

Stylized Depiction in Computer Graphics

Non-Photorealistic, Painterly and 'Toon Rendering

an annotated survey of online resources
by [Craig Reynolds](#)

News

The 3rd International Symposium on Non-Photorealistic Animation and Rendering
[NPAR 2004](#)
June 7-9, 2004 in Annecy, France
Paper submission deadline: **October 23, 2003**

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While I have not done research in this area myself, I am fascinated by the computer graphic technique known as *non-photorealistic rendering*. (Admittedly it is a little odd to name a field of study by what it is not. Stanislaw Ulam apparently once remarked: "The study of *non-linear physics* is like the study of *non-elephant biology*.") My list of links on this topic began to outgrow its place on my bookmarks list, so I created this page to give them a home, and perhaps to help other people interested in the field.

To better describe the kinds of techniques listed here, and to define the informal taxonomy used on this page, it is helpful to note that techniques for stylized depiction can be classified along the axis from interactive to fully automatic, and that there are three distinct types of input for these *stylized depiction* processes:

1. *3D scenes* (described in terms of geometry, color, lighting, etc.) for rendering
2. *images* for processing
3. *brushstrokes* from a user (like the input to a paint system)

In computer graphics, *photorealistic rendering* attempts to make artificial images of simulated 3d environments that look "just like the real world." So non-photorealistic rendering (NPR) is any technique that produces images of simulated 3d world in a style other than *realism*. Often these styles are reminiscent of paintings (*painterly rendering*), or of various other styles of artistic illustration (sketch, pen and ink, etching, lithograph, ...) Of

particular commercial interest are techniques that can render 3d scenes in styles which match the "look" of traditionally animated films. Often called *'toon shading*, these techniques allow for seamless combination of 3d elements with traditional cel animation.

Another important application of non-photorealistic rendering is to help the user understand that a depiction is only approximate. Psychologically, photorealistic rendering seems to imply an exactness and perfection which may overstate the fidelity of the simulated scene to a real object. The [Piranesi](#) system (mentioned below) has proved more useful than photorealistic rendering in an application that pre-visualizes kitchen remodeling. The [Teddy](#) modeler (see below) uses a sketchy rendering style to suggest the approximate 3D shapes it has inferred from the user's 2d drawing.

Also listed here are some *image processing* techniques which can transform an image into a style that suggests a painting or other artistic styles. The images can be photographic or from any other source. Some of the techniques have the ability to process a series of images, as from a video or film camera, and to produce a stylized image that remains stable from frame to frame, allowing the creation of something like an "animated painting."

This page also includes: (1) some computational techniques that carefully simulate traditional artistic media such as watercolor and ink painting, (2) some references to work on *non-traditional perspective* common to traditional illustration but rare in computer graphics, (3) techniques for finding and using silhouettes of 3D objects, (4) non-realistic techniques designed for real time or interactive rates, and (5) non-traditional halftones and screenings.

Finally it should be noted that any claim that an automatic process can produce "art" or a "painting" should be regarded as suspect. Making *art* is a creative and thoughtful process. It may even be uniquely human. The possibility of *artificial creativity*, let alone *artificial intelligence*, are open research questions. None of the techniques described here are candidates for true artificial creativity. I have tried to use neutral language ("...suggests a painterly style...") on this page to skirt the distinction between *art* and procedural techniques for stylized depiction.

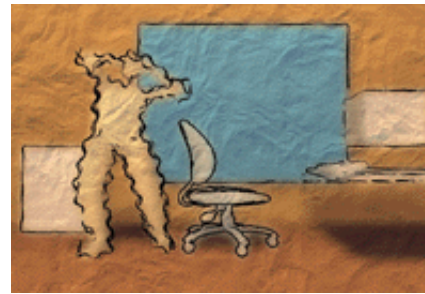
(Note: items marked **[new]** have been added in the three months prior to the time of the "last update" indicated at the bottom of this page.)



© 1996 [Barbara J. Meier](#)

Painterly Rendering

- [Painterly Rendering for Animation](#) (1996, PDF 0.26MB, [abstract](#)) by [Barbara J. Meier](#). [\[ResearchIndex\]](#) (See also this student project based on Meier's work: [The Painterly Approach](#) by [Wasinee Rungsarityotin](#) and [Victor Zordan](#) at Georgia Tech.)
- [Painterly Rendering from 3D](#) by [Remco Chang](#), [Markus Meister](#) and [Caroline Dahllof](#)
- [Computer-Generated Watercolor](#) (1997) by [Cassidy Curtis](#), [Sean Anderson](#), [Josh Seims](#), [Kurt Fleischer](#) and [David Salesin](#). See these [images](#).
- [Exploring the Parameter Space of a Ray-Traced Painterly Renderer](#) (1997) by [Jon Levene](#) and [David Weitzberg](#).
- [Implicit Painting](#) (1998) by [Ergun Akleman](#), procedurally drives "brushes" around implicitly defined surfaces, leaving either a trace of color or a tooth-paste-like extrusion of material.
- [Deep Canvas: Integrating 3-D Painting and Painterly Rendering](#) (2000) by George Katanics and Tasso Lappas (at the [Disney Tech](#) site) describes the technique first used in Disney's feature film [Tarzan](#). See also: a one page SIGGRAPH 1999 sketch [Deep canvas in Disney's Tarzan](#) (1999) by [Eric Daniels](#), this [Interview with Eric Daniels, CG Artistic Supervisor, "Tarzan"](#) (1999) by Audrey Doyle in [VFXPro](#), and a brief [illustration](#) of the technique at the official [Tarzan](#) web site. See also [Deep Background](#) (1999) by Barbara Robertson in [CGW](#).
- [Image Moment-Based Stroke Placement](#) (1999, PDF 4.7MB) by [Michio Shiraishi](#). Describes an enhancement to Haeberli's 1990 work *Paint By Numbers*, an automatic technique for determining stroke parameters which had been selected by hand in the original work.
- [Painterly Rendering for Realtime Applications](#) (2003) by [Daniel Sperl](#) is a realtime implementation in the [Cg](#) language of painterly rendering inspired by Meier. The site includes a [thesis](#) (in German, PDF 1.1MB), a [paper](#) (in English, PDF 1MB), images, movies, source code and an application. **[new]**

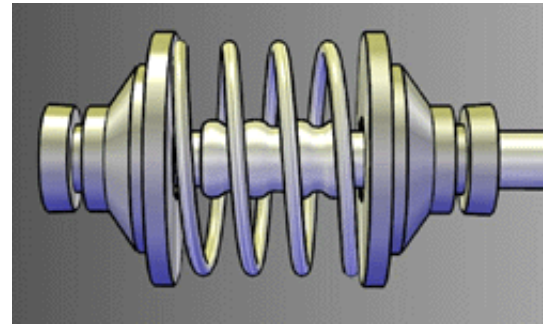
© 1998 [Cassidy Curtis](#)© 1998 [Jörg Hamel](#)© 1999 [Victor Ostromoukhov](#)

Sketching, Pen-and-Ink, Engraving (and related high-contrast rendering styles)

- [Computer Sketching](#) (1990) by [Paul Bourke](#), transforms line drawings from a CAD system to look something like a hand-sketched pencil drawing.
- [How to Render Frames and Influence People](#) (1994) by [Thomas Strothotte](#), [Bernhard Preim](#), [Andreas Raab](#), Jutta Schumann and [David Forsey](#). Early, influential paper on sketch rendering and the perceptual effects of various rendering styles on the user.
- [Computer-Generated Pen-and-Ink Illustration](#) (1994) by [Georges Winkenbach](#) and [David Salesin](#).
- [Computer Generated Copper Plates](#) (1994) by [Wolfgang Leister](#), see these [images](#).
- [Rendering parametric surfaces in pen and ink](#) (1996) by [Georges Winkenbach](#) and [David Salesin](#)
- [Assessing the Effect of Non-Photorealistic Rendered Images in CAD](#) (1996) by Jutta Schumann, [Thomas Strothotte](#), [Andreas Raab](#), and Stefan Laser.
- [Scale-dependent Reproduction of Pen-and-ink Illustrations](#) (1996) by Mike Salisbury, [Corin Anderson](#), [Dani Lischinski](#) and [David Salesin](#). See also this related 1998 [class project](#) by [Audrey Wong](#).
- [daLi! - Drawing Animated Lines!](#) (1997) by [Maic Masuch](#), [Stefan Schlechtweg](#) and [Bert Freudenber](#). See also [Animating Frame-to-Frame Coherent Line Drawings for Illustrative Purposes](#) (1998) by [Maic Masuch](#), [Lars Schumann](#) and [Stefan Schlechtweg](#). And see the [daLi! gallery](#) of sketch rendering.
- [A nonphotorealistic renderer](#) by [Antonio Haro](#), see also this [gallery](#).
- [Lines and How to Draw Them](#) (1997) by [Stefan Schlechtweg](#) surveys three expressive styles of line drawing.
- [Inklination](#) commercial Mac software to convert from 3d models to artistic portrayals. See their [galleries](#).
- [Loose and Sketchy Animation](#) by [Cassidy Curtis](#). See also this related [student project](#) by [John Halstead](#).
- [Orientable Textures for Image-Based Pen-and-Ink Illustration](#) (1997) Mike Salisbury, Michael Wong, [John F. Hughes](#) and [David Salesin](#).
- [An Approach to Visualizing Transparency in Computer-Generated Line Drawings](#) (1998, Postscript 2MB) by [Jörg Hamel](#), [Stefan Schlechtweg](#) and [Thomas Strothotte](#). See these [pictures](#)
- [Virtual sculpting and virtual woodcut printing](#) (1998, abstract) by [Shinji Mizuno](#), Minoru Okada, and [Jun-ichiro Toriwaki](#). Constructs models reminiscent of carved wooden sculpture, which can be used to generate a woodcut print. The [full paper](#) (PDF, 886KB) is available but requires a paid subscription to *The Visual Computer*.
- [Capturing and Re-Using Rendition Styles for Non-Photorealistic Rendering](#) (1999, PDF 9MB) by [Jörg Hamel](#) and [Thomas Strothotte](#). See these [pictures](#).
- The [IRIT](#) system by [Gershon Elber](#) includes a *line drawing illustration tool* ("illustrt"). See these [images](#).
- [An Illustration Technique Using Hardware-Based Intersections and Skeletons](#) (1999) by [Oliver Deussen](#), [Jörg Hamel](#), [Andreas Raab](#), [Stefan Schlechtweg](#), and [Thomas Strothotte](#).
- [Digital Facial Engraving](#) (1999) by [Victor Ostromoukhov](#), full paper is [available](#) (PDF 12MB). Process to transform images into *gravure* style graphics.
- [Line Direction Matters: An Argument For The Use Of Principal Directions In 3D Line Drawings](#) (2000, PDF 6.2MB) [Ahna Girshick](#), [Victoria Interrante](#), [Steven Haker](#) and [Todd Lemoine](#). Using lines along the first and second principal directions of curvature to communicate surface shape. Abstract and compressed PDF files [here](#).
- [Floating Points: A Method for Computing Stipple Drawings](#) (2000, PDF 0.7 MB) by [Oliver Deussen](#), [Stefan Hiller](#), [Cornelius van Overveld](#) and [Thomas Strothotte](#). Pen-and-ink illustrations with simulated stippling, uses a relaxation method based on Voronoi diagrams. [ResearchIndex](#)
- [Illustrating Smooth Surfaces](#) (2000) by [Aaron Hertzmann](#) and [Denis Zorin](#). Line-art rendering of smooth surfaces: new techniques for finding silhouettes and their visibility (a novel approach using homogeneous coordinates and dual surfaces), automatic method for creating hatch marks to convey surface shape. Full paper is [available](#) (PDF 7 MB).
- [Computer-Generated Pen-and-Ink Illustration of Trees](#) (2000, PDF 0.6 MB) by [Oliver Deussen](#) and [Thomas Strothotte](#) describes automatic creation of pen-and-ink illustrations of trees with different drawing styles and levels of abstraction. The technique is suitable for animation.
- [Line-Art Rendering of 3D-Models](#) (2000) by [Christian Rössl](#) and [Leif Kobbelt](#) presents an interactive system for generating line art drawings to illustrate 3D models that are given as triangulated surfaces. Strokes are

defined by tracing streamlines of principal curvature.

- *Algorithms for Sketching Terrain* (2000) by [Mahes Visvalingam](#) in a presentation to the Royal Institute called [Art in Scientific Visualization of Terrain Data](#). See also [Sketch-based Evaluation of Line Filtering Algorithms](#) (2000, [abstract](#)) regarding cognitive evaluation of sketches



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Stylized Depiction to Enhance Legibility

- [Comprehensible Rendering of 3-D Shapes](#) (1990) [Takafumi Saito](#) and Tokiichiro Takahashi, Proceedings of SIGGRAPH 90, Computer Graphics, Annual Conference Series, 1990, pages 197-206.
- [Interactive Intent-Based Illustration: A Visual Language for 3D Worlds](#) (1993) Ph.D dissertation by [Dorée Duncan Seligmann](#) describes the IBIS system for intent-based illustration. Its goal is to generate a 3d rendering of a scene to convey a *intent* expressed in a high-level specification language.
- [A Non-Photorealistic Lighting Model For Automatic Technical Illustration](#) (1998) by [Amy Gooch](#), [Bruce Gooch](#), [Peter Shirley](#) and [Elaine Cohen](#). See this page of [Images and References](#).
- [Generating Scientific Illustrations in Digital Books](#) (2000, PDF 0.73MB) by [Stefan Schlechtweg](#) and [Thomas Strothotte](#) describes the creation of illustrations for a digital book based on 3d geometrical models and various styles of visualization. (From [Smart Graphics](#).)
- [Rendering Effective Route Maps: Improving Usability Through Generalization](#) (2001) by [Maneesh Agrawala](#) and [Chris Stolte](#) describes a technique for producing non-realistic *route maps* (directions for driving from one place to another) which are more legible than geographically accurate maps. They exaggerate the lengths of short roads to maintain visibility and straighten the shape of roads to produce a simple, clean map. You can use these [LineDrive](#) directions yourself at [MapBlast](#). [[ResearchIndex](#)]



© 1999 [Kowalski](#) *et al.*

Other Rendering Styles

- [Non-Photorealistic Rendering](#) (1998) by [Bill Feth](#) (based on earlier work by [Bruce Land](#)). Built upon the [DX](#) (Data Explorer) system, creates shaded images with limited palettes (reminiscent of serigraphs), outlined in a pen-and-ink style.
- [Non-Photorealistic Rendering Image Gallery](#) (and related pages) by [Daniel Teece](#). See also this citation of a SIGGRAPH Sketch: [3D painting for non-photorealistic rendering](#) (1998).
- [Art-Based Rendering of Fur, Grass, and Trees](#) (1999, PDF 748KB) by [Michael A. Kowalski](#), [Lee Markosian](#), [J.D. Northrup](#), [Lubomir Bourdev](#), [Ronen Barzel](#), [Loring S. Holden](#) and [John F. Hughes](#).
- [EVA Expressive Renderer](#) (1999) by [Dave Gordon](#) is a unique rendering framework utilizing a C++ based shading language and provides a host of 2D and non-photorealistic effects based on the concept of a *mark generator*. Take a look at the amazing imagery in the [EVA gallery](#).
- [Art-based Modeling and Rendering for Computer Graphics](#) (2000, PhD dissertation, PDF 2.8MB) by [Lee Markosian](#). Seeks to use techniques from traditional art and illustration to increase the expressive power of 3D computer graphics. See also the related pages of the [Art-based Modeling and Rendering](#) project.
- [Art-based Rendering with Continuous Levels of Detail](#) (2000) by [Lee Markosian](#), [Barbara J. Meier](#), [Michael Kowalski](#), [Loring S. Holden](#), [J. D. Northrup](#) and [John F. Hughes](#). Extends [previous art-based rendering](#) work to provide better frame-to-frame coherence of the *graftal* elements of which the images are constructed. The page includes an abstract, the full [paper](#) (PDF, 0.4MB) and animated sample images.
- [The Lit Sphere: A Model for Capturing NPR Shading from Art](#) (2001) by [Peter-Pike J. Sloan](#), [William Martin](#), [Amy Gooch](#) and [Bruce Gooch](#) describes a system for *shading by example*. 3D models are shaded with a spherical diffuse color map. This map is created by interactively selecting regions of a prototype stylized image to form pie-slice shaped sectors of the sphere map. The full paper is [available](#) (PDF 1.26 MB).
- [View-Dependent Particles for Interactive Non-Photorealistic Rendering](#) Derek Cornish, [Andrea Rowan](#) and [David Luebke](#) represents a 3D model as a system of particles, placed by a view-dependent clustering

algorithm. The algorithm unifies several tasks: placing strokes, regulating screen-space stroke density, and ensuring coherence for animation. The full paper is [available](#) (PDF, 0.15 MB). [ResearchIndex](#)

Stylized Halftoning

- [Artistic Screening](#) (1995) by [Victor Ostromoukhov](#), full paper is [available](#) (PDF 3.7MB). Technique to create halftone style images using arbitrary high contrast micro art to shape the halftone "dots." See also the [ArtScreen](#) page.
- [Special Effects with Half-Toning](#) (1996) by [John W. Buchanan](#).
- [An interface for the interactive design of artistic screens](#) (1998) by [Nicolas Rudaz](#), [Roger D. Hersch](#), and [Victor Ostromoukhov](#), full paper is [available](#) (PDF 1MB).
- [Importance Driven Halftoning](#) (1998, Postscript 2.2MB) by [Lisa Streit](#) and [John Buchanan](#). Introduces a user-defined *importance function* which controls the nature fo the half tone, allows user selection of drawing primitive.
- [Multi-Color and Artistic Dithering](#) (1999) by [Victor Ostromoukhov](#), full paper is [available](#) (PDF 5.5MB). Generalizing the Artistic Screening to color printing.
- [Halftoning with Image-Based Dither Screens](#) (1999) [Oleg Veryovka](#) and [John Buchanan](#). Full paper is [available](#) (compressed Postscript 495 KB).
- [Non-photorealistic Rendering Using an Adaptive Halftoning Technique](#) (1999, Postscript 4.4MB) by [Lisa Streit](#), [Oleg Veryovka](#) and [John Buchanan](#). Control of tone and texture for non-photorealistic halftones.
- [Comprehensive Halftoning of 3D Scenes](#) (1999, PDF 718KB) by [Oleg Veryovka](#) and [John Buchanan](#). Uses additional information from rendered 3D scenes to create stylized halftones better suited to the subject matter.

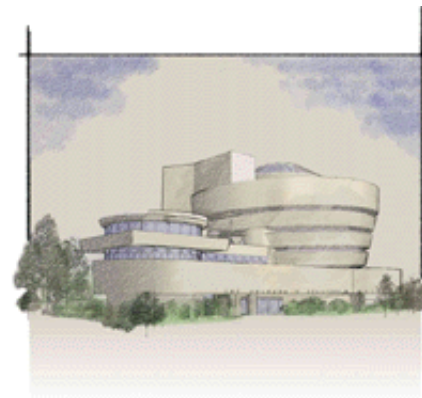


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Real Time Techniques (or at least, those running at *interactive rates*)

- [Real-Time Non-photorealistic Rendering](#) (1997) by [Lee Markosian](#), [Michael A. Kowalski](#), [Samuel J. Trychin](#), [Lubomir Bourdev](#), [Daniel Goldstein](#), and [John F. Hughes](#). Trades accuracy and detail for speed, uses a method for determining visible lines and surfaces which is a modification of Appel's hidden-line algorithm.
- [Implicit Surface Renderer](#) (1998) by [David Bremer](#) and [John F. Hughes](#) features (almost) real time non-photorealistic rendering of implicit surfaces in a *sketchy* style. See also [Rapid Approximate Silhouette Rendering of Implicit Surfaces](#) (1998, (6.3MB Postscript))
- [Interactive Line Art Rendering of Freeform Surfaces](#) (1999, 2.8MB compressed Postscript) by [Gershon Elber](#). Uses extensive preprocessing to provide display of polynomial and rational surfaces at interactive rates.
- [Interactive Technical Illustration](#) (1999) by [Bruce Gooch](#), [Peter-Pike J. Sloan](#), [Amy Gooch](#), [Peter Shirley](#) and [Richard Riesenfeld](#). Uses non-photorealistic lighting, silhouetting, and shadowing in an interactive environment to produce rendering of 3d models enhanced for illustrative purposes.
- [Real-Time Painting](#) (1999) by [Aaron Hertzmann](#) is a high speed version of his techniques described in the *Painterly Image Processing* section of this page.
- [Real-time Principal Direction Line Drawings of Arbitrary 3D Surfaces](#) (1999) by [Ahna Girshick](#) and [Victoria Interrante](#). Uses the principal directions of curvature to guide lines over curved 3D surface, can be rendered in real-time.
- [Cartoon Rendering on the GeForce 256](#) (1999) by [Sim Dietrich](#). This white paper written for [NVIDIA](#) developers describes toon rendering techniques implemented on the GeForce 256 hardware.
- [SigGraph/UIUC Real-Time Painterly Rendering](#) (2000) by [Josh Michaels](#), Shanon Drone, Phil Smith, Don Schmidt. The page includes an abstract, sample images, and source code.
- [Shades of Disney: Opaquing a 3D World](#) (2000, PDF, 0.3 MB) by [Jeff Lander](#) describes real time cartoon and sketch rendering for use in games. See the companion article [Under the Shade of the Rendering Tree](#) (2000, PDF, 0.3 MB). They were published in in the February and March 2000 issues of [Game Developer](#) magazine. See also this [online supplement](#) with links to source code and executable for a real-time cartoon rendering demo.
- [Stylized Rendering Techniques for Scalable Real-Time 3D Animation](#) (2000, PDF, 2.4 MB) by [Adam Lake](#), [Carl Marshall](#), [Mark Harris](#) and [Marc Blackstein](#). See also this project page: [Non-Photorealistic Rendering \(Toon\)](#) and these [slides](#) from a presentation at the Game Developers Conference 2000.
- [Interactive Artistic Rendering](#) (2000, PDF 1.66 MB) by [Matthew Kaplan](#), [Bruce Gooch](#) and [Elaine Cohen](#). Rendering subdivision surfaces of complex scenes, at interactive rates, in a variety of artistic styles using an interactively editable particle system. See also this page of [sample animations](#).
- [Performance-Driven Hand-Drawn Animation](#) (2000, PDF 713KB) by [Ian Buck](#), [Adam Finkelstein](#), Charles Jacobs, [Allison Klein](#), [David Salesin](#), [Joshua Seims](#), [Rick Szeliski](#) and [Kentaro Toyama](#). Describes a method for generating performance-driven, hand-drawn animation in real-time. Does multi-way morphs to generate real-time animation that mimics the expressions of a user.
- [Painterly Rendering for Video and Interaction](#) (2000, PDF 0.9 MB) by [Aaron Hertzmann](#) and [Ken Perlin](#). Real time painting over successive frames of animation, applying paint only in regions where the source video is changing. Brush strokes may be warped between frames using optical flow.

- [Non-Photorealistic Virtual Environments](#) (2000) by [Allison W. Klein](#), [Wilmot Li](#), [Misha Kazhdan](#), [Wagner Toledo Corrêa](#), [Adam Finkelstein](#) and [Thomas A. Funkhouser](#). Real time walk-throughs of architectural interiors using stroke-based textures and image based rendering methods. Full paper is [available](#) (PDF, 12.5 MB).
- [NPRQuake](#) (2000) by [Alex Mohr](#), [Erik Bakke](#), [Andrew Gardner](#), [Christopher Herrman](#) and [Steve Dutcher](#) modifies GLQuake to render in several real-time stylizations. This is accomplished by intercepting the OpenGL library calls. See the Mohr and Gleicher I3D 2001 paper (below) for more details.
- [Non-Invasive, Interactive, Stylized Rendering](#) (2001) by [Alex Mohr](#) and [Michael Gleicher](#) describes a technique for taking an existing OpenGL application and changing it to use new visual stylizations. This is done "non-invasively": without modifying the application's source code. Instead the OpenGL calls are intercepted and reinterpreted to produce stylized portrayal. The web page includes animation, additional figures and the full paper is [available](#) (PDF, 0.04 MB).
- [Real-Time Hatching](#) (2001) by [Emil Praun](#), [Hugues Hoppe](#), [Matthew Webb](#) and [Adam Finkelstein](#) a real-time system for non-photorealistic rendering of hatching strokes over arbitrary surfaces. Preprocessing builds a *tonal art map*. Hardware multitexturing blends hatch images over rendered faces, varying tone while maintaining spatial and temporal coherence. Based on [lapped textures](#). The full paper is [available](#) (PDF 5.75 MB).
- [Real-Time Stroke Textures](#) (2001, PDF 0.6 MB) by [Bert Freudenberg](#) uses per-pixel-shading graphics hardware to implement non-photorealistic shading with hatching textures. There are links to slides and movies on the author's [publication](#) page.



created with [Piranesi](#)
by [Kyoto Institute of Technology](#)

Interactive Techniques

- [Paint By Numbers: Abstract Image Representations](#) (1990) by [Paul Haeberli](#) (full paper is [available](#) (PDF 7.4 MB) but requires ACM Digital Library access). Describes interactive "over-painting" of an image with a shaped color-sampling brush. For an interactive sample, visit Paul's [Impressionist](#) applet. (This techniques is now available in commercial software such as [Instant Photo Artist](#) and [Deep Paint](#))
- [Interactive Pen-and-Ink Illustration](#) (1994) Michael P. Salisbury [Sean Anderson](#), [Ronen Barzel](#) and [David Salesin](#).
- [Piranesi](#) is a commercially available system which allows interactive post processing of rendered 3d scenes (with z-buffer data) to achieve various artistic styles. See this [gallery](#). Originally *Piranesi* was an academic project, see; [Interactive Rendering and Non-photorealistic Rendering](#): the *Piranesi* system, see its [Gallery of Non-photorealistically Rendered Images](#), and the paper [Interactive Computer Rendering](#) (1995) by [Paul Richens](#) and [Simon Schofield](#) and [Beyond Photorealism](#) (1997) by [Paul Richens](#).
- [LiveArt](#) (formerly ThinkFish LiveStyles)
- [Harold: A World Made of Drawings](#) by [Jonathan Cohen](#), [John F. Hughes](#) and [Robert Zeleznik](#). Creating 3d virtual environments from hand-drawn 2D input. 3D objects are made of planar strokes, reoriented for camera motion. The page includes an abstract, the full [paper](#) (PDF, 845KB) and a video demonstration.
- [Decoupling Strokes and High-Level Attributes for Interactive Traditional Drawing](#) (2001) by [Frédo Durand](#), [Victor Ostromoukhov](#), [Mathieu Miller](#), [François Duranleau](#) and [Julie Dorsey](#) describes an interactive drawing system in which the user draws abstract *strokes* over a reference photograph. The system has high level controls to select various stylizations which are displayed in real time. Sample images and the full paper is [available](#) (PDF 3.3 MB).
- [WYSIWYG NPR: Drawing Strokes Directly on 3D Models](#) (2002) by [Robert D. Kalnins](#), [Lee Markosian](#), [Barbara J. Meier](#), [Michael A. Kowalski](#), [Joseph C. Lee](#), [Philip L. Davidson](#), [Matthew Webb](#), [John F. Hughes](#) and [Adam Finkelstein](#). Allows the user to paint brush strokes directly on the surface of a 3d model. Silhouette and hatching strokes are identified. The number and placement of hatching strokes is adjusted as the model is rendered. Silhouette strokes in a similar style are synthesized for newly exposed object edges. The project page contains the [full paper](#) (PDF 2.5MB), movies and still images.
- [Object-Based Image Editing](#) (2002, PDF 16MB) by [William Barrett](#) and [Alan Cheney](#), uses image segmentation to identify *objects* in the image as regions of pixels. The objects can then be "scaled, stretched, bent, warped or even deleted."

3D Modeling Based on 2D Sketch Input

- [Teddy](#) a sketch-based 3D modeling system (1999) by [Takeo Igarashi](#), [Satoshi Matsuoka](#) and [Hidehiko Tanaka](#), uses a fast sketch renderer. See the paper [Teddy: A Sketching Interface for 3D Freeform Design](#) (PDF, 650KB) and the [Java applet](#).
- [Sketching with Projective 2D Strokes](#) (1999) by [Osama Tolba](#), [Julie Dorsey](#), and [Leonard McMillan](#). Describes a 2D sketching program which incorporates a simple representation of 3D space, essentially providing a panoramic sketchpad. See also this [PDF](#) (4.24 MB) version of the paper, [MPEG video clips](#) and this [Java applet](#).

- [SketchUp](#) (2000) a commercial sketch-based 3D design system. Infers 3D architectural forms from sketched input. Free demo version [available](#). See this [gallery](#) and these animated [demos](#) of the system.

Toon Shaders/Plug-Ins (and related "cel-look" effects)

- [Using Arbitrary Output Variables in PhotoRealistic Renderman](#) (1998, Application Note #24) includes examples of "cel-like", "painted-like", and "pen and ink" rendering styles.
- [Cartoon-Looking Rendering of 3D Scenes](#) (1996) by [Philippe Decaudin](#)
- [toon - A shader for cartoon rendering](#) (1997, for RenderMan) by [Colin Doncaster](#)
- [Toon Rendering](#) for [Softimage](#) by [Michael Arias](#). This is one of the more widely used toon rendering plug-ins. The site contains sample images, tutorials, and other articles.
- [Cartoon Shading Using Shading Mapping](#) (for PowerAnimator) by [Jake Morrison](#)
- [Super Hero](#) tests (still and animated) by [Vision Scape Imaging](#) for a client called Ideal Entertainment.
- [Super Cel Shader 1.00 Tips and Tricks](#) (for LightWave 3D) and a [gallery](#) at the [Celshader.com](#) site of [Jennifer Lynn Hachigian](#).
- CartoonReyes is a [plug-in](#) shader for 3D Studio MAX. Here is a [sample image](#) and a demo program is available. This [tutorial](#) and this [review](#) apparently refer to the same system.
- [The Incredible Comicshop](#) (for 3D Studio Max, see [also](#)) from [Meme-X](#).
- [Illustrate!](#) toon and illustration renderer plug-in for 3D Studio Max. See this [gallery](#).
- [Toon Up Pro](#) cel shading for trueSpace. See this [gallery](#).
- [Scene III](#) a 3d plug-in for Animo 3, supports Cartoon Shading
- [Toon!](#) for Ray Dream 5.02 and 5.5 (and Carrara(?)) by Eric Winemiller, see this [gallery](#).
- [Toony Shaders](#) for RenderMan ("Dang I'm tired of photorealism") by [David "Neal" McDonald](#), see also this [Page Of Really Way Too Large Images](#)
- [Alice: Toon-Textures](#) a stylized rendering package for the [Alice](#) Interactive Graphics Programming Environment from CMU's [Stage 3 Research Group](#).
- [ToonShader](#) (2001) from [Toon Boom](#) is a plug-in for the USAnimation system and exports to Maya. It is described on this [brochure](#) (PDF 0.05 MB)



© 1993 [Cabral](#) and [Leedom](#)



© 1999 [RE:Vision Effects](#)



© 1998 [Aaron Hertzmann](#)

Painterly Image Processing Techniques

- [Imaging Vector Fields Using Line Integral Convolution](#) (1993) by [Brian Cabral](#) and [Leith \(Casey\) Leedom](#) (full paper is [available](#) (PDF 1.5 MB) but requires ACM Digital Library access). Primarily used for visualizing 2 and 3 dimensional vector fields, the LIC technique operates by distorting texture maps along streamlines of the vector field. It can be used to produce a "wind-blown wet paint" version of a source image.
- [Speckle Painting](#) (1997) by [Paul Bourke](#), simulating the paintings of the aboriginal Australian.
- [Processing images and video for an impressionist effect](#) (1997) by [Peter Litwinowicz](#) (full text in [PDF](#) format (3.5 MB), requires ACM Digital Library access, as does this description of, and image from, Pete's animation [Impressions of San Francisco](#)). See also this [summary](#) by [Matthew Ward](#).
- [Painterly Rendering with Curved Brush Strokes of Multiple Sizes](#) (1998) by [Aaron Hertzmann](#), full paper is [available](#) (PDF 425KB). See also [Painterly Video Processing](#) on an approach to process sequences of video frames.

- [Painterly Rendering with a Painter's Perspective](#) by [Caroline Dahllof](#)
- [Automatic Generation of Non-Photorealistic Images](#) by Steve Treavett (?)
- [RE:Vision Effects](#) makers of the *Video GoghTM* system, a simple version of their technology seen in the 1998 feature film [What Dreams May Come](#) (see also the [official site](#) and this page at [GOAT](#)).
- [Artistic Rendering of Portrait Photographs](#) thesis research by [Eric Wong](#): preliminary samples of photographic portrait images processed into what looks like pencil drawing. (*Note: Eric graduated, Cornell removed his pages. When he sets up a new web site this link will be updated. 12-7-99*)
- [Generalized Impressionistic Texture Matrix Generator](#) by [Ken Musgrave](#) and [Myeong L. Lim](#). GIT creates *juxtaposition* of color (producing tones by placing small areas of several colors close to each other) in a manner suggesting the impressionist technique. See also Lim's [GIT](#) page and his [gallery](#). See also this draft of a SIGGRAPH art sketch [The Generalized Impressionistic Texture Matrix Generator](#) (Postscript 794KB) and a draft paper [A Statistical Approach to Color Juxtaposition](#).
- [Non-Photorealistic Effects](#) (1998) by [Rob Ashdown](#), a gallery of several images processed into several styles (pencil, watercolour, tapestry, chalk, by numbers, etching).
- [Paint Alchemy](#) a Photoshop plug-in from Xaos Tools for painterly image processing. See this [gallery](#).
- [Paint By Relaxation](#) (2001) by [Aaron Hertzmann](#) describes painterly image processing of still and moving images. A user-defined *energy function* controls the stylization. The output image is generated by searching for a collection of *brush strokes* with minimal energy. This approach yields good frame to frame coherence for moving images. Full paper is available in several lengths and formats including this CGI 2001 [paper](#) (PDF 17 MB).
- [Image Analogies](#) (2001) by [Aaron Hertzmann](#), [Charles E. Jacobs](#), [Nuria Oliver](#), [Brian Curless](#), and [David Salesin](#) describes processing images by example: learning an image transformation from one pair of *before* and *after* images, then applying the transformation to a third image to produce a fourth. The [project page](#) links to full paper, examples images and software.
- [Abstracted Image Stylization](#) by [Doug DeCarlo](#) and [Anthony Santella](#) contains images and links related to two related 2002 papers: [Abstracted Painterly Renderings Using Eye-Tracking Data](#) (PDF 1.8 MB) and [Stylization and Abstraction of Photographs](#) (PDF 1.8 MB). In this work, eye tracking technology is used to capture which areas of a photograph are most important. A stylized version of the image is created introducing line along edges and abstracted regions of constant color obtained from segmentation. Detail is concentrated in the areas deemed important during eye tracking.
- [Stylized Video Cubes](#) (2002) by [Allison W. Klein](#), [Peter-Pike J. Sloan](#), [Adam Finkelstein](#) and [Michael F. Cohen](#). Describes an approach to stylizing video which treats the video as a space-time volume of image data. Stylized elements, such as brush strokes, are defined over time and space, then sampled as needed. The [full paper](#) (PDF 1.5MB) is available online.

© 1986 [Steve Strassmann](#)

Simulation of Traditional Artistic Media

- [Hairy brushes](#) (1986) by [Steve Strassmann](#) simulates the traditional Japanese art of *sumi-e* by modeling the motion and bristles of the brush and the absorption of the ink into the paper. There is a brief description of Strassmann's work in [Lines and How to Draw Them](#) (1997) by [Stefan Schlechtweg](#). The gist of Strassmann's work was reimplemented in 1999 as a [Java applet](#) by [Golan Levin](#).
- [Modeling Watercolor by Simulating Diffusion, Pigment, and Paper Fibers](#) (1990) by [David Small](#) (Better version available in [Postscript](#).)
- [Microscopic Structural Modeling of Colored Pencil Drawings](#) (1997, article requires ACM Digital Library access, [abstract](#) is free) by [Saeko Takagi](#) and [Issei Fujishiro](#).
- [Cellular-Automaton-Based Simulation of Ink Behavior and Its Application to Suibokuga-like 3D Rendering of Trees](#) (1999, abstract) by [Qing Zhang](#), [Youetsu Sato](#), [Jun-ya Takahashi](#), [Kazunobu Muraoka](#) and [Norishige Chiba](#). See the full [citation](#), and these [images](#).
- [Volumetric Modeling of Artistic Techniques in Colored Pencil drawing](#) (1999) by [Saeko Takagi](#), [Issei Fujishiro](#) and Masayuki Nakajima. See also the [Pumpkins](#) project whose aim is to "capture the charm of colored pencil drawing."
- [Observational Model of Blenders and Erasers in Computer-Generated Pencil Rendering](#) (1999) by [Mario Sousa](#) and [John Buchanan](#). See also [Computer-Generated Graphite Pencil Rendering of 3D Polygonal Models](#) (GZipped Postscript 3MB) by the same authors.
- [3D Physics-Based Brush Model for Painting](#) (1999) [Suguru Saito](#) and Masayuki Nakajima. A 3D physically based brush model that allows users to paint various strokes intuitively and directly on a computer with a pen-type input device.
- [Observational Models of Graphite Pencil Materials](#) (1999, PDF 19.5 MB) by [Mario Sousa](#) and [John Buchanan](#). Presents a model of graphite pencil, drawing papers, blenders and kneaded erasers that produce realistic looking pencil marks, textures and tones.
- [Simulating Decorative Mosaics](#) (2001) by [Alejo Hausner](#) converts input images to mosaics composed of shaped tiles. Uses a relaxation technique to minimize the visible *grout* (the area between tiles) while aligning tiles with user-specified feature boundaries. The full paper is [available](#) (PDF 1.7 MB)
- [dAb: Interactive Haptic Painting with 3D Virtual Brushes](#) (2001) by [Bill Baxter](#), [Vincent Scheib](#), [Ming Lin](#) and [Dinesh Manocha](#) describes itself as "capturing the sight, touch, action, and feeling of painting" through

interactive use of a physically based paint brush and paint model with haptic feedback providing a natural interface via simulation of traditional artists' tools. The project page includes movies and the full paper in two resolutions: [high](#) (PDF 10 MB) and [low](#) (PDF 0.2 MB).

- Pastel-Like Rendering Considering the Properties of Pigments and the Support Medium (2002) by [Kyoko Murakami](#) and Reiji Tsuruno. "A new NPR technique that reproduces pastel drawing-like textures by focusing especially on the attributes of pastel pigments." This SIGGRAPH sketch is apparently not online, but there is a PDF article of the same name in this [special issue](#).
- Automatic Generation of Pencil Drawing Using Line-Integral Convolution (2002) by [Xiaoyang Mao](#), Yoshinori Nagasaka and Atsumi Imamiy. "A new technique for automatically generating pencil drawings from 2D gray-scale images using line-integral convolution."
- [Sketchy Rendering](#) (2002) by [John Haddon](#) briefly describes software to "reproduce the appearance of line drawings in both pencil and ink, along with other effects such as the bleeding of ink in water and the application of pastel to paper." [Full text](#) (PDF, 1.5MB) is available online.

Silhouettes

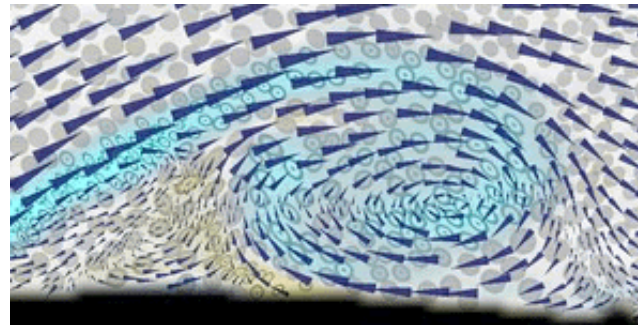
- [Image Jets, Level Sets, & Silhouettes](#) (1998) by Lance Williams, on shape and shading from silhouettes.
- [Non-photorealistic "Outlining" Effects Using Sphere-mapping](#) (1998) by [Kenny Hoff](#) uses [OpenGL](#)'s sphere-mapping facilities to create novel stylized shading.
- [Image Precision Silhouette Edges](#) (1999) by [Ramesh Raskar](#) and [Michael Cohen](#). Includes [demo code](#) and these additional [images](#).
- [Introduction to 3D Non-Photorealistic Rendering: Silhouettes and Outlines](#) (1999, PDF 171KB) by [Aaron Hertzmann](#)
- [Contour Rendering](#) (1999) by [Per H. Christensen](#), describes the Mental Ray contour shader. Unfortunately the illustrations from the hardcopy edition of *Computer Graphics* 33(1) are not included on this web page.
- [Calculating Distance-to-Silhouette on k-Manifolds](#) (1999, 1.07MB Postscript) MS Thesis by [Paul Brewster](#). See also this related earlier work: [Fixed-Width Silhouettes on Parametric Surfaces](#)
- [Artistic Silhouettes: A Hybrid Approach](#) (2000) by [J. D. Northrup](#) and [Lee Markosian](#). Describes a technique where silhouette edges are processed in image space, leading to more consistent detection and subsequent rendering. The page includes an abstract, the full [paper](#) (PDF, 312KB) and both still and animated sample images.
- [The Edge Buffer: A Data Structure for Easy Silhouette Rendering](#) (2000, PDF 421 KB) by [John Buchanan](#) and [Mario Sousa](#). The edge buffer is a technique for highlighting silhouette edges, boundary edges, and artist defined edges. See also this [demo program](#).

Non-traditional perspective (for viewing and modeling)

- [Multiperspective Panoramas for Cel Animation](#) 2MB PDF (1997) by [Daniel Wood](#), [Adam Finkelstein](#), Craig Thayer, [John Hughes](#) and [David Salesin](#).
- [Multiple-Center-of-Projection Images](#) (1998 abstract) by [Paul Rademacher](#) and [Gary Bishop](#), the full paper is [available](#) (PDF 1.4MB) Note: the applicability of this paper to non-photorealistic rendering is questionable, but it fit really well into this sub-category!
- [A Framework for Non-Realistic Projections](#) (1998, PDF format 604K) Master's Thesis by [Jon Levene](#). This novel work explores non-photorealistic "perspective" projections.
- [View-Dependent Geometry](#) (1999) by [Paul Rademacher](#), full paper is [available](#) (PDF 931KB)
- [Observer Dependent Deformations in Illustration](#) (2000, PDF 2.4 MB) by [D. Martín](#), [S. Garcia](#) and [J. C. Torres](#). Deformations of objects and space contributes to the expressiveness of illustration. Presents use of *hierarchical extended non-linear transformations* as a powerful tool for obtaining such expressivity.
- [Artistic Multiprojection Rendering](#) (2000) by [Maneesh Agrawala](#), [Denis Zorin](#) and [Tamara Munzner](#) describes an interactive system for creating multiprojection images where each object in the scene can have it own local camera. The project page includes images, movies and the [full paper](#) (PDF, 14.6 MB) in several formats.
- [Animating Chinese Landscape Paintings and Panoramas](#) (2001) Master's thesis by [Nelson Siu-Hang Chu](#) describes an IBMR approach for making fly-through or walk-through animations from a single large multi-perspective landscape painting or panorama. This page contains links to animations, the thesis and a CGI 2001 paper by Chu and Tai: [Animating Chinese Landscape Paintings and Panorama using Multi-Perspective Modeling](#) (PDF 6MB).

Stylized Motion and its Depiction

- [Speedlines - Depicting Motion in Motionless Pictures](#) (1999, PDF 529KB) by [Maic Masuch](#), [Stefan Schlechtweg](#), and [Ronny Schulz](#). See additional images in this [gallery](#).
- [Non-photorealistic Rendering of Dynamic Motion](#) by [Jessica Hodgins](#), [Nancy Pollard](#), *et al.* See also [Artistic Renderings of Dynamic Actions](#), this page featuring stylized [speedlines](#) and this related page at [Brown](#).
- [Style Machines](#) (2000) by [Matthew Brand](#) and [Aaron Hertzmann](#). Stylistic motion synthesis by learning motion patterns from motion capture (or other sources). New motions can be generated from learned styles, or combinations of them. Full paper is [available](#) (PDF 1.4 MB).



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Scientific Visualization

- [Image-Guided Streamline Placement](#) (1996) by [Greg Turk](#) and [David Banks](#). "Accurate control of streamline density is key to producing ... visualization of 2-dimensional vector fields. We introduce a technique that uses an energy function to guide the placement of streamlines at a specified density..."
- [Visualizing Multivalued Data from 2D Incompressible Flows Using Concepts from Painting](#) (1999, PDF, 1.6 MB) by [R. Michael Kirby](#), [Haralambos Marmanis](#) and [David H. Laidlaw](#). Uses a combination of visual elements arranged in multiple layers to visually represent multivalued data. The representations are inspired by the brush strokes artists apply in layers to create an oil painting.
- [PLIC: Bridging the Gap Between Streamlines and LIC](#) (1999) by [Vivek Verma](#), [David Kao](#) and [Alex Peng](#) compares flow visualizations using streamlines and line integral convolution (LIC), describes a methodology for flexibly generating flow visualizations that span the spectrum of streamline-like to LIC-like.
- [Non-Photorealistic Volume Rendering](#) (1999) student project by [Michael Sharps](#), [Kim Harrington](#) and [Evelyn Chun-Yi Wang](#) portrays volumetric data sets using non-photorealistic rendering to emphasize pertinent detail.
- [A Flow-guided Streamline Seeding Strategy](#) (2000) by [Vivek Verma](#), [David Kao](#) and [Alex Peng](#) describes a seed placement strategy for streamlines based on flow features of 2d vector fields. Its goal is to capture flow patterns in the vicinity of critical points in the flow field.
- Various reports from NASA's [Numerical Aerospace Simulation Systems Division](#) on flow visualization using LIC and diagrammatic imagery:
 - [AFLIC](#) (Animated Flow Line Integral Convolution) and [...Generating Surface Oil Flow Visualizations..](#) (1996)
 - [Enhanced Line Integral Convolution with Flow Feature Detection](#) (1996) by Arthur Okada and David Lane
 - [Unsteady Flow Analysis Toolkit \(UFAT\)](#) (1996)
 - [New Software Tool Improves Interactive Analysis of CFD Numerical Flows](#) (1998)
 - [Which Way Is the Flow?](#) (1999) by [David Kao](#), [figures](#).
- [Volume Illustration: Non-Photorealistic Rendering of Volume Models](#) (2000) by [David Ebert](#) and [Penny Rheingans](#) colors (and shades) volumetric data sets according to local operations on small voxel neighborhood. The full paper is [available](#) (PDF 0.24 MB). [ResearchIndex](#)
- [Formalizing Artistic Techniques and Scientific Visualization for Painted Renditions of Complex Information Spaces](#) (2001) by [Christopher G. Healey](#) describes a method for visualizing complex information spaces as painted images. See also his [Nonphotorealistic Visualization](#) project page.
- [Combining Perception and Impressionist Techniques for Nonphotorealistic Visualization of Multidimensional Data](#) (2001) by [Christopher G. Healey](#) this course presentation surveys a number of issues in nonphotorealistic rendering and visual perception, then discusses their relevance to computer graphics and scientific visualization through a series of descriptions, examples, and practical applications. The page contains movies, presentation slides and the full [paper](#) (PDF 4.1 MB).

Computer Graphic Effects for Traditional Cel Animation

- [Shadows for Cel Animation](#) (2000) by [Lena Petrovic](#), [Brian Fujito](#), Lance Williams and [Adam Finkelstein](#). Describes a semi-automatic method for creating shadow mattes for hand-drawn characters in cel animation. Employs a scheme for inflating 2D line art to produce 3D figures. The full paper is [available](#) (PDF, 3.2 MB).
- [2D/3D Hybrid Character Animation on "Spirit"](#) (2002) by [Doug Cooper](#) briefly describes a production process that allows freely intermixing traditional hand-drawn 2d character animation with toon-shaded 3d rendering. [Full text](#) (PDF, 0.1MB) is available online.

Books

- [Non-Photorealistic Rendering](#) (2001) by [Gooch](#) & [Gooch](#). [A.K. Peters Ltd, Publishers](#)
- [Non-Photorealistic Computer Graphics: Modeling, Rendering, and Animation](#) (2002) by [Thomas Strothotte](#) and [Stefan Schlechtweg](#). [Morgan Kaufmann Publishers](#)

Surveys and Overview Articles

- [Expressive Rendering: A Review of Nonphotorealistic Techniques](#) (1995, abstract) by the late [John Lansdown](#) and [Simon Schofield](#) in [IEEE CG&A](#). The full article is available to those with access to the IEEE Digital Library in [HTML](#) and [PDF](#) formats.

- [Different Strokes](#) (1997) by Barbara Robertson, *CGW Magazine*. (Note: Pennwell, CGW's publisher, is rebuilding their web site, so this article is temporarily unavailable.)
- [Ten Papers on Non-Photorealistic Rendering](#) (1998, revised 1999) survey by [Tom Janzen](#)
- There was a focus on [non-photorealistic rendering](#) in the [SIGGRAPH Computer Graphics Newsletter](#) (February 1999), see this [introduction](#) by the guest editor.
- [Seeing Between the Pixels](#) (1999) by [Brian Hayes](#) (in [American Scientist](#)) an essay about non-raster image representations.
- Lecture notes by [Jonathan Cohen](#) for a 1999 course on [Rendering Techniques](#) including sections on: [Non-photorealistic Rendering: Pen-and-Ink Illustration](#) (PDF, 2.6MB), [Painterly Rendering](#) (PDF, 3.3MB) and [Non-photorealistic Illumination Models](#) (PDF, 0.9MB).
- [An invitation to discuss computer depiction](#) (2002) by [Frédo Durand](#) brings the perspective of Art History to the analysis of stylized depiction, and proposes a classification of techniques for stylized depiction according to four criteria. Project page includes the [full paper](#) (PDF 0.3 MB) and presentation slides. [[ResearchIndex](#)] [[ACM DL](#)]

Miscellaneous

- **Conferences and conference sessions on these topics:**
 - [NPAR](#)
 - [The First Annual Symposium on Non Photorealistic Animation and Rendering](#) was held June 5-7, 2000 in conjunction with the *Animated Film Festival* of [Annecy, France](#). The official [online proceedings](#) require ACM Digital Library access, some of the individual papers are available from the authors, see above.
 - The [International Symposium on Non Photorealistic Animation and Rendering](#) (NPAR 2002) will be held June 3-5, 2002 in [Annecy, France](#). See also the [NPAR site](#).
 - [SIGGRAPH](#)
 - SIGGRAPH 96: [Illustration](#)
 - SIGGRAPH 97: [Non-Photorealistic Rendering](#)
 - SIGGRAPH 98: [Art, Illustration, Expression](#)
 - SIGGRAPH 99: [Imaginative Rendering](#)
 - Course 17: [Non-Photorealistic Rendering](#). See this [course page](#) for an abstract and full [course notes](#) (PDF, 13MB)
 - SIGGRAPH 2000: [Non-Photorealistic Rendering](#)
 - SIGGRAPH 2001:
 - Course 32: [Nonphotorealistic Rendering in Scientific Visualization](#)
 - SIGGRAPH 2002:
 - Paper session: [Painting and Non-Photorealistic Graphics](#)
 - Course 23: [Recent Advances in Non-Photorealistic Rendering for Art and Visualization](#)
 - Sketch sessions: [Non-Photorealistic Rendering](#), [2D Aesthetic in a 3D World](#) and [Shape](#).
- **Research groups and project pages related to these topics:**
 - [University of Utah](#) *Non-Photorealistic Rendering*
 - [Brown University](#) *Art-based Modeling and Rendering*
 - [New York University](#) (Media Research Lab) *Non-Photorealistic Rendering*
- **Films using these techniques:**
 - *Teddy Ruxpin* test (1985?), Digital Productions, toon shading. Please contact [me](#) if you know any details.
 - [Oilspot and Lipstick](#) (1987) Walt Disney Pictures, all toon shaded.
 - The Toon Shading process was developed by Tad Gielow and MJ Turner. Tad says: "The process involved two renders, one for color (via Wavefront's Render) and one for plotter output (via Wavefront plot). The plotter output render was suitable for driving a pen plotter to create artwork that integrated into the traditional Ink and Paint process (used on [The Great Mouse Detective](#), [Oliver and Company](#), [The Little Mermaid](#), and a number of shorts). We took the plotter output and wrote a script to drive a [Pixar Image Computer](#) to draw the lines. The lines images was then composited over the color render."
 - *Burning Love* (1988) short by Carlos Arquelos *et al.* at PDI. Please contact [me](#) if you know any details.
 - [The Funtastic World of Hanna-Barbera](#) (1989?), deGraf/Wahrman Inc., toon shading of Bedrock (and other locales?)
 - [Gas Planet](#) (1992) short by Eric Darnell *et al.* at PDI. [[Quicktime clip, 4.6MB](#)]
 - [The Lion King](#) (1994): toon shading on stampeding wildebeests [[fan site](#)]
 - [Brick-a-Brac](#) (1995) short by [Cassidy Curtis](#) *et al.* at PDI.
 - [Hercules](#) (1997): toon shading for the Hydras
 - [Impressions of San Francisco](#) (1997) short by [Peter Litwinowicz](#).
 - [What Dreams May Come](#) (1998): painterly rendering for Chris' Paradise [[official site](#)] [[goat](#)]
 - [Mulan](#) (1998): toon shading for the Hun cavalry charge.
 - [The Prince of Egypt](#) (1998): toon shading on props and "extras" in crowd scenes
 - [The New Chair](#) (1998) short by [Cassidy Curtis](#)
 - [Blixxorr!](#) (1999) short by Matt and Dan O'Donnell ([Cicada](#)), all toon shaded.

- [The Iron Giant](#) (1999): toon shading of the giant [\[official site\]](#) [\[Animation Artist\]](#)
- [Tarzan](#) (1999): *deep canvas* 3d painterly backgrounds [\[official site\]](#)
- [Fishing](#) (1999) short by David Gainey *et al.* at PDI. [\[VFXPro article\]](#) [\[Quicktime clips\]](#)
- [Officer Down](#) (2000) short by Matt and Dan O'Donnell ([Cicada](#)), all toon shaded.
- [My VH1 Music Awards](#) (2000 and 2001) cel shaded bumpers by [Psyop](#), see video at their site from [2000](#) and (MPEG, 1.6MB). [2001](#) (MPEG, 5.7MB).
- [Osmosis Jones](#) (2001): ...will contain toon rendering, say informed sources... [\[official site\]](#)
- [Le Déserteur \(The Deserter\)](#) (2001) by [Olivier Coulon](#) [Aude Danset](#) [Paolo De Lucia](#) and [Ludovic Savonnière](#). Produced at Supinfocom, won the Jury Award at SIGGRAPH 2002. See especially this [gallery](#) of images from the film. See also this [article](#) in [pixelcreation](#).
- [Sarah](#) (2001) by Justine Bonnard *et al.* stylized as an acrylic painting ([bad English translation](#)).
- [DNA](#) (2002, QuickTime, 3.8MB, 60 seconds) cel shaded TV spot for Volkswagen by [Psyop](#). Video is available on this page of [VW Commeercials](#), at [Ads.com](#) and at Psyop's [gallery](#). Their site also has two other NPR VW spots: [Sheep](#) (MPEG, 7.8MB) and [Cones](#) (MPEG, 3.5MB).
- [A Flatpack Project](#) by [John Haddon](#) (2002)
- ...
- **Real-time interactive systems using these techniques:**
 - [AlphaWolf](#) (2001) used a real time "charcoal rendering" technique.
 - See this page with pictures [describing AlphaWolf](#) (PDF, 0.1MB). This paper describes the AlphaWolf project: [Leashing the AlphaWolves: Mixing User Direction with Autonomous Emotion in a Pack of Semi-Autonomous Virtual Characters](#) (2002, PDF, 3MB) by [Bill Tomlinson](#), [Marc Downie](#), [Matt Berlin](#), [Jesse Gray](#), Derek Lyons, Jennie Cochran and [Bruce Blumberg](#). See a brief video of [Bill Tomlinson describing AlphaWolf](#) (MPEG video, 7.2MB) from SIGGRAPH Online.
- [Non-Photorealistic Rendering Jargon File](#), a glossary by [Craig Gulow](#).
- [Since Less is often More: Methods for Stylistic Abstractions In 3D-Graphics](#) (1995) by [Antonio Krüger](#) and [Thomas Rist](#). See also the first authors' page on [Graphical Abstraction](#)
- The book [Computational Visualization: Graphics, Abstraction, and Interactivity](#) (1998) by [Thomas Strothotte](#) *et al.* explores *abstraction* in computer graphics. It discusses non-photorealistic animation, non-traditional perspective, and other topics of interest to readers of this page.
- [Understanding Comics: The Invisible Art](#) (1993) by [Scott McCloud](#). See also this [review](#) of the book. Now Scott has published a companion volume: [Reinventing Comics](#) (2000).
- [2D Paint and Cel Animation](#) from SGI. See also their article about [The Prince of Egypt](#).
- [Fleeting Image Animation](#) "animation that integrates traditional and computer generated techniques"
- [Cicada Interactive](#) is a small independent animation production company that specializes in toon-style films. Their proprietary software is called *Mexico*.

Not yet categorized

- [Comic-Strip Rendering](#) (1995) by Peter Hall. [\[ResearchIndex\]](#)
- *Computer Drafting of Stones, Wood, Plant and Ground Materials* (1979) by Chris Yessios in Computer Graphics 13(3) SIGGRAPH '79 Proceedings, pages 190-198.
- [Creating Informal Looking Interfaces](#) (1997?) by [Jonathan Meyer](#) and Michael Crumpton. See more about [The EtchaPad Project](#)
- [Minimal Graphics](#) (1999) by [Ivan Herman](#) and [David Duke](#), full paper is [available](#) (compressed Postscript 1.6 MB). A preliminary investigation into an automatic rendering system based on a model of cognitive information processing
- [Animated CharToon Faces](#) (2000, Postscript 3MB) by [Zsófia Ruttkay](#) and [Han Noot](#). Java-based, realtime animation of nonrealistic 2d cartoon faces. See also these [color plates](#) (Postscript 9.7MB) from the paper, and the [CharToon](#) project page.
- [Digital Animation De-construction and Restoration](#) describes a image processing service offered by [Dynacs Digital Studios](#). They scan old animation and "de-construct" it into line art backgrounds and overlays, allowing it to be reprocessed and recomposited.
- [Interactive Dynamic Abstraction](#) (2000, PDF 1.6 MB) by [Scott Sona Snibbe](#) and [Golan Levin](#)
- [Special Issue on Non-photorealistic Rendering](#) (2002 v1n2) in [The Journal of the Society for Art and Science](#). Note: I cannot display these articles, perhaps the PDF files do not contain font data?
-

Send comments to [Craig Reynolds](mailto:cwr@red3d.com) <cwr@red3d.com>

visitors since June 27, 1999

Last update: September 22, 2003