in a three-minute item on 13 January. The program ended at 2355, and there were more than six hundred successful registrations in the first hour. Over the next seven weeks, the number of registered citizens of *The Mirror* rose to 2,250, including 300 from outside the UK. A total of almost 5,000 user hours were recorded, and over 250,000 lines of chat were exchanged. Availability of *The Mirror* worlds was close to 100 percent, and total data transferred from the server was 40 Gbytes.

An online Forum provided an opportunity for citizens to post news and views about *The Mirror*. The Forum was not moderated, and overall the comments were favourable. Several postings applauded the vision of the collaboration in exploring the current technical boundaries of Inhabited TV. There were also calls for a "Mirror anonymous" group for addicts and a threat from one citizen to withhold the BBC license fee if the project really did come to an end!

Conclusions
In addition to the technical hurdles, perhaps the greatest outstanding challenges are in understanding the economics and structure of compelling content. *The Mirror* confirmed the appeal of social chat, and supported the argument that anonymity acts as the alcohol of shared spaces, lubricating creative and open dialogue that challenges the conventions of physical gatherings. Inhabited TV as a commercial service remains a long-term vision, but *The Mirror* is an important early experiment, from which enduring lessons have been learnt.



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Peloton: A VRML-Based Bicycling Simulator

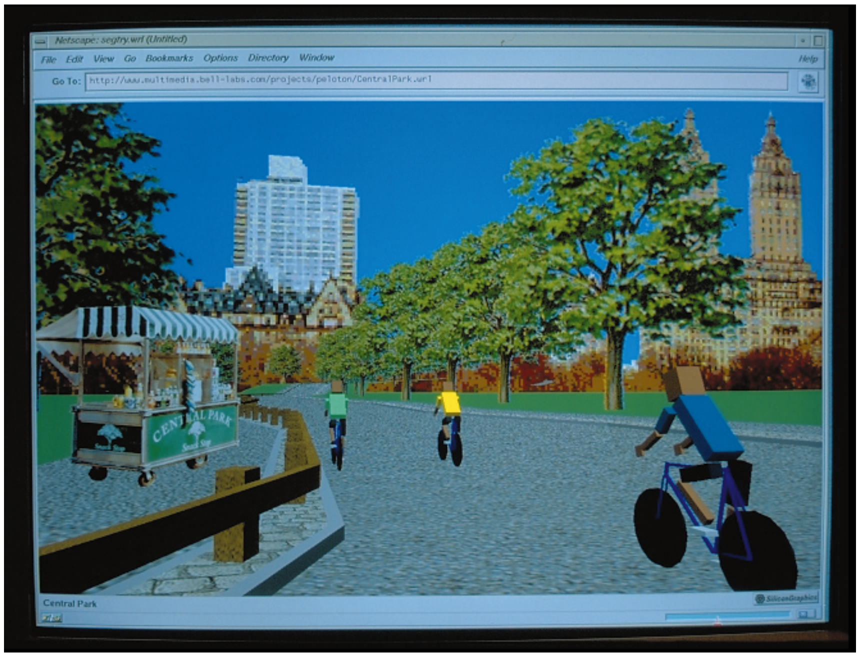
Peloton is a distributed simulation system, suitable for athletic training and competition, that creates virtual environments for bicycle rides. Peloton users ride stationary bicycles within computer-generated environments that provide the sights, sounds, and pedaling resistance of actual road courses. The bicycle serves as the rider's primary control device during a simulation session. It is connected to a local computer through sensors and feedback devices. The computer uses input from the sensors to regulate creation of the simulation's virtual environment.

The visual component of this environment is a synthetic, three-dimensional landscape, which combines computer-generated graphics with images of actual road courses. When the rider pedals faster or slower, a corresponding avatar moves along the synthetic course more quickly or slowly. The virtual environment also includes auditory and force feedback. Users' bicycles are connected to devices that regulate pedaling resistance. When the cyclist is climbing a steep hill in the simulated environment, the resistance applied to the bicycle's rear wheel is much greater than it is when the cyclist is traveling on a simulated stretch of level terrain.

People may participate in a common Peloton simulation even while they are geographically separated. When two or more people are interacting through a common simulation, their computers are connected to a Peloton server by the World Wide Web server that coordinates activities on participant computers to create a common virtual environment for the system users.

Peloton is an experiment to discover ways to build virtual reality systems for collaboration over the Web. With Peloton, we connect exercise equipment to the Web, allowing people to share physical activities during group interactions. While it focuses initially on bicycling, Peloton can serve as a prototype for a variety of athletic events over the Web. It is built with standard Web programming tools. Its simulation coordinator, communication session manager, and parts of its input/output modules are programmed with Java. The visual component of its virtual environment is modeled with the Virtual Reality Modeling Language (VRML) and is rendered by a VRML browser. (Java is also used to program behaviors of VRML objects.)

Peloton represents a new class of applications for the Web. This sketch describes the system in more detail and discusses ways that Peloton's implementation has dealt with some of the limits of existing Web technology (especially Java and VRML). It discusses Web browsers and applet security constraints, describing their impact on Peloton's client/server architecture, communication network configuration, and interfaces for unconventional input/output devices. The sketch also highlights significant shortcomings of the VRML specification, including its lack of support for real-time interaction among users in shared environments and its binding of a world's current viewpoint to the current camera to the viewer's avatar.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Go To: http://www.multimedia.bell-labs.com/projects/peloton/CentralPark.wrl
CENTRAL PARK
Central Park
Silicon Graphics

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The Electric Body Project is a software tool for creating choreography using gestural sampling and mapping techniques. Movement is sampled using Ascension Technologies Flock of Birds, a six-degree-of-freedom motion capture system.

The project is a stand-alone software package running on the SGI platform that is designed to work as a plug-in with Life Forms choreographic software and create movement for choreography and animation. What was previously accessible only through synthesized movement phrases in Life Forms can now be accessed and explored with real-time sampled movement phrases input directly from a participant “dancing” within the system.

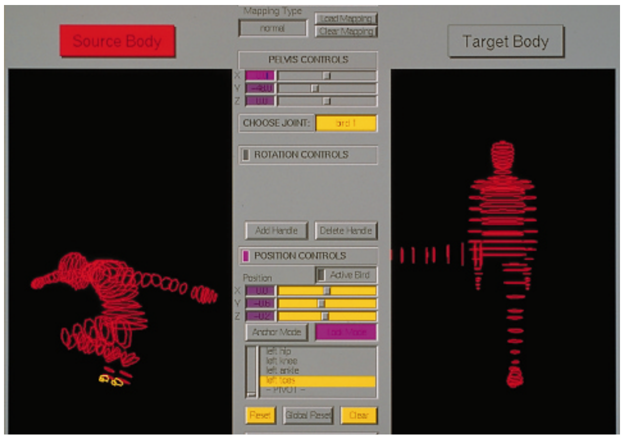
Movement of the participant is literally sampled, displayed, and metaphorically treated to influence, direct, and determine what is presented and represented visually. The Electric Body uses a series of mapping systems, which originate from the physical mirrored body and result in the transformed mapped body. Mapping strategies include “imprinting,” “following,” and “tracing,” concepts informed by choreographic studio techniques. Movement is sampled and treated using inverse kinematics techniques.

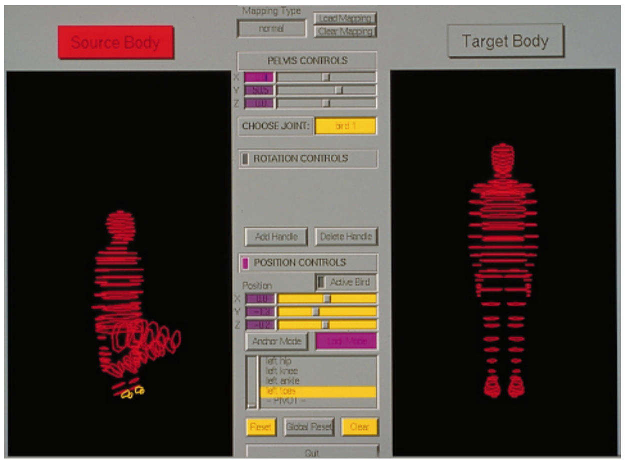
The Electric Body extends the literal, photo-realistic world model of motion capture by introducing the concept of metaphorical mapping used in composing and choreographing movement for dance in the studio. Metaphorical mapping means that a sampled input gesture can be transformed using User Defined Maps that are predefined, or that are created on the fly during the data capture process. Sampled input data can be amplified, filtered, mapped to alternate limbs or limb groups, and distributed to multiple limb groups using the concepts of acceleration (gradual increase of the range of movement over time) or deceleration (gradual decrease of the range of movement over time). In addition, User Maps can be combined over time, to produce additive phasing. These filters can be applied infinitely to sampled movement, enabling movement definition in layers (much in the same way that images can be layered in Photoshop). These techniques provide a mechanism for composing movement that parallels the sound filtering used in music composition and image filtering used in image processing.

Users can work directly with the computer display, or in a performance situation, interact with their own life size projected images. It is possible for performers to replicate and enhance those images, and encounter and respond to imprints of their own projected movements. This enables dancers to use characteristics of their own gestures to compose and influence movement created through the filtering process. Gesture enables participants to compose their own places within a dance, modify timing and placement of visual images, and select and integrate movement phrases.

This real-time movement exploration system can be used in performance by creating virtual dancers whose movement is generated directly from the live performer in such a way as to produce a complex responsive system.

This project has been sponsored by the Media Arts Section of the Canada Council.





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Visualization of the Best Approximation

Computer images, animation, and graphical user interfaces have many applications in undergraduate linear algebra teaching. Topics like vector spaces, linear transformation, orthogonality and eigenvalues can be represented by computer graphics, and interactive techniques and visualization of math objects can strengthen understanding of linear algebra theories. On the other hand, linear algebra is an important foundation for a computer graphics class where topics like geometric transformation and viewing are based on linear algebra theories.

Several computer projects are proposed for a linear algebra class: Flying Objects in 3D Space, Shears Transformation, Eigenvalues on a Circle, the Principle of Least Squares, etc. Graphics, animation, and GUI techniques are used to visualize concepts such as subspace spanned by vectors, theories of linear transformation, orthogonality, and eigenspace and develop mathematics games such as least squares competition. Computer graphics are implemented with the Java programming language so that students can learn and play on the Internet.

In this sketch, a computer graphics project is used to demonstrate the concept of orthogonal projection in a least-squares procedure. A way of looking at the least-squares problem geometrically is to minimize the length of the error vector. The error vector is at a minimum when the error vector is an othorgonal projection of the column space of the coefficient matrix. The visualization of the least-squares is designed as the following:

Let A be the coefficient matrix, S=(au + bv) be the column space of A spanned by vector u and v. On the Java applet, the plane S in 3D space is used to represent the column space. One end of a vector w is connected to the plane S. The error vector of the least-squares approximation is represented by e.

To demonstrate the orthogonal projection, the error vector e is connected to the projection p of the vector w in the column space S. A mouse is used to drag the connection point of the vector e and the projection p. Meanwhile, the length of the vector e and the angle between e and the projection p are calculated and displayed on the Java applet. The vector e and the projection p are also painted on the applet following the movement of the mouse.

In this project, students will visualize the relationship among the projection angle, the value of the least-squares cost function, and the length of the error vector. The visualization and the interactive techniques will strengthen the understanding of the principle of least squares.

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In the traditional digital video publishing paradigm, video editing and deployment compression tasks require separate applications. Generally an edited videotape, once completed, is sent to an outside compression house to be compressed to the deployment media standard, usually MPEG1 for CD-ROM. In this paradigm, the information about the video editor's manipulation (special effects, transition, cuts) is not used during the compression process. Conversely, there is no method for the compression engine to impact how the video editor creates his title. With this lack of integration, the process of video editing and compression for multimedia projects is a slow and costly process.

Video compression can benefit from information that the compression engine can extract from the video material to aid it in discarding irrelevant and / or redundant video information. In this environment, the video editor can manipulate the video to achieve the desired effect. The combination of editing and deployment compression in a single application has advantages above and beyond increased productivity due to integrated workflow.

RenderComp is the set of processes in which edit rendering and MPEG compression occur as a single real-time process with automatic feed-forward and feedback. This communication is facilitated by the fact that both the edit engine and compression exist locally within the same application. The edit engine is capable of feeding forward information about the video to the compression engine to aid it in its compression of the video. Conversely, the compression engine can feed back information to the edit engine that will aid the editor in creating video that is optimally compressible. This sketch provides a primer on RenderComp and how the combination of editing and deployment compression in a single application improves productivity, creative control, and video quality.

Two examples:

1 Fade to Black is arguably one of the most common transitions used in video today. One of the many video tools used by the compression engine is to select a subset of light intensities that can be used to represent a picture. This subset is chosen at the outset of the compression process to produce the best achievable video quality given the particular type of video material (e.g. natural vs. graphics vs. sports). With RenderComp, the editor can indicate to the compression engine that the following frames will be getting progressively dimmer, and to change the subset of light intensities it uses for compression appropriately.

2 As an example of the converse process, the compression process outputs compressed video in groups of related frames with a particular pre-determined length (this is an oversimplification). If the editor creates a scene that is slightly longer or shorter than this length, extra overhead will be required to represent the video. In this case, the compression engine can inform the editor about how the video can be more optimally compressed.

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Virtual Parts Catalog and Component Sourcing with VRML

We are investigating the use of Virtual Reality Modeling Language (VRML) to represent engineering parts of CAD/CAM origin in Internet-accessible supplier catalogs. In its present form, our application can load pre-defined assembly databases and manipulate them in various ways. And it now runs on various UNIX and PC-based VRML browsers (for example, SGI CosmoPlayer, InterVista WorldView). This application is now functional in both the CAVE and ImmersaDesk platforms – VR platforms developed at the University of Illinois at Chicago (UIC) Electronic Visualization Laboratory (EVL). A VRML 2.0 browser for these environments is in the beta stage of development.

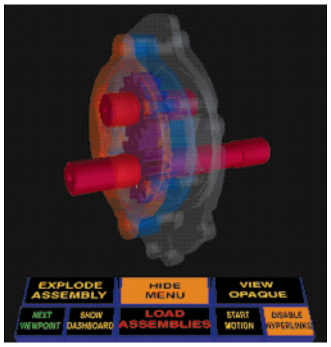
As of this writing, user interaction consists of the following: loading and unloading one of three assembly databases; turning on/off animation sequences displaying simple dynamics that would occur as the assembly is functioning; toggle transparency; toggle exploded view of assembly; toggle display specific VRML browser dashboard; sequentially move through pre-defined viewpoints; toggle between manipulation mode of the assembly's orientation; and displaying anchors or links on individual parts of the assembly. When anchors are active, the user can click with the mouse or other pointing device on particular parts and bring up an HTML document that displays the specifications for the part.

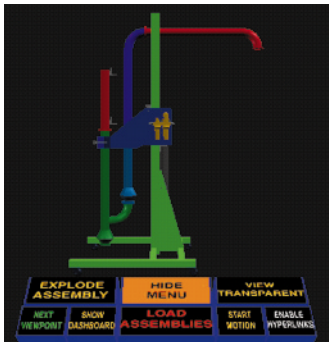
Current efforts are focused on three major areas of research and development:

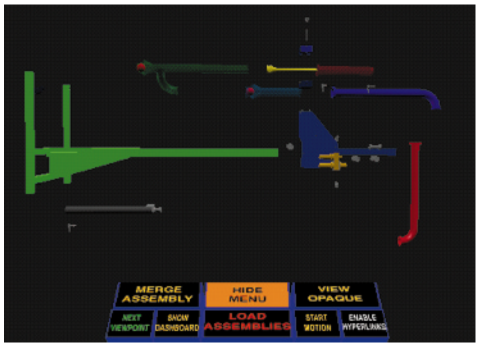
1 Database engine integration/intercommunication, which is still in the conceptual phase. VRML 2.0 is very new and still in the refinement stage. There are a number of ways that a VRML application can be coupled to a commercial database. Which approach is taken may also depend upon a particular VRML browser. For instance, some VRML browsers support a Java External Authoring Interface (EAI), a proposed informative Annex to the VRML specification. This would lead one down the road of using Java Applets to link communication between the HTML browser, the VRML browser, and the database engine. Other options also exist, and are presently being investigated.

2 Collision detection, which will be implemented using a high-level wrapper around I-COLLIDE, which introduces convex masks to reduce the necessity of decomposing non-convex objects. The rationale behind convex masks is the fact that not every object feature is of interest for our collision detection process. A convex mask encapsulates all relevant object features. This then becomes a highly efficient method for collision detection. How best to integrate this into a VRML application is under investigation.

3 A group of controlled experiments involving subjects in a mock training environment. A strict set of criteria will be used to compare level of training progress achieved with respect to various aspects involving industrial assemblies.







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1 Structure

We have designed and realized a text-driven deaf-mute sign language synthesis system. Its input is text, and its output is a virtual 3D human body that represents real-time movements of hand posture. The 3D human body is synthesized using computer graphics methods. See Fig. 1.1.

2 Geometric Model of 3-D Human Body

The articulated human body is composed of 44 kinetic units and 42 joints. The kinetic units are represented by an irregular triangle network, and the joints are represented by non-uniform rational B-splines.

3 Kinetic Control Model of Human Hand and Arm

One human hand and one human arm have a total of 18 joints and 27 degrees of freedom. Movements of the human hand and arm can be formally presented by a 54-dimensions state space. Each state of state space represents a posture of human hand and arm. One state sequence presents a sign-language word. The hand posture changes of sign language are presented by the state changing of state space.

4 Construction of the Gesture Base

A sign-language word is presented by continuously changing hand postures (the state number of state sequence is infinite in state space). We can only use infinite state to approximately represent changes in hand posture. Since each sign-language word is composed of many gesture actions, we use the initial and final hand posture state of gesture action to approximately represent the gesture, and then name these state values as sign-language parameters. The result: a visual interactive description language that obtains sign-language parameters. We use description language to interactively obtain state values for hand postures. The state value sequence that presents sign language words is stored in a database (the gesture base).

5 Experiment and Conclusion

With this method we have successfully synthesized a 3D human body that can display changing hand posture sequences according to input text. Experimental results prove that the method is effective. The results basically meet human visual demands. Fig.5.1(a) is the gesture for the letter a, and (b) is the gesture for the number 1. Fig. 5.2(a), (b), and (c) are the first, second, and third gestures of sign language for the word "future."

6 Application

This *Text-Driven Deaf-Mute Sign Language Synthesis* system can be used to teach sign language and create interactions between users and avatars in virtual environments.

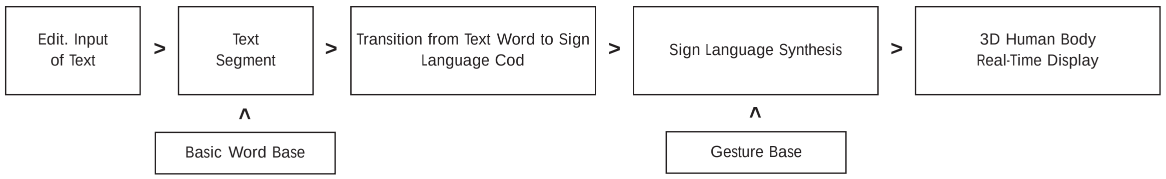

FIGURE 1.1 Text Driven Deaf-mute Sign Language Synthesis System Structure

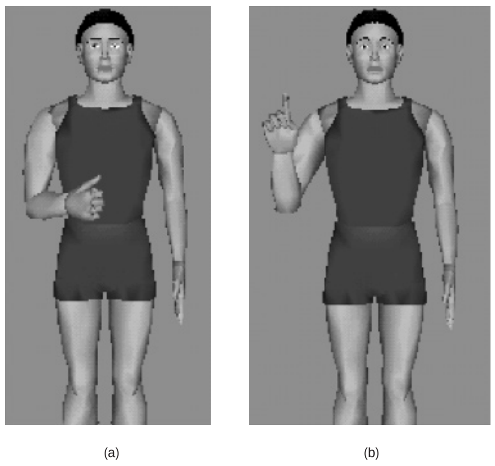

FIGURE 5.1 Hand postures of letter “a” and number “1”.

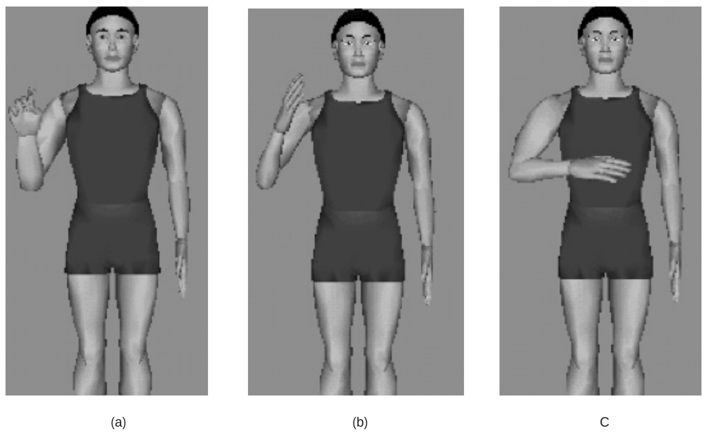

FIGURE 5.2 Hand postures of sign language word “future.”

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Virtual Arts Therapies

Arts therapies involve the performing and graphics arts (music, dance, movement, drama, painting, photography, and so on) in a systematic, controlled, therapeutic environment, supervised by board-certified arts therapists, often in conjunction with medical practitioners (physicians, psychiatrists, psychologists, nurses, and others). These therapies, which often appear to untrained observers as “play sessions,” are actually respected methods of communication – a palette upon which clients and care-givers may reveal expressive, non-verbal ideas with detail and precision, for further analysis.

Virtual Arts Therapies (VAT) combines traditional arts therapy techniques with computer technology to alleviate symptoms, enhance creativity, induce relaxation or other mood states, and promote client well-being. Through VAT, group and individual participation is no longer restricted to local access. It can occur remotely, with patients and therapists separated by great distances. Another advantage of VAT is that immediate self-therapeutization can be provided when and where it is needed. Furthermore, therapy sessions can be recorded for analysis, experimentation, or repetitive administration with a level of precision previously unattainable with traditional methods.

In our research, we have worked closely with the Music Therapy Department of Immaculata College to develop and explore settings for clinical use of computer art tools. Many of these experiments have incorporated both audio and visual components. For example, we created SoundWorld, an interactive setting where musical instruments can be played, using the Jack Human Factors Modeling System from the University of Pennsylvania. 3D graphics and sound have also been used in a comics-style setting in order to elicit thoughts about fears by young teenagers. Work with blind and severe psychiatric inpatient subjects has illustrated the successful use of gestural devices for expressive MIDI instrument control by untrained musicians. Web-based systems and virtual metaphors have been used to examine themes of community art, music performance, and social discourse. Various aspects of the neighborhood – the garage in which music is created, the porch on which conversations take place, the walls on which murals are painted – are presented in an interactive setting to enable communications among diverse populations of participants.

This sketch includes brief video segments depicting the various *Virtual Arts Therapies* applications mentioned above. If time permits, we will review the results of some of our clinical trials, and discuss the limitations and potentials of arts technology in the health care setting.

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This computer-assisted curriculum to teach Foundation Design 1 (two-dimensional design) in the Ball State University Art Department used short interactive programs written in Macromedia Director, which became the basis for more complex and extensive finished pieces using traditional artist's materials and techniques such as paint and collage. Since the learning time for this software was minutes, many solutions to given problems were required, and students were expected to fully explore many variables in each assignment.[1]

The software is now being modified to solve more and new problems. One of these new problems will be the exploration of grids, both visible and invisible. Grids have long been an organizing device in design. From the Renaissance to the present, graphic designers, painters, and others have explored grids in order to make sense of information and create unity on a surface. Showing a beginning design student the significance and potential of a grid is the basis of the interactive problems and software programs demonstrated in this sketch.

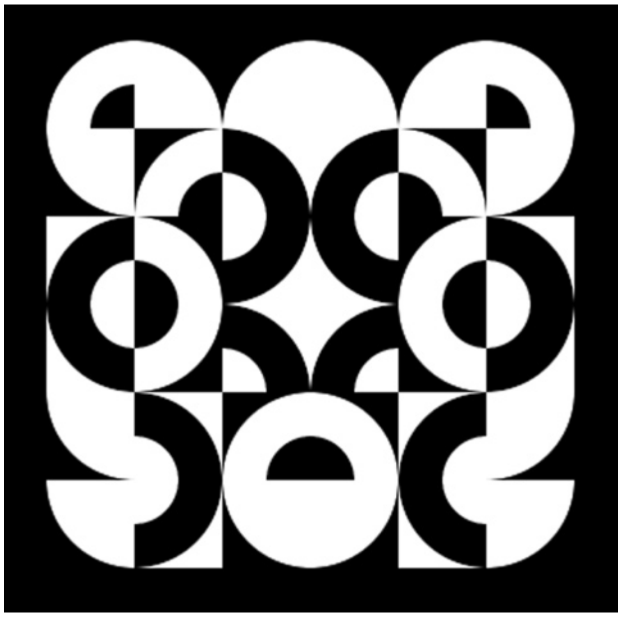
Three approaches are utilized in designing the problems:

1 Grids with units acting as windows with elements trapped inside, but movable within the window. The windows butt to windows that are adjacent to each other. Window outlines can be turned on and off. Elements can be added, subtracted, scaled up or down, colored, moved, and drawn inside each window. If the element edge intersects its windows edge, it disappears underneath it, so the grid structure is always evident in any overall design. Positive/negative and Gestalt relationships are emphasized. The entire grid surface can be randomly reorganized via a "randomize" button, which produces totally unexpected results.

2 Pre-existing grids overlayed with elements. In this version, a pre-existing grid pattern is overlayed and modified with elements chosen from a menu. The grid structure can be "broken" or "violated" by placing these chosen elements in positions not strictly adhering to the underlying grid structure. In this fashion, the grid structure can be obscured, but the underlying sense of order is preserved.

3 Grids with elements that can be changed, but the positions of the elements cannot change. Internal patterns can be developed by changing groups of elements. Each element can undergo up to 15 changes. The resulting surfaces can lead to results very similar to optical art, such as that of Victor Vasarely.

We also plan to introduce variations of the above approaches, utilizing grid structures based on the golden mean, and other irregular grids. Students will also do one exercise on a network, in real time, via Shockwave. They will "improvise" on each oother's solutions to a grid problem, much like jazz musicians improvise on a theme together.



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WordNozzle

WordNozzle is equal parts digital graffiti and digital concrete poetry, an experiment in "painting" with text. It enables the user to select any text-only file as input to the "nozzle," and then spray the words in a continuous stream while controlling the font, size, style, and color of the text.

WordNozzle was motivated from two directions, one quite practical and the other quite theoretical. On the practical side, *WordNozzle* is an attempt to address the clumsiness with which current page-layout and graphics programs handle text manipulation. First, the user must type in the text, then select it (or portions of it), select a different font from a menu, view the result, select another font from the menu, view the result, go to a different menu to change the size, view the result, go to the menu again to change the size, view the result, and so on. The same steps must occur in order to sample styles and color as well. The entire process requires multiple repetitive steps. *WordNozzle* attempts to circumvent this laborious process by treating the text like a stream, much in the same way the "paint" used in the spraycan of most popular graphics packages treats color. The user chooses a text stream and can then manipulate the visual appearance and location of each word as it comes out of the nozzle in a continuous, free-flowing fashion.

The theoretical motivation stems from a study I undertook of the Concrete Poets of the mid-60's and onward, and their Futurist and Dada ancestors in the early part of this century. These artists treated the visual appearance of text as a principal dimension in the production of meaning. Their interest in such experimentation grew out of – among other things – a deeply held belief that traditional forms of written communication, with its clean spacing, rectilinear layout, and sober letterforms, no longer did justice to the cultural schizophrenia of the modern age. Working within the constraints of traditional letterpress, these artists artists and poets managed to explore text's visual presence in ways that seem fresh even to the MTV- and David Carson-jaded eyes of the 90's. *WordNozzle* represents my attempts to partially answer the question: What would a Futurist/Concrete Poet want in a tool for digitally manipulating text?

Interaction

As *WordNozzle* boots up, a title screen appears while the program loads the fonts particular to the user's computer. The program then fades onto the main screen. As soon as the user clicks anywhere, she is prompted to choose a text source. This text, or more appropriately, text-stream, is loaded, and the first word appears at the nozzle. It is at this point that the writer can change the appearance of the word by using the characteristics palette to the left of the writing surface.

The characteristics palette works via rollovers. By moving the word currently at the nozzle over the area marked font and letting it hover there, the user can cycle through all the fonts available on the system. This action applies each font to the word in turn. The user selects a particular font by simply moving the word out from the font area. Adjusting the size works in a similar manner, and picking a color is simply a matter of dipping the word into the appropriate area of the bar at the top of the screen. When the user has achieved the appearance she wants, she simply locates the word on the canvas where she wants it and clicks. This sprays the word down, and the next word appears, ready to be manipulated. If the user holds the mouse button down, the words come out in a continuous stream.

File input-output is handled in the area below the characteristics palette. Positioning the current word over wipe canvas and then clicking clears the screen. (The current position in the text-stream is maintained in this action.) Doing the same over load text allows the user to select another text document as the text-stream. Clicking on save-image lets the user name and save the canvas as a PICT file.

Next Steps

WordNozzle is currently at the proof-of-concept stage. The interface in particular does not take advantage of an even wider functionality supported by the software engine. For instance, the software engine is capable of allowing the user to choose between having the text-stream advance a character at a time, a word at a time (as it is presently set), a sentence at a time, or a paragraph at at time. It also supports using keys to adjust the size and font parameters anywhere, without having to resort to the characteristics palette. Giving the user access to such functionality is part of the next iteration.

Eventually I would like to rewrite *WordNozzle* from the ground up in C++ in order to attain satisfactory interaction speeds. I see such a version as both a stand alone application and as a plug-in for something like Photoshop or Painter.

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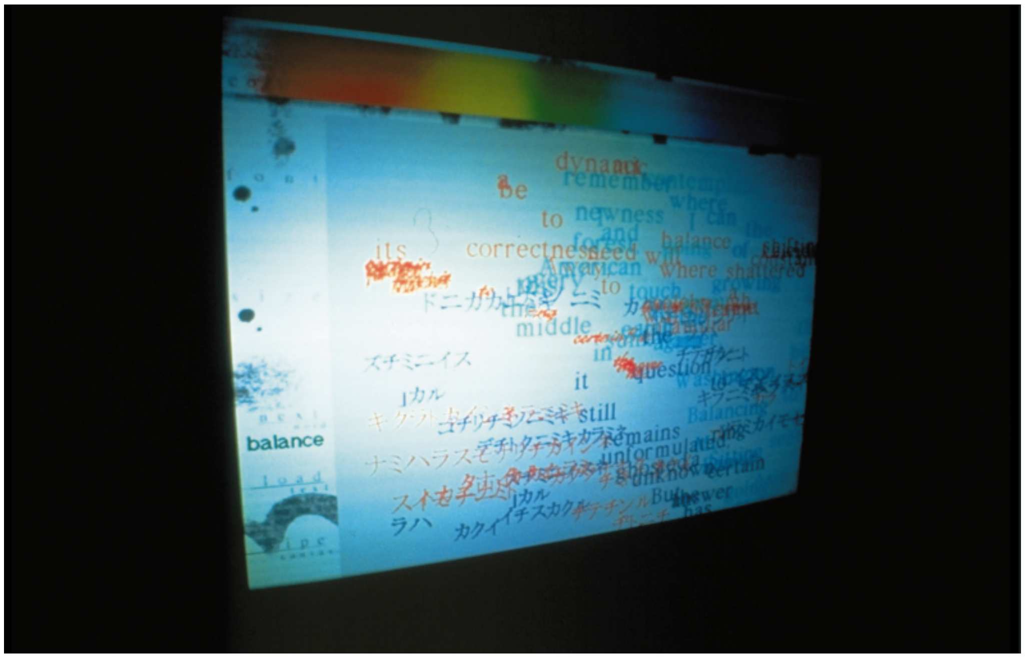

This sketch presents the process used to create a realistic animated walk-through of a portion of the Midway Face region of the Dixie National Forest in southern Utah. The project was part of a study being conducted by environmental psychologists at the University of Arizona to compare computer-generated walk-throughs in two different formats with video and actual walk-throughs of the same forest path. At the Texas A&M Visualization Laboratory, our job was to create a highly realistic prerecorded animation, while landscape architects at the University of Illinois produced an online walk-through at a lower level of realism using interactive technology .

Purpose

The goal of the study is to provide definitive experimental data about the efficacy of computer visualization of a natural site in eliciting human responses similar to responses to the actual site. The study also seeks to establish whether or not high realism is an important factor in refining response. This has important scientific and public policy implications. It is common practice for planners to use predictive simulations to determine the future state of a forest under various management plans. This study will tell planners what level of visualization they need to reliably depict these future states and will lend credibility to their presentations.

Process

The project is among a select few, in the short history of scientific visualization, that has employed the expert skills of an artist from the beginning, as an integral part of the research process. The first step in development of the visualization was to send the artist on a visit of several days to photograph and sketch the site. This radically changed our original perspective. For example, we found that the existence of aged trees – trees almost falling down, dead trees lying on the forest floor, and decaying nursing trees covered with small, new trees – were as significant to the appearance of the forest as were the healthy trees. The imagery and impressions of that early visit were used daily, and the eye of the artist continually played an essential role in ongoing work.

Starting with detailed tree surveys and terrain data, a four-minute animation was created. It contains approximately 1,500 trees and covers 66,000 square meters. The animation simulates a person walking through a forest, stopping at predetermined points, turning around for a 360-degree look at the forest, and then continuing on to the next point. The process involves creating the following elements: a parameter set to grow realistic Engleman Spruce trees, a reformatted survey dataset to be used in later programming, a smooth camera path through the forest, motion tests, rendered texture maps of individual trees, and approximately 1,100 rendered scenes of the complete forest.

Using BOGAS (the Branching Object Generation and Animation System of Kitagawa-DeLeon), a detailed geometric model of the trees was created, down to the needle cluster level. Texture maps and shadowed scenes were formatted as RIB files with custom software and rendered with Pixar's PhotoRealistic RenderMan on an SGI Power Challenge supercomputer. Significant effort was expended to reduce computation time. First, the level of rendered detail was controlled for distant trees by using texture maps on rectangular polygons, and for nearer trees by interpolating between geometry with and without displacement and texture shaders. Second, the quantity of stored geometry was reduced by using multiple instances of the same tree. Depth cuing provides a realistic depth of field.

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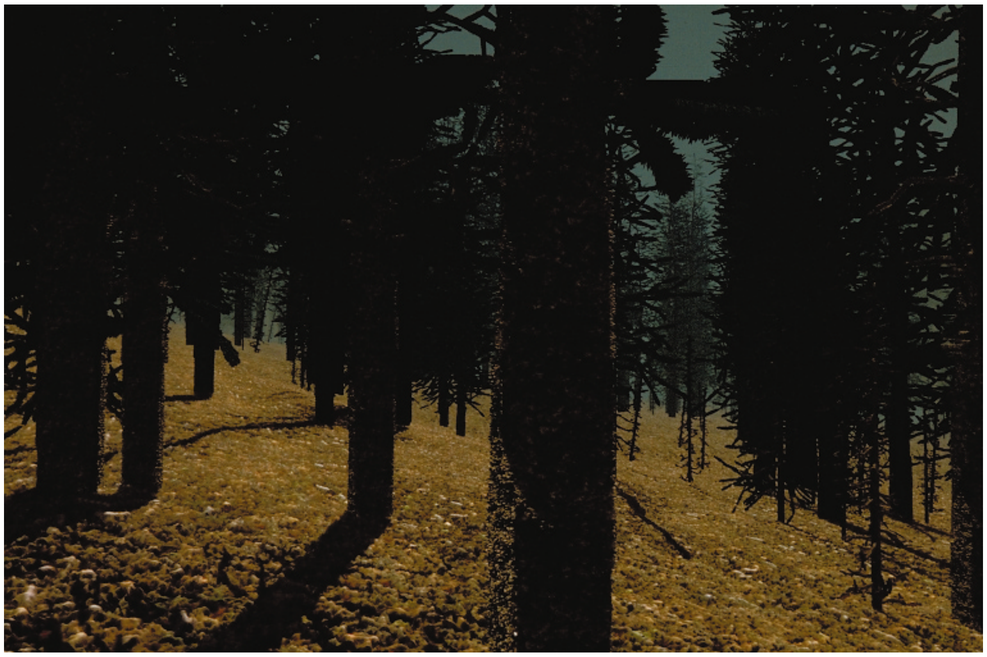

Performance Capture and Character Animation

Over the last 10 years, motion capture has evolved into a powerful animation tool if not a controversial one. If the nature of the character requires extremely realistic or very characteristic motion, then capture tools can be employed to extend the palette of the character animator into uncharted regions of expression for digital characters.

At Digital Domain, we have utilized capture tools and methodology to this end. Performance Capture, as we term it, was used to "digitize" the essence of two very distinct performers: Michael Jackson and André Agassi. The technology allowed them to have a significant hand in the authoring of their respective characters and allowed audiences to enjoy the new artistic expression of these two traditional performers.

In the first example, Michael Jackson was able to author the skeleton character through Performance Capture and cutting edge computer graphic techniques. Under the direction of Stan Winston, Michael danced very specific blocked and timed motion before the capture hardware. Once the motion was processed and edited, we translated the basic kinematic skeleton into Alias PowerAnimator, attached this motion to a Polygonal and NURB model and proceeded to build the overall scene.

Through a set and lighting survey and careful integration, we were able to place the skeleton character anywhere within the virtual set. Because the virtual camera had to match the real camera dynamics exactly for proper compositing, the set survey allowed us to track the real camera against the background plates. This allowed the director and visual effects supervisor to visualize the skeleton character in context for final placement and performance.

Most shots required layering of key-frame animation. Animators helped realize aspects of the performance that we couldn't capture or that the director wanted to see well after the fact. Once the animations were finalized, each shot was rendered with exact lighting placement, to match the on-set lighting for the final integration before compositing. Once all elements were rendered, each was composited, in Flame or Nuke (Digital Domain's in-house compositing system), back into the background plate and tweaked to place the character into the scene as envisioned by the director to help tell the story.

In the second example, André Agassi was captured to bring his performance into a purely virtual world. The nature of the commercial required that virtual André play tennis with a human opponent who wielded a cyber-headset and racket wand. The point of the spot was high energy and fast action.

Unlike the skeleton, we were going to be representing a near photo-real André Agassi. This required us to start with a head Cyberscan and model his body and Nike clothing in NURBS. Once André's motion was captured and processed, we brought the internal skeleton into Alias and proceeded to build the shots. The key to this commercial was moving the virtual camera in ways that would be impossible to do in the real world, all the while featuring the kind of tennis performance only André Agassi could do.

Once the cameras were animated, we rendered the foreground elements in either Alias or Lightwave and then composited them into backgrounds rendered in Lightwave for the final dynamic effect, all within Flame.

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It is possible to do a wider range of work with motion capture than people usually think – by using it more like puppetry and less like acting.

Floops is an episodic animated cartoon for the Web. So far, we've made 40 25-second episodes. SGI Webcasts these in VRML2.0. Working for this application means working within limitations: few polygons, few textures, no morphing, only one full character. With so many limitations, I wanted to make the character animation as good as possible.

The main issue is that *Floops* is supposed to be a peppy, hyperactive little pet. Motion capture doesn't do this kind of motion easily – it's realistic, and unexaggerated. How could I get the kind of stylized movements I wanted? I devised a me-to-*Floops* mapping that exaggerated his limbs while retaining the overall sense of mass in his body. With this, even when I was walking casually across the stage, *Floops* would bound across it like a five-year-old. These tricks only go so far, and aren't generically usable in all cases. They also have an unfortunate tendency to deaden the original motion a little. So this alone wasn't enough.

Another partial solution was to exaggerate my own movements as I performed. I found it was a big help to think like a puppeteer, to focus on *Floops'* movements and ignore my own entirely. (We use a video visor to watch our characters as we perform.) It was not a matter of being casual or performing movements that felt natural, even though you'd think that would always be best with motion capture. What reads well on a person doesn't necessarily read well on a *Floops.* For that matter, given that I was using an unusual movement mapping, movements wouldn't be 1:1 translated on *Floops* anyhow. Even though I'm sure I looked silly, the moves looked right to me on *Floops.*

Another challenge: stylizing as I performed. I tried to simplify the movement down to its essence, avoiding all inessential movements. This would happen after rehearsing a scene a number of times. It would start to fall into a pattern, and I'd know where and when every major pose was going to be. Settling into poses also made it more likely that people would be able to read the movements even at six fps. I was excited to receive mail from a couple of keyframe animators who'd seen *Floops,* and liked it, but weren't sure whether it was motion capture or keyframe!

You can also do some even stranger mappings. One of our characters is a worm. Your right hand manipulates his head, your left hand his tail, and your feet his mid-segments. This requires real puppeteering skills to do well, but it also takes on a stylization that is fun and interesting, with a very different look than the serious realism of most motion capture. Another example is a series of walking letters that spell out words. To give these a less human, peppier look, I put sensors on a piece of foam rubber, and manipulated that as a puppet, walking it around our stage.

Non-realistic motion can sometimes be a lot more interesting. It has gone through an artistic interpretation. The other reason to do it is that there are some body types you can do with puppetry (such as the worm) that are so different from the human shape that there's no other way to do it live. This is a messy, fuzzy, unscientific process, and not as all-purpose as keyframe animation. Yet, I think this whole grey area has some of the benefits of keyframe animation (exaggerated, stylized movement), while keeping the real-time benefits of motion capture. Maybe it won't be long before we see worms as well as monkeys hosting TV shows.

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This work was done with **Steve Rein, Dan Hanna, Floops, Mike Morasky,** and other characters at Protozoa.

Ubiquitous Animation: An Element-Based Concept to Make 3D Animations Commonplace

So far, 3D animations have not been able to establish themselves as multimedia elements anywhere near as well as graphics, video, and audio. The reason for this is the great amount of time and expense associated with creation of a 3D animation. In order to overcome this obstacle and make animations commonplace, we are developing CASUS.

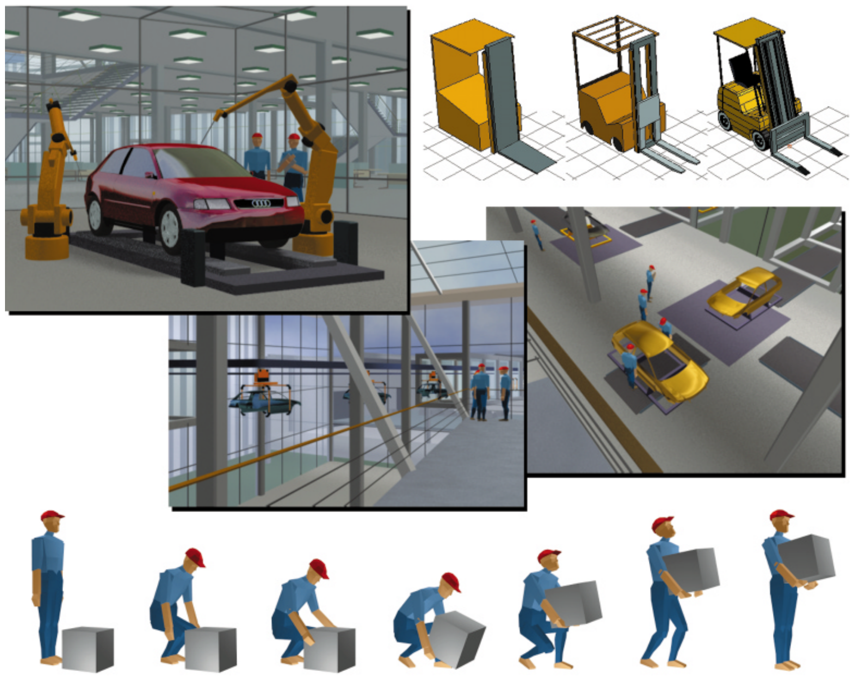
The system's framework consists of an animation tool (CASUS Anim), the public-domain VRML2.0 browser CASUS Presenter, and additional tools for simple linking of event-oriented simulators and integration of CAD data. The integral part of the concept, however, is the animation elements library CASUS Base.

Animation elements are analogous to Clipart when using graphics. They are the objects prefabricated by designers with object-specific functionalities and possessing an independent intelligence. For example, the animation element "worker" generates animated behaviors, such as walking, carrying, sitting, and discussing, which can be fetched for the creation of animations. This can occur graphic-interactively through the user or through linked simulators. An animation element even possesses knowledge about itself (for example, about its geometric proportions) in order to avoid distortion when scaling, as well as for mapping simulator events on visible behavior. Animation elements can be flexibly tailored to meet certain requirements, as in the sense of derivation in the paradigm of object orientation, in order to realize the demand for cost-effectiveness. Since so much preliminary work is taken care of by the animation elements, animation development becomes less time-consuming.

CASUS Base, however, is more than just a loose collection of animation elements. Because it also includes element classification, multimedia database functionalities, and network capability, CASUS Base offers the possibility of functioning as a distributed marketplace for animation elements and offering them in catalog form. Security mechanisms have been conceived that allow animation elements to be offered commercially. This encourages third-party developers to make these kinds of elements available for a fee.

Our current research is focused on identification of basic functionalities and generation of a standardization proposal for animation elements. First results, applications to date:

- Visualization of simulation results in the area of storage / shipping.
- Internal validation of simulation models in the area of logistics (in both cases, automatic animation generation through simulator linking).
- Presentation film: production planning of an automobile manufacturing plant (the model of protocol layers was filled with animated workers and shipping elements).



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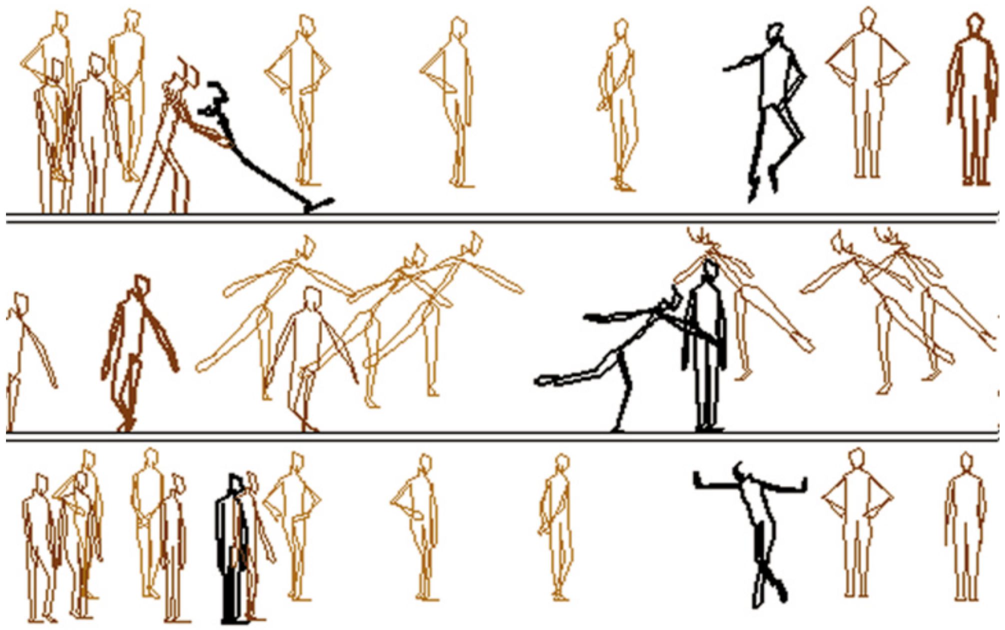
Isaacks is one of the latest choreographic works by Jimmy Gamonet De Los Heros ("Jimmy") of the Miami City Ballet Company. It is the first of five sections for the neoclassical ballet piece entitled "Supermegatroid," which was commissioned by Wolf Trap in Washington, D.C. Three of the five sections composed by Jimmy, including *Isaacks*, were choreographed on the computer using only the Life Forms animation software to direct a company of virtual dancers. Life Forms, originally designed for human movement animation, is now one of the tools being used to refine the *Isaacks* choreographic work into an animated short of the same name.

This sketch shows how the animation evolved from an empty stage to a few sets of shape palettes, a vast vocabulary of locomotor sequences, and multiple versions of the full choreography. In the initial preparatory work with the music and score, Jimmy treats Life Forms as a virtual studio to actualize and explore movement ideas inspired by the music. From the start, he knows how his dancers will move in his mind. He uses Life Forms to physicalize the movement in his mind to movement with virtual bodies; to transform between known middle, beginning, and end points in each movement phrase; and to work out key formations for constantly changing groups of interacting dancers.

Issacks has over 100 associated files, which are used to produce approximately 20 different versions of the full choreography. Most of the files contain short single-figure movement sequences that define the vocabulary of the piece. A new version of the full choreography is created when there is a major change in the order of key formations. Most of Jimmy's one-month animation time for *Isaacks* involved the creation of the vocabulary. After the work on the computer, it required only three hours for the live dancers to learn the piece in the studio. Of course, a two-week training period follows, for perfection of the dance for performance!

Creation of *Isaacks* on film as an animated short will take much longer than two weeks. The current work in progress is focused on fine-tuning the animated movement and starting the design work for storyboarding, modeling, and rendering. Related issues, approaches, and early storyboards and renderings show the next steps in the production of *Isaacks* as a rendered dance animation.

Supermegatroid was inspired by the big band music of the 1940s. In particular, *Isaacks* was choreographed for a full-orchestra arrangement of "When the Saints Go Marching In" created by Keiko Endo of The Miami City Ballet Company. The three-minute *Isaacks* animation builds on Jimmy's maturing style, which has been described as "the true, laughing love-child of an affair between ballet's neoclassic movement vocabulary and the geometric possibilities of cyberspace."



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The Tapir: Combining Myth and Contemporary Musical Structures to Create a Personal Perspective with 3D Computer Animation

Rather than the typical western way of storytelling, in which the audience expects a moral at the end of a story, *The Tapir* has an unusual narrative. It presents a conflict, develops it into an action-climax situation, and surprises the audience by ending in suspense. Because the narrative in *The Tapir* is a myth, it can contain numerous meanings. There is also an underlying notion that the story was always there, complete.

In my creative process, I intend to search for similarities between ideas that have guided musical composition in the 20th Century and the fundamental elements of storytelling. I intend to extract from stories the essential structure of the narrative, starting with the descriptive outer layer of characters, places, and situations, and ending with the inner layer, where just the structure of a narrative is revealed. My sequential images can be read as a musical score, or vice versa.

There are three main reasons I have chosen contemporary music as a template for my piece: the structural aspect of the musical composition, its close connection with the studies of physics of sound, and its singular understanding of the graphic translation of sound events.

The three ideas that I have chosen to guide the visual construction of the animation are: a traditional harmonic construction ending in suspension instead of repose; simultaneous layering of events; and an atypical beginning that is filled with elements (props, characters, situations) that will all disappear as the story progresses.

Narratively, the story is divided into nine scenes, each one corresponding to a different layer within the same space. The camera moves from the front layer to the last, passing by all the different events. The simultaneity of the events is depicted in the nine layers, which are horizontally superimposed. From the point of view of the first layer, one can see part of each one of the subsequent layers.

The simultaneity of musical events is also introduced in the abstract level, where each character is constructed of a set of polygons layered on top of each other. The design is basically made of bi-dimensional shapes superpositioned in a three-dimensional space. The emphasis in not in the creation of three-dimensional models. Instead, the three dimensionality is explored horizontally, when the camera travels in space from the first scene and makes its way to the ninth. The sound track is based on a musical interpretation of these layers of polygons. The images were read as a musical score, and the simultaneity, the harmonic construction, and the empty ending were musically described.

Later in the creative process, the sound and images were cleaned out and the visual elements stripped away, so the structural matter would not overwhelm the importance of the storytelling. The animation is constructed within a half sphere, which acts as a metaphor for both the sky and the “oca” (a typical Indian dwelling in the Amazon). Here the geometry in the three-dimensional space suggests a reference to the background of the myth and the people and culture from which it comes. Societies create their myths as a way to keep and worship their ancestral knowledge. As an artist, what interests me is deconstruction of the myth by manipulating the visual and musical structures of the narrative. The deconstruction is followed by a new construction as a myth, in an artistic type of game, where the structure does not destroy the myth, but recreates its quality. The 3D space is the medium for a new interpretation of the myth, but it can never overpower the essential and universal nature of its storytelling.

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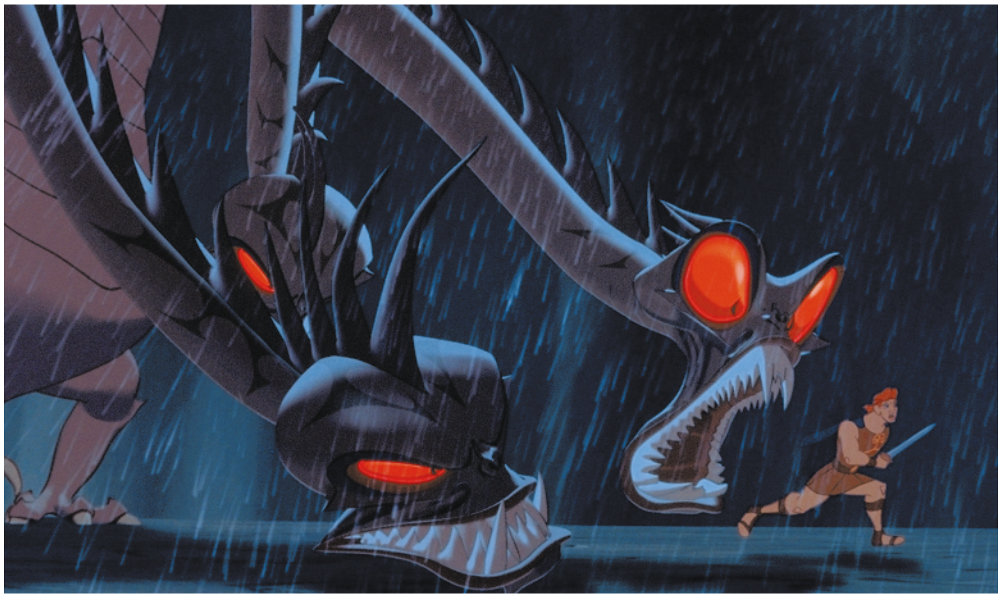
Starting in the fall of 1994, the directors of “Hercules,” John Musker and Ron Clements, whose previous credits include "The Little Mermaid” and “Aladdin,” decided they wanted an unprecedented monster. Working from the Greek myths, they envisioned a battle between Hercules and the multi-headed Hydra. But to be really wild, instead of a three- or six-headed beast, they wanted a 30-headed monster.

Contrary to popular misconception, the Disney films are still animated with pencil and paper, just as “Snow White” was made 60 years ago. The difference today is that on each film we look for opportunities to incorporate computer animation to bring something to the screen that was previously unattainable in a traditionally animated film. Bringing the Hydra to life was just such an opportunity.

With a crew of 10 technical directors and eight animators, over the course of two and a half years, we worked to create a computer character that doesn't look like a computer character. Our two main challenges were matching the movement and the visual style of a traditionally animated film. The hand-drawn animation in “Hercules” is especially cartoony, with an amazing looseness and freedom. So we had to create a computer animation skeleton that would allow our animators to achieve the same level of flexibility and elasticity in their acting.

Secondly, the graphic, ink, and paint style of “Hercules” is not what computer animation normally resembles. So we created a rendering technique to produce line “drawings” that matched the hand-drawn pencil line. These were combined with rendered flat paint areas and graphic highlights to seamlessly blend the Hydra with the hand-drawn characters and hand-painted backgrounds.

This tight collaboration between designers, programmers, technical directors, and animators produced the first fully computer-animated character ever to co-star in a traditionally animated film. The final result is a five-minute action sequence that stands as the centerpiece of the movie.



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Turner Classic Movies: “Hopper”

In 1995, Colossal Pictures was asked to produce three 30-second station IDs for Turner’s new channel, Turner Classic Movies. The idea behind the new station was to deliver classic films on a dedicated channel. With this in mind, Colossal was asked to create something unique and memorable that was also able to address the aesthetic tastes of people who are interested in “classic” films. The idea was to bring to life something truly American, something that held in its iconography familiar symbols that spoke of classic America.

Colossal chose to bring to life the American painter Edward Hopper. The first question was how would we tackle the aesthetic and technical challenges presented by such a daunting task. Many other questions followed: How could we create a sense of time and space with only a given set of existing paintings? What are the legal issues surrounding the re-purposing of famous paintings scattered all over the globe? Would the environments be 3D? Parallaxing paintings? Or maybe even traditional cel animation?

With each project, we try to look at what is the most creative way to work with the tools we have, to create the best imagery. In this case, we searched for the most cost-efficient and creative way to make Hopper’s art move. Our chosen platform was the Apple computer system, using a combination of 2D and 3D animation packages. In addition, we used traditional art, which was scanned into the computer and digitally manipulated. Boards were drawn up and approved by the client. The next phase was to create the hand-painted traditional artwork.

The director selected several original Hopper paintings to use as reference points for creating new “Hopperesque” images. The line drawings of these paintings were then used as templates to create 3D environments. These would later be used to create the moving shadows contained within the scenes. Stills were taken of the 3D environments and used as (locked-off) camera positions to create the traditional paintings. By doing this, we could make the shadows match the paintings directly. Traditional animators drew the key frames for the human elements, which were then hand painted, scanned, and morphedinto their respective positions. Other elements, such as background plates, poles, and chimneys, were all painted as individual elements. We found that, when looking at them on television, these traditional painted elements gave us the look and feel of a real painting but lacked the punch we wanted. Fortunately, because all of the hand-painted elements had been scanned into the computer, we were free to make creative changes to color, value, and focus.

After the elements were repainted, After Effects was used to not only composite, but give dimensionality to the piece. Multi-plane movement and rack focus techniques were used to achieve this effect. Finally, we rendered the spot to D1. We feel the final product addresses all the issues Turner Broadcasting brought to the table. In addition, Colossal created a dreamy world that blurs the lines between traditional painting and the digital realm.

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Up… Down… Up…, like many of the projects we do, is a hybrid production combining traditional cel animation with the best enhancement that digital animation can offer. Our goal in this 30-second commercial, as with every project we undertake, is to push the envelope in existing software, and in our techniques, a little further each time.

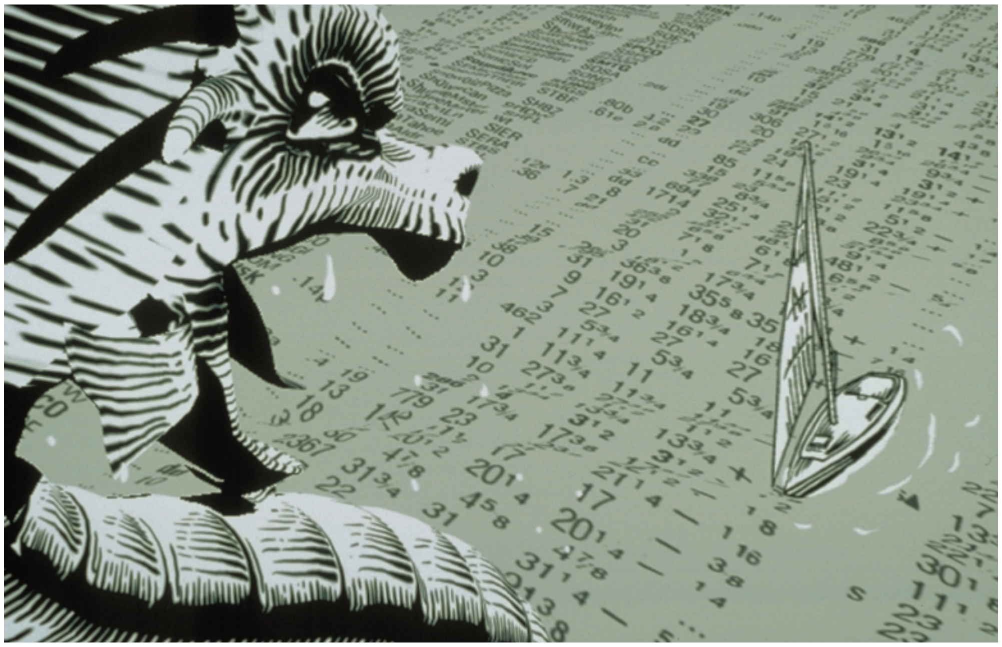
On this production we worked closely with a director from a traditional animation background, John Hays, of Wild Brain Inc. On first looking at the boards, it seemed that our task would be to model elements and render and print out digital frame reference for the cel animators to ink and paint. However, we felt strongly that we could also create many of the elements and animate them in 3D, saving time and money, and more importantly pushing the technique of combining cel and digital animation further. Because a 2D woodcut look and fee had to be preserved at all costs, a seamless synthesis had to be forged between the traditional cel animation and the 3D digital animation. This began a series of experiments that led to the dragonesque sea-serpent, along with the sea of mutual funds and all the letters representing the wake and splashes from the sea, being created, animated, and rendered in 3D.

Boards and loose sketches were quickly interpreted, and changes were made almost on a daily basis to create a more cinematic story line. Elements were modeled, and specific black-and-white textures were hand drawn and applied to the polygonal-based models to give them just the right 2D look and feel. Our biggest challenge by far was the 3D sea serpent. Again, for the sea serpent, each texture was hand drawn and applied to the model. There are over 20 different textures on the head alone.

Special code was then written to create a field chart that could ensure the deadly accurate registration for the cel to digital ink and paint transitions essential to hybrid productions such as this. Digital frames were printed as reference to guide the cel animators at Wild Brain who were creating the cel sailboat, cloud god, water effects, droplets and splashes. This digital referencing program is designed to work with the standard Softimage Toonz settings in NTSC or PAL for ease of use in digital ink and paint.

At Little Fluffy Clouds, we are seeing a movement back to the traditional style of animation, almost as a refreshment from the automated special effects look. Through experiment and play, even within the tight confines of the creation of a 30-second commercial, we were able to satisfy our clients' needs and take digital animation one step higher. All of which proves that it is possible to create different kinds of looks that are not generally associated with 3D, and that we can synthesize 3D and 2D in a such a seamless way that no one can tell the cel from the digital. We continue to work in this style, with a very specific look combining cel and digital animation. In this way, we hope to revive a very traditional look and preserve all the benefits of digital animation.

It's worth noting that this entire spot was composited in-house using Softimage's Eddie. The benefits of this are not only felt in the budget, but more in that each scene, as completed, can be composited, shown to the client, and approved during production. This saves time and allows the client to truly be a part of the production. This is especially important for smaller digital animation studios that put their time, effort and energy into focusing specifically on digital animation, but who still have to compete with the ever expanding larger houses and the trend to place 3D "quick fix" departments in post houses.



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Dynamically Simulated Characters in Virtual Environments

Virtual environments and games often include animated characters that must respond to the actions of the user. The unpredictable actions of the user require a highly interactive environment that is not amenable to motion-generation techniques based on a library of predefined sequences. In this sketch, we present one approach to populating interactive virtual environments: using dynamic simulation to generate the motion of characters that respond in real time to the actions of the user. Simulation provides an effective way to generate realistic and compelling motion for virtual environment applications in which realism is essential.

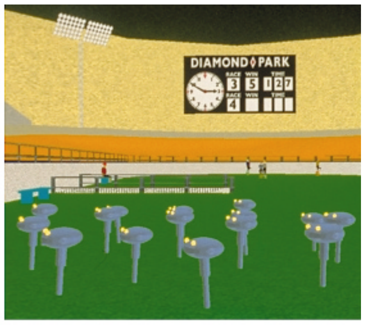
To illustrate the use of simulation in virtual environments, we have built two environments with interactive characters. The first is a game in which a herd of one-legged hopping robots moves around the environment. The user navigates by steering and pedaling a stationary Tectrix bicycle and attempts to herd the robots into a corral. Each robot has knowledge of the locations of the other robots and of the user, and uses that knowledge to avoid collisions in a reactive fashion. This environment served as an aggressive testbed for control algorithms for dynamically simulated robot groups[1] and as a driving application for distributed computing.[3]

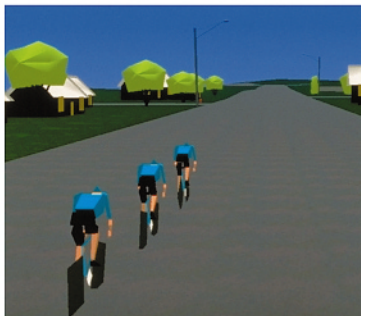
The second environment is a virtual recreation of the Atlanta Bicycle Road Race of the 1996 Olympics. The goal is to create a virtual environment where an athlete can experience the course both visually and physically in the presence of simulated bicyclists. Such an environment should prove valuable to the avid biker or professional racer who is limited by time, money, bad weather conditions, or insufficient situational training. For example, the racers at the Olympics are allowed only limited time on the course without traffic and might benefit from additional time to tune their racing strategies to a particular course or field of competitors. We plan to explore the use of this system for both physical and strategic training for individuals and teams.

The virtual environment is designed to accurately reflect the terrain of the road race. Using topographic maps of Atlanta, we digitized and modeled the 13 km course, preserving dimensions and height information. The user rides a racing bicycle mounted on a motion platform that pitches fore/aft by +/-12 degrees to allow simulation of hills. The bicycle is instrumented to measure the speed of the rear wheel and the turning angle of the front wheel (+/-20 degrees). The rear wheel is mounted on a generator and flywheel to allow limited freewheeling and to match the wheel load to the terrain angle. The system will eventually model such effects as wind drag and increased efficiency from drafting.

Much of the visual interest of the virtual environment comes from the synthetic bicyclists. Each actor is dynamically simulated and pedals in a realistic fashion around the race course using control algorithms described in Hodgins et al.[2] We have implemented a distributed system that allows us to simulate multiple bikes in nearly real time and to display the graphical environ-ment at 15 frames per second. The dynamic simulations are computationally intensive and are distributed one per processor on an SGI Power Challenge with 12 R8000 processors. A software barrier enforces synchronization between simulations to maintain a consistent world state via shared memory. Graphical information is shipped via sockets to a dedicated graphics server.

Although the presence of the simulated bicyclists in the environment adds greatly to the visual appeal of the scene, we are just beginning to develop algorithms that will allow the synthetic cyclists to mimic the sophisticated racing strategies of human cyclists for drafting, blocking, and breakaways. We expect that the addition of racing strategies will result in a useful training environment by providing the user with virtual opponents and teammates and allowing the exploration of biking and team strategies for a particular race.





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Transitions Between Dynamically Simulated Motions: Leaping, Tumbling, Landing, and Balancing

Animating characters for video games is a challenge because a good game requires a wide variety of appealing character motion and realistic responses to unpredictable user input. Video game systems usually generate continuous action by selecting an appropriate motion from a library of data and then smoothly interpolating between the current motion and the newly selected motion. We present an alternative, simulation-based approach that computes the desired motion by making smooth transitions between a set of parameterized basis control systems.

One potential advantage of dynamic simulation is that a basis control system can be parameterized to produce a variety of motions.[1] We use the term basis controller to describe a control system for a specific low-level task such as leaping, tumbling, landing, or balancing. Each basis control system provides a set of parameters for modifying the desired behavior. For example, the basis controller for leaping allows the specification of the height and the distance of the jump. To produce the equivalent range of behavior using a motion library, a number of jumping sequences would have to be interpolated.

By using a sequence of basis controllers, we can create a wider variety of motions for more complex tasks. Control systems can be designed so that the exit state of one control system usually leaves the simulation in a valid initial state for the next control system, making transitions easy to achieve.[2] We demonstrate the basis control systems and transitions between them by generating a diverse set of behaviors for a male and female character, including an inward 2-1/2 somersault pike, standing forward and backward somersaults, a handspring, and various leaping maneuvers.

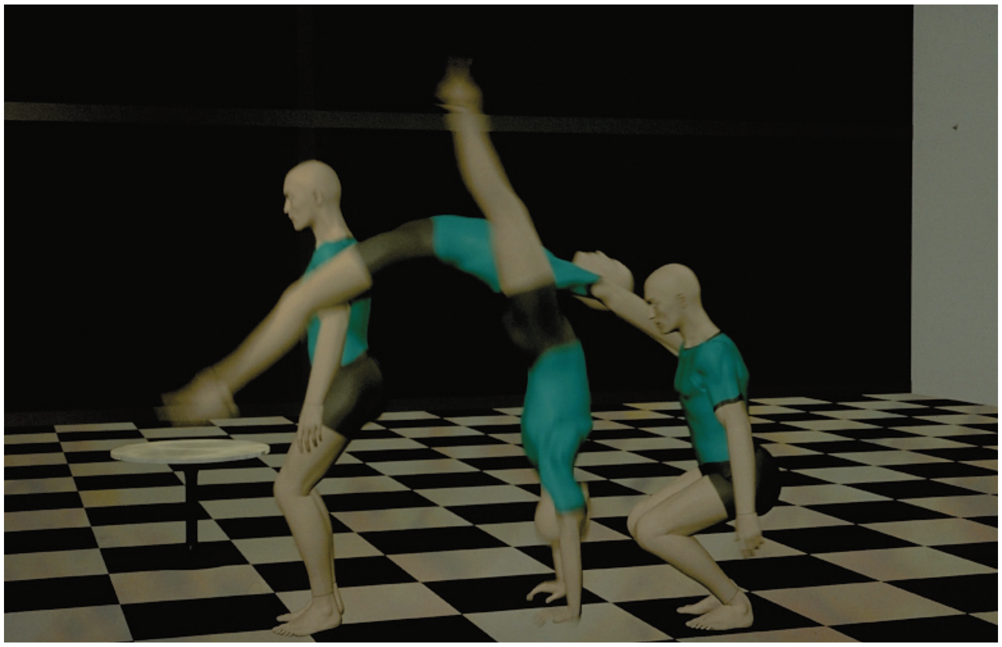
We have developed a small set of basis controllers to demonstrate the feasibility of this approach. The balance controller prevents the character from falling down by keeping the ground projection of the character's center of mass within the area of support. Two parameters modify the behavior of the balance controller: the height of the hips above the ground and an offset for the desired location of the projected center of mass.

The leaping controller propels the character into the air. The height of the leap can be controlled by modifying the height of the hips at the beginning of the leap. Horizontal distance can be controlled by modifying the location of the projected center of mass with respect to the area of support. Modifying the timing of hip, knee, and ankle extension alters the character's angular velocity at lift-off.

The tumbling controller produces aerial maneuvers from combinations of somersaults and twists in pike, tuck, or layout positions. Although angular momentum is conserved during flight, the angular velocities are modified within the tumbling controller by adjusting the tightness of the tuck or by transferring angular velocity from one axis to another.

The landing controller acts as a transitional controller to take the character from flight to a state suitable for the balance controller. In preparation for touchdown, the legs are positioned such that the velocities of the center of mass are near zero when the projected center of mass approaches the center of the area of support. The kinetic energy attained during the flight phase is absorbed by bending the knees and hips.

Although the system we have developed is not yet complex enough to be a usable alternative to a motion library, we have demonstrated that a small set of parameterized basis controllers can be concatenated to create a set of fundamentally different behaviors. However, more basis controllers would be needed to produce a sufficient variety of motion for a video game. The transitions will likely become more complex as the variety of behaviors increases, and it may be necessary to use several intermediate controllers, like the landing controller, for complex transitions.



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Animating Quadrupeds with Footprints

All land dwelling animals leave trails of footprints on the ground whenever they walk along an impressionable surface. Our work attempts to do the opposite. Given a four-legged animal, we create the footprints and use these to animate the animal as it might have moved. This allows footprints to be used as a flexible and intuitive means for specifying quadruped motion.

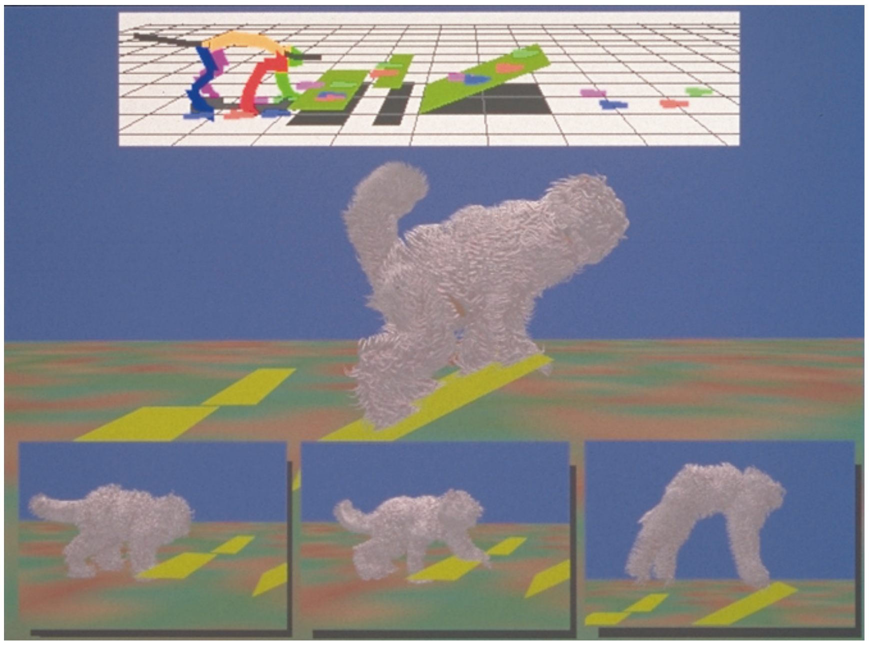
The user interface allows the user to load an animal, set the gait of the animal, and then position the footprints in the environment. Each footprint has several user-controlled parameters, namely a position, direction, time of creation, and duration. Our algorithm then generates movements of the animal that satisfy the footprint constraints.

We use a hybrid physically based / kinematic model to generate the animation. The underlying motion is represented using spline-based trajectories, which are subjected to optimization. A feature of our method is that it uses both physics and *comfort constraints* in the optimization function to ensure that the motion looks physically realistic and visually pleasing. The physical model is a coarse approximation of the real quadruped. Two point masses are used to represent the front half and back half of the animal, and the pairs of virtual legs attach to the body at the spine.

Optimization with respect to physics ensures the feasibility of acceleration in the movement. Note that this is not the same as examining static support, as commonly proposed in dedicated walking algorithms. The comfort constraints are a means of explicitly ensuring that awkward leg positions are avoided. The result of the optimization is a pair of trajectories for the two point masses.

Reconstructing the full motion from the trajectories requires constraining various degrees of freedom until the whole skeleton is constrained. We use the footprints to compute desired bends at the shoulders and hips. For the legs, we incorporate a flexible, parameterized inverse-kinematic model that uses table lookup for accelerated computation. Finally, secondary passive motion is employed to compute the motions of the tail and fur.

The results to date have been encouraging. Walking, running, and jumping motions as well as the associated transitions can be animated over variable terrain with little effort. Animated examples include coordinated jumping motions, bounding over stairs, walking on hind legs, and walking through tires.



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On a dark and stormy night, the appliances of a suburban household come to life. They scamper through the house, out to the sidewalk, and join all the other electrical gadgets from the neighborhood to see their cousin who has made the big time: the Electric Car. This scenario was the basis for “Appliances,” a commercial for the first car in history designed from the ground up as a mass-production electric vehicle.

Both computer graphics and animatronic models were used to make the spot. Slightly more than half the shots were CG, including the shots of appliances jumping off tables and running down the sidewalk, and the final shot with over 530 characters in it. We used CG whenever complex motion was desired, and when the sheer number of appliances made it impractical to do any other way.

Character design issues were critical in the creative development of the project. Just how would a toaster walk, if it did walk? Who would win if a vacuum cleaner and a blender had a race to the curb? (Answer: vacuum cleaner.) Initial tests used highly exaggerated motion, lots of squash and stretch, and other “cartoony” effects. As we refined the motion, we moved towards a more “realistic” look, while still trying to preserve the character and personality of each appliance. Walk cycles for each character were animated.

This sketch traces the creative and technical development of the project. It includes videotape of the earliest tests, principal photography, character modeling, and animation design.

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KEY CREDITS
Director: **Joe Johnston**
Producer: **Kip Larsen**
Director of Photography: **Allen Daviau**
Visual Effects Supervisor: **Alex Seiden**
Consulting Supervisor: **Sandy Karpman**
Lead Technical Director: **Doug MacMillan**
Lead Animator: **Paul Griffin**
Production Coordinator: **Amy Beresford**

"The Relic"

VIFX created a wide range of visual effects for "The Relic," but the main concern was the construction, animation, rendering, and compositing of the marauding star of the film: Kothoga.

Computer graphics solutions were essential for getting a rampaging performance from a fantastic creature – for the heavy action shots as well as the monster's six-foot tongue, which lovingly licks the heroine. Since the director wanted Kothoga's movement to resemble a big cat, we referenced wildlife footage of lions and tigers. Animators needed to have these ideas firmly planted in their heads.

We then turned our attention to researching animation tools. An armature (digital input device) was built to capture poses, but it was discarded in favor of software controls the R&D group built into the creature. Animators had solid CG backgrounds and, with movement references established, could translate their knowledge into useful techniques for animating Kothoga.

Procedural animation characteristics were also considered and discarded when it became apparent that the director had very shot-specific ideas on Kothoga's movements. Each scene featured some new aspect of the creature, so his animation would be unique from shot to shot. This parameter required that we divide the workflow appropriately, to exploit the strengths of multiple animation packages so animators could build on take after take in an efficient and timely manner.

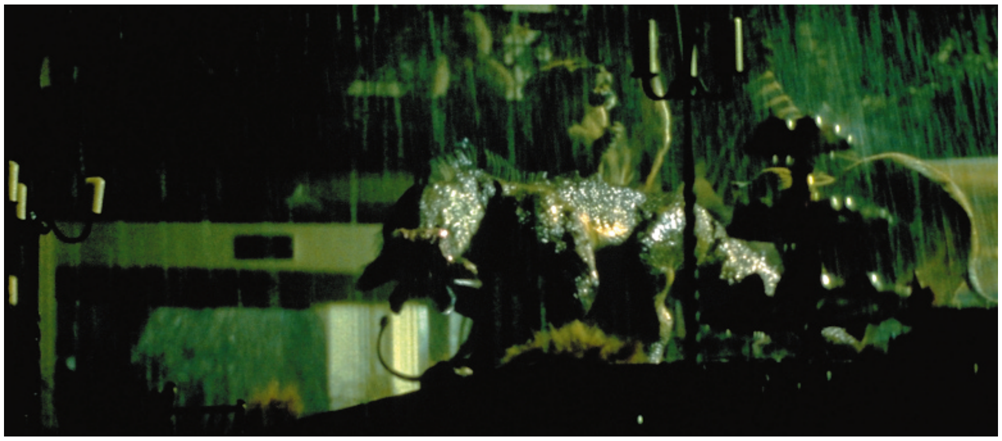
The problem was broken down in this fashion: We needed a place to track the scene (Prisms); to create reference geometry for scene tracking and character interaction (Prisms); to animate the skeleton many times over (Softimage); to skin the creature and create muscle deformations (Alias); to 3D paint color textures as well as displacement maps (Alias); and finally to render the final creature element (Sage/Prisms/Renderman). The packages were chosen based on their strengths at the time of R&D for this production (fall of 1995). VIFX in-house proprietary compositing software was used to bring the elements together.

Work on "The Relic" consisted of a vast array of CG techniques. A Chicago skyline matte painting was created. Digital skylights were tracked onto a museum rooftop. A stuntman's legs were removed and replaced with CG gore. A CG SWAT cop was decapitated. A CG shadow was added to the clean plate of a frightened dog. Wires and yellow-raincoated puppeteers were digitally removed from shots. Tons of CG debris (glass shards, wood splinters, candelabras) were added to scenes of destruction. CG drool was added to the tongue shots along with a digital "tug" on the heroine's dress and skin. CG rain and rain shaders were used on Kothoga to provide interaction of the water on his skin.

R&D for "The Relic" ran two and a half months, from the end of November 1995 to the end of January 1996. Actual post-production lasted from February through the beginning of May. At the end of this schedule, director Peter Hyams decided it would be extra fun and exciting to see Kothoga chase our heroine while he was on fire. So we quickly developed the look of Barbecued Kothoga.

No one technique seemed to work, so we settled on a combination of real fire elements (patch fire) and CG fire created with noise fields and displacement shaders (shader fire). CG smoke and embers added to the illusion. Construction of the end sequence was made more difficult because the shots into which burning Kothoga needed to be inserted were not designed as effects plates. It all had to be redesigned from scratch.

This last-minute creation demonstrates that CG effects are being used not only as tools of post production. They are also integral tools of the primary production process. The new ending of the film was conceived when the director realized what was available to him to tell his story, and he made production decisions based on possibilities he saw during the process.



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Most filmmakers choose to use computer-generated visual effects in their projects to go beyond the boundaries of the existing and traditional techniques. Director Roger Donaldson, in our early preproduction meetings, outlined his artistic and technical requirements for creation of synthetic lava and confirmed that “Dante’s Peak” would challenge all past attempts to create photo-realistic lava.

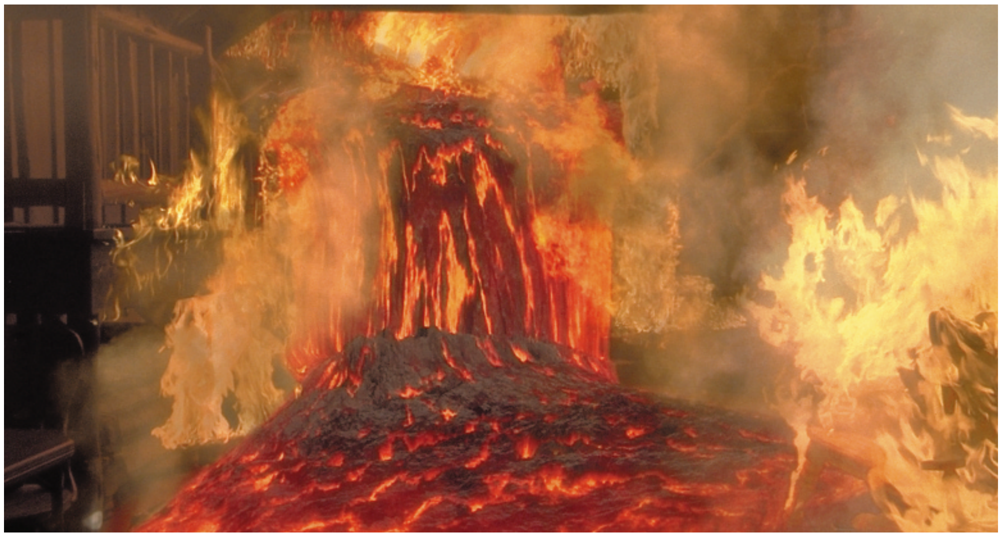
The director’s wish list included a fast moving river of lava, characterized by the familiar orange-red of molten rock at the edges, with a surface crust that is graphite black for the night shots and generic gray granite for the daylight scenes. The shape, speed, and viscosity of the lava had to be created according to its underlying terrain, interacting with stationary and moving objects in the various scenes, such as cars, furniture, trees, etc. The fast-moving lava nighttime scenes had to cast interactive lighting on the surrounding environment with moving orange light. The energy radiated by the lava surface had to produce a ripple-like heat distortion effect on the background objects. And the majority of the shots had to be photographed using hand-held cameras.

To resolve the complex set of issues involved in creating and integrating CG lava, Digital Domain's team created a production pipeline flexible and generic enough to give the director creative freedom and at the same time applicable to all type of shots.

The first step in creating the digital lava was the scientific approximation of its rough shape, position, and motion according to the production terrain and various locations the lava was moving over. We built a 3D computer model of the terrain for every production location in which lava interacted. The flexibility of this setup allowed artists relative ease in making necessary adjustments, based on creative input from the director, while maintaining the proper physics of the lava flow.

The next step was to make lava interact with objects from the live-action environment. A simulation of interaction between liquid and solid objects is not trivial, so a whole range of techniques including collision detection were developed.

Once the shape and motion of the lava were settled, all the surface details were added when the lava was rendered. Crust, cracks, and molten lava were all generated using a complex series of multifractals. These surface features were altered based on the behavior of the lava and the crust being enveloped by molten lava in areas where the lava geometry was colliding with objects in its path. This procedural method gave the lava a detailed and organic appearance, and was used to help simulate a variety of different lava "looks" for different scenes in the movie.



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"101 Dalmations"

The live-action remake of Disney's classic animated feature, "101 Dalmatians," called for computer-generated dalmatian puppies to seamlessly interact with (and in some cases replace) real dalmatians in a manner that was completely believable. In this project, we developed technical solutions that minimized costs, maximized efficiency, and, in so doing, allowed us to focus our energy primarily on maintaining the highest aesthetic standards. Due to the complexity of the shots in combination with the tight production schedule, we identified opportunities throughout the animation process to leverage reusable models, pre-animated cycles, and motion libraries.

From a creative perspective, animation was always our main concern. We wanted to match the CGI puppies' motion as accurately as possible with the motion of the live puppies. However, animating each individual dog (an average of 90 for every shot) would have been impossible in view of the time and budget constraints. Whatever the approach, we needed to guarantee as much visual consistency as possible in the animation. To address these challenges, we devised an animation pipeline incorporating reusable motion libraries that in turn allowed us to focus on the quality of the animation rather than the quantity.

During preproduction, various walk cycles, run cycles, trot cycles and sitting dogs were animated using Softimage 3.0 and an in-house program called Caricature. Then, using path animation, these cycles were attached to a spline object to recreate the correct amount of forward motion. Thereafter, the cycles were documented and added to a library database. To allow a dog to change its gait or behavior during a scene, various transition cycles (walk to run, run to walk, fast run to slow run, walk to stop) were also created. Together, these new files would offer a wide range of complex behaviors for use by the animators.

The next step in the process involved automatic creation of files with a non-animated figure that we referred to as the "pawn." The pawn was animated on a path that corresponded to the final animated cycle and transitional animation. These were used to choreograph and time the overall animation for each shot to ensure that no dog intersected another at any time. We defined each creature trajectory and projected it onto the "floor geometry," which was match-modeled to the shape of the terrain in the live action plate. A python script was developed so that animators could automatically connect each trajectory to a combination of dog cycle files. The animator would specify the type of gait and relative speed at a number of key frames. The script would insert appropriate motion curves from various gait and transition files, splicing them together and stretching them to fit together seamlessly. The pawn animation file served as an interactive and flexible way of addressing visual shot composition and allowed us to specify the number of dogs required for the shots, accurately reflecting what the final animation was going to be.

Once the overall choreography was approved, the pawn animation file was processed by a second python script to create animation files with complete articulated dogs. Because the motion used in the pawn animation was derived from the actual articulated animation cycle files, the fully animated dogs aligned exactly with their positions and speeds in the pawn animation, including through transitions.

Finally, animation of key dogs created by the script was enhanced by traditional CG animation techniques. In this step of the process, we created unique interactions of the CGI dogs with live dogs or with each other and the environment. The nuances and variations that were incorporated prevented the final animations from appearing cyclical.

"101 Dalmatians" was a landmark project in the development of techniques for addressing the monumental challenges faced when creating photo realistic animation that involves multiple creatures. This technique has been further improved and perfected as illustrated by our recent work on "The Lost World: Jurassic Park."

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Computer vision techniques are playing an increasingly important role in computer graphics applications requiring enhanced realism.[1,5] This synergy between computer vision and computer graphics is of paramount importance in virtual reality applications, where the use of complex models such as humans or other articulated objects and the modeling of their motions is often necessary.[2,6] A growing number of invasive solutions exist for three-dimensional estimation of the motion parameters of the human body, but these approaches suffer from cumbersome set-ups and alteration of user motion. More importantly, attaching markers makes it impossible for the system to be extended for many other applications such as performance evaluation in real sport competitions.

In this sketch, we describe a system that allows creation of an anthropometrically correct graphical model of a subject and of animations of the subject moving using the vision-based estimated parameters of motion (Figure 1). Our new system has a motion analysis part and a motion playback part. For the analysis part, the input is a sequence of grayscale images taken from multiple views, while the output is the anthropometric dimensions of the subject and the three-dimensional positions and orientations of the subject's body parts at each time instant. The motion playback part animates an anthropometrically correct graphical model of the participant resulting in real-time human motion visualization.

The system is currently passive; that is, the model is driven by the observations. For the current implementation, the background of the scene is static, and the subject is wearing tight-fitting clothes. This new algorithm advances the state of the art in motion capture because:

1. The use of occluding contours obviates the need for markers or special equipment.
2. The accuracy of tracking body parts is comparable to the accuracy achieved using markers.
3. The shape model is obtained from the observations and allows for enhanced realism.
4. The use of multiple cameras mitigates the difficulties arising due to occlusion among body parts since body movements that are ambiguous from one view can be disambiguated from another view.
5. Selection of the subset of cameras that provide the most informative views is accomplished in an active and time-varying fashion.
6. The estimation is based on the whole apparent contour rather than just a few points.

We demonstrate two case studies of possible applications of human body motion tracking, namely performance measurement of people with disabilities and vision-based trajectory input for dynamic simulators.

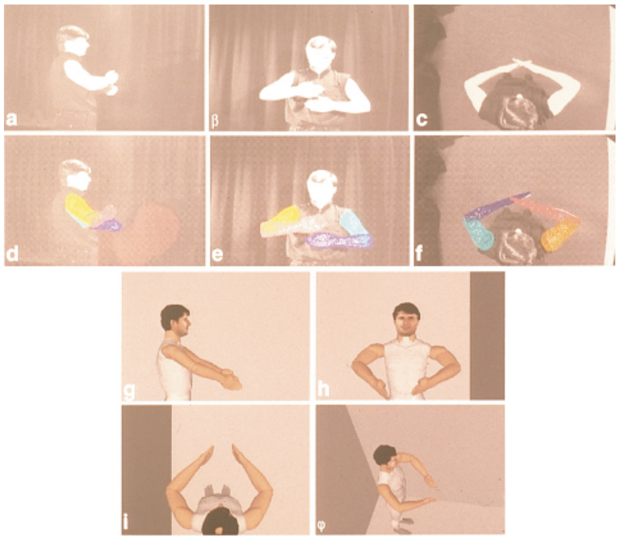

FIGURE 1

(a-c) Side, front and top views of the subject performing a complex two-arm motion.

(d-f) Recovered three-dimensional pose of the subject's upper and lower arms.

(g-i) The estimated motion parameters for the motion of the subject's arms have been applied to a *customized graphical model of the subject.*

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Visual Tracking and Pose Recovery for Special Effects

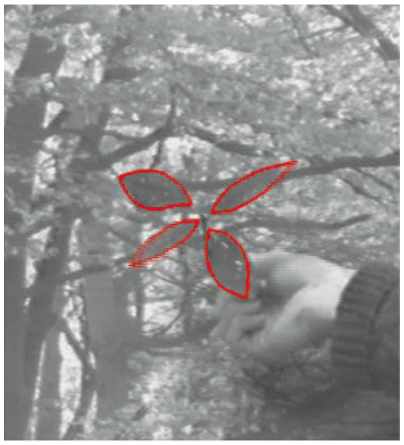
Object outlines are modeled as quadratic B-splines whose control points lie in a linear shape-space of possible configurations.[1] A rigid three-dimensional object can be modeled using a linear shape-space assuming that the outline of the object can be thought of as a wire-frame and that the available object views can be approximated using orthographic projection. The required shape-space is 3D affine and is eight-dimensional; moreover a simple, fast, and robust algorithm exists to compute the 3D pose of the object using the 3D affine coordinates. The pose specifies a coordinate frame for the tracked object, which can be used to render graphics onto the image that appears to be "attached" to the real object.

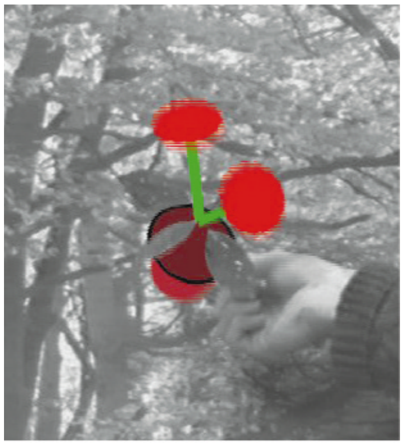
In order to construct the 3D affine shape-space, two views of the object are needed: one fronto-planar and one rotated through 90 degrees. These are computed using a robust approach that avoids problems with occlusion, using several uncalibrated views, all fairly close to the frontal view and processing them by means of a factorization method.[3] The recovered 3D structure can be used to build a solid model of the object that allows hidden surface removal and therefore rendering of artificial objects that pass behind the real one.

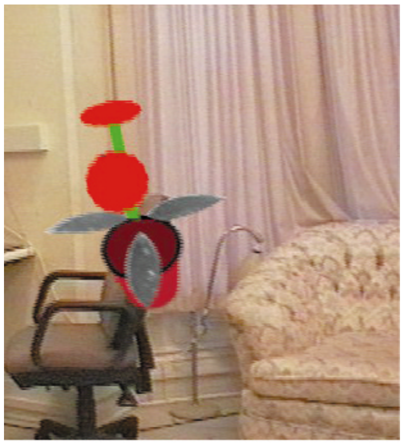
In order to reliably track an object through clutter it is necessary to construct a model of the object's likely motion as well as its shape. We use a standard form of motion model and learn the model from a training sequence.[1] Due to the heavy image clutter, a traditional Kalman filter tracker cannot be used, and we instead rely on the Condensation algorithm,[2] which is slower but more effective in clutter. We filmed two sequences showing the same small bunch of leaves being translated and rotated, first for 26 seconds against a white background, and then against a background of heavy clutter for five seconds. Fifteen views of the leaves were used to construct the 3D affine space, and a motion model was learned using the initial portion of the uncluttered sequence. The leaves were tracked using this model through both full sequences. The pose of the leaves was recovered from each tracked frame and used to superimpose a computer-generated bunch of flowers and flowerpot on the original images as shown in the figure.

Due to the difficulty of the tracking problem, a large number of random samples (N=7500) was used in the Condensation algorithm, and the algorithm ran at approximately two seconds per field on an SGI Indy R4400 200 MHz. Although the background demonstrated is static, no background subtraction was performed, and a moving background could equally well be tolerated. The figure also shows the more traditional matting application of transferring an object from one image sequence to another. Since pose has been recovered, computer graphics can be rendered attached to the foreground object at the same time.

We have demonstrated that state-of-the-art visual motion tracking can be combined with pose recovery to segment complex objects from a complex background and overlay computer-generated models on the original images. We have not, however, exploited all of the potential of the Condensation algorithm. It is clear that motion tracking and pose recovery are now sufficiently powerful and robust that they can usefully be included in the computer graphics toolkit. As graphics researchers begin to use such techniques from computer vision, new problem areas will be isolated and applications will be discovered hat will benefit both fields.







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Lip Synchronization for Animation

We report on research into the lip synchronization of speech that has not been preprocessed into phonetic units. It is based on the notion that given any spoken words as input, a computer can accurately portray the mouth movements made during the pronunciation of those words, and can do so without the necessity of speech recognition or electromechanical devices attached to the jaw.

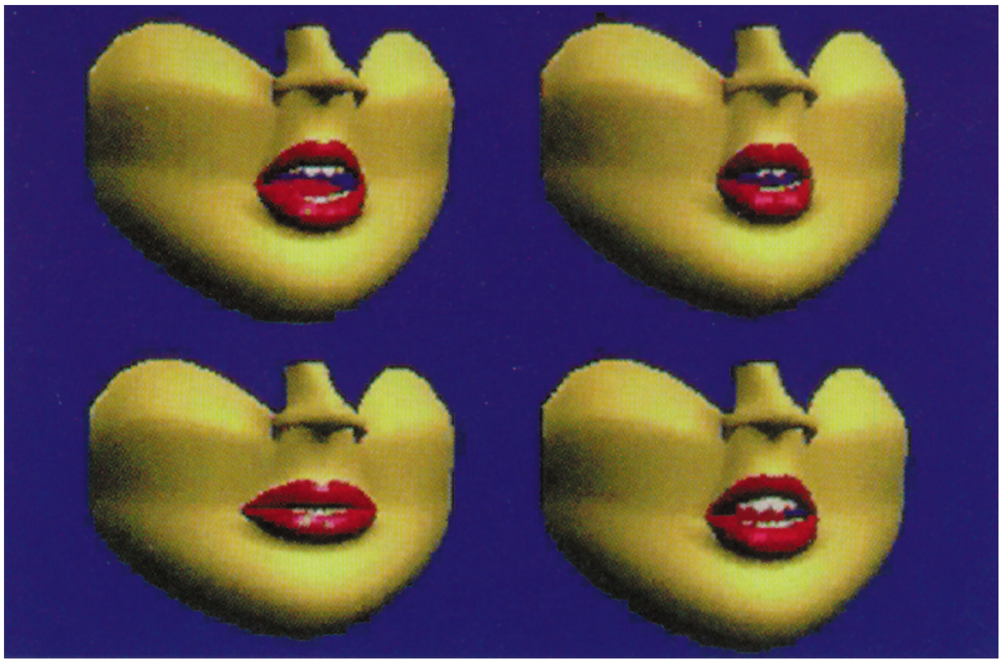
Our method is based on correlating parameters of lip and jaw movement with parameters drawn from the spectrum of the speech signal. We found a minimum of three parameters – horizontal lip opening, vertical lip opening, and jaw height – sufficient to allow the animation of a model of a generic human mouth. The speech parameters are derived by treating the magnitude of the discrete Fourier Transform as a probability density function and using well known statistical measures called moments to characterize the shape of the distribution.

To establish mouth shape predictor or training functions, which are described mathematically as a surface in multi-dimensional space, we videotape and record a speaker uttering a set of basic training sound transitions that cover the ranges of jaw position, lip rounding, and lip spreading. Using a very accurate glottal pulse estimation technique, the first, second, and third moments; second and third central moments; and various linear and nonlinear combinations of these moments are used to produce a set of independent variables. The mouth measurements obtained from the video are then used as the dependent variable, and a multivariate training surface (a thin plate spline) for each mouth parameter is derived from the training utterances.

When the speaker who was videotaped to train the system is used to test the system, the accuracy of the predictions is extremely high, well above the threshold necessary to animate the mouth in concert with the speech. We are currently working on construction of training surfaces that would provide adequate predicted mouth motion, independent of the speaker. We are also attempting to incorporate vowels that occur in languages other than English. We will then move to include voiced consonants such as /m/, /v/, /r/, and /z/.

We are augmenting this technique to include additional parameters such as tongue position and differentiation between the edges of the lips and the horizontal opening of the lips during speech. These parameters will help introduce more realism into the model. Modeling of actual human faces will be attempted later.

Applications include animation, training in lip reading, speech therapy, video conferencing, man-machine interfaces, voice compression, training and education, linguistic research, and help in speech recognition.



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Layered Compositing of Facial Expression

How does one make an embodied agent react with appropriate facial expression, without resorting to repetitive prebuilt animations? How does one mix and transition between facial expressions to visually represent shifting moods and attitudes? How can authors of these agents relate lower-level facial movements to higher-level moods and intentions?

We introduce a computational engine that addresses these questions with a stratified approach. We first define a low-level movement model having a discrete number of degrees of freedom. Animators can combine and layer these degrees of freedom to create elements of autonomous facial motion and then recursively build on this movement model to construct higher-level models. In this way, they can synthesize successively higher levels of autonomous facial expressiveness.

A key feature of our computational approach is that composited movements tend to blend and layer in natural ways in the run-time system. As the animator builds at higher levels, the correct layering priorities are always maintained at lower supporting levels. We have used this approach to create emotionally expressive autonomous facial agents.

Building on our work in improvisational animation (SIGGRAPH 96), we use a parallel layered approach. Our authoring system allows its user to relate lower-level facial movements to higher level moods and intentions by using a model inspired by optical compositing. We first allow the animator to abstract facial motion into a discrete number of degrees of freedom. The system does not impose a particular model at this stage, but rather allows the animator to define the degrees of freedom that he or she finds useful.

Given a set of degrees of freedom, we allow the animator to specify time varying linear combinations and overlays of these degrees of freedom. Each definition becomes a new, derived, degree of freedom. Collectively, these derived degrees of freedom create a new abstraction layer. We allow animators to recursively create successive abstractions, each built upon the degrees of freedom defined by previous ones.

More specifically, we internally represent each of the model's K degrees of freedom by a K dimensional basis vector, which has a value of 1 in some dimension j, and a value of 0 in all other dimensions. The state space for the face consists of all linear combinations of these basis vectors. We allow the animator to create time-varying functions (coherent noise and splined curves) of these linear combinations, to create a simple vocabulary of "basis motions." We then provide a motion compositing engine, which allows the animator to specify a compositing structure for these basis motions. The engine gives motions varying "opacities" and does alpha blending, much as Photoshop composites layers of images. The animator can then encapsulate sets of time-varying weights for each of the basis motions in the above engine and define each such set as a new motion basis. By doing this recursively, the animator can describe successively higher levels of an emotional vocabulary.

We have found that in this way, successively higher semantic levels of facial expressiveness can be effectively synthesized. In particular, we find that movements defined with this method tend to blend together and overlay in natural ways. As the animator works within higher abstractions, the system always maintains correct priorities at all lower supporting abstractions. The result is real-time interactive facial animation that can achieve a convincing degree of emotive expressiveness.

The eventual goal of this work is to give computer/human interfaces the ability to represent the subtleties we take for granted in face-to-face communication, so that they can function as agents for an emotional point of view. By automating the creation of facial expression in the run-time engine of an interactive agent, we enable such an agent to operate without the explicit intervention of a human operator.

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