

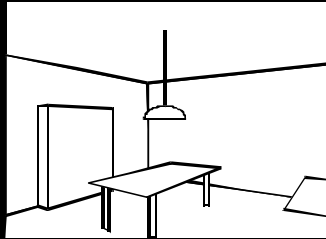
The Art and Science of Depiction

Photorealism vs. Non-Photorealism in Computer Graphics

Fredo Durand
MIT-Lab for Computer Science

Global illumination

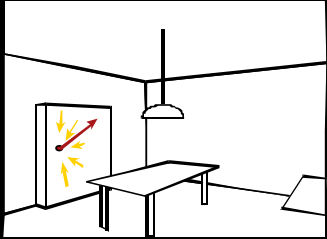
- How to take into account all light inter-reflections



Photorealism vs. NPR 2

The Rendering equation

- Light leaving one point in one direction
 - Integral of incoming light from every direction
 - Multiplied by BRDF (reflectance)



Photorealism vs. NPR 3

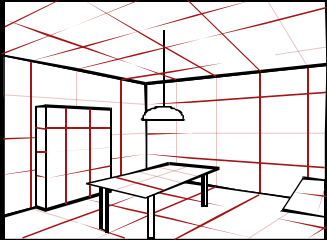
Radiosity

- E.g. Lightscape
- Assume surfaces diffuse (independent of direction)

Photorealism vs. NPR 4

Radiosity

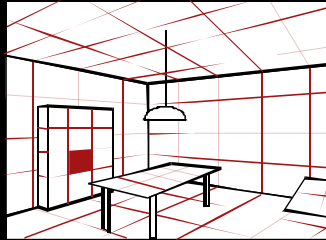
- Subdivide the scene into discrete elements



Photorealism vs. NPR 5

Radiosity

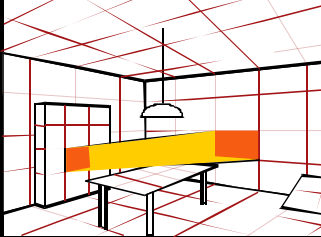
- Subdivide the scene into discrete elements
- Each element is assumed to have constant radiosity



Photorealism vs. NPR 6

Radiosity

- Form-factor between 2 elements: ratio of light leaving one element that reaches the other

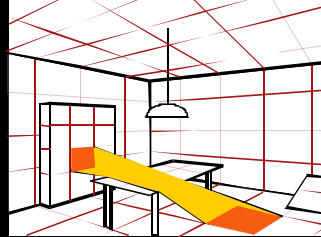


Photorealism vs. NPR

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Radiosity

- Form-factor between 2 elements: ratio of light leaving one element that reaches the other
 - Taking visibility into account

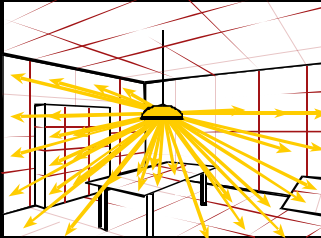


Photorealism vs. NPR

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Radiosity

- Iterative solution
- Shoot light from the most luminous source

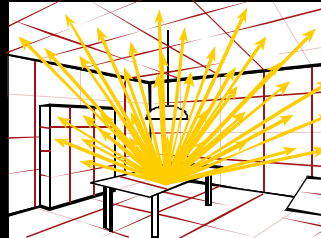


Photorealism vs. NPR

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Radiosity

- Iterative solution
- Shoot from element with the most unshot radiosity

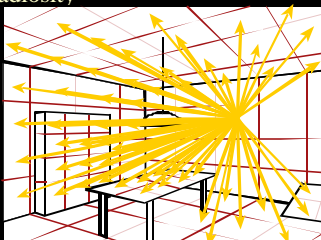


Photorealism vs. NPR

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Radiosity

- Iterative solution
- Shoot from element with the most unshot radiosity



Photorealism vs. NPR

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Radiosity

- Smoothing and other gimmicks



Photorealism vs. NPR

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Radiosity

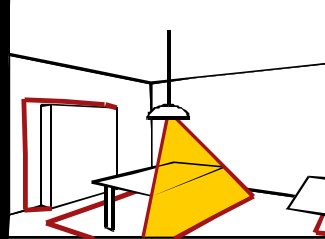
- Pros
 - View independent
- Cons
 - Meshing is costly
 - Memory
 - Mostly limited to polyhedra
 - Aliasing (jagged shadow boundary)
 - Diffuse assumption (can be sort of alleviated)

Photorealism vs. NPR

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Discontinuity meshing

- Subdivide along shadow boundary
- But costly and complex (not in commercial soft)

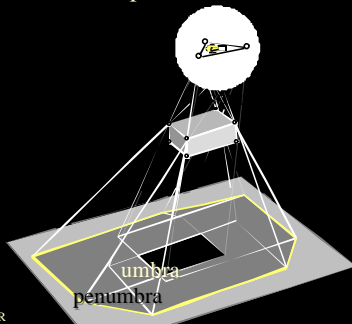


Photorealism vs. NPR

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Discontinuity meshing

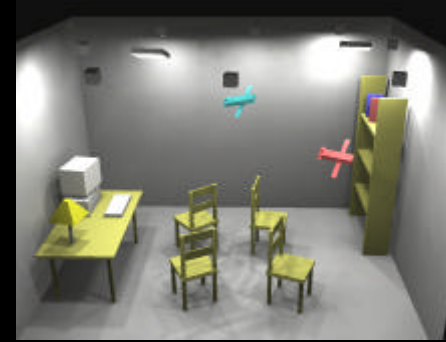
- Limits of umbra and penumbra



Photorealism vs. NPR

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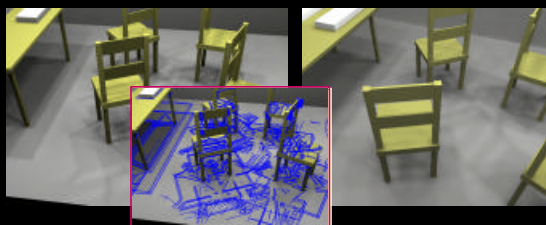
Discontinuity meshing



Photorealism vs. NPR

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Comparison



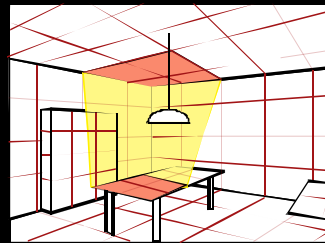
10 minutes 23 seconds
Photorealism vs. NPR

[Gibson 96]
1 hour 57 minutes

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Hierarchical approach

- Group elements when the light exchange is not important
 - Control non trivial



Photorealism vs. NPR

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Lightscape



Photorealism vs. NPR

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Lightscape



Photorealism vs. NPR

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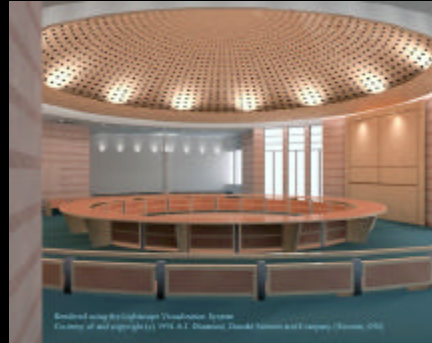
Lightscape



Photorealism vs. NPR

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Lightscape



Photorealism vs. NPR

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Lightscape



Photorealism vs. NPR

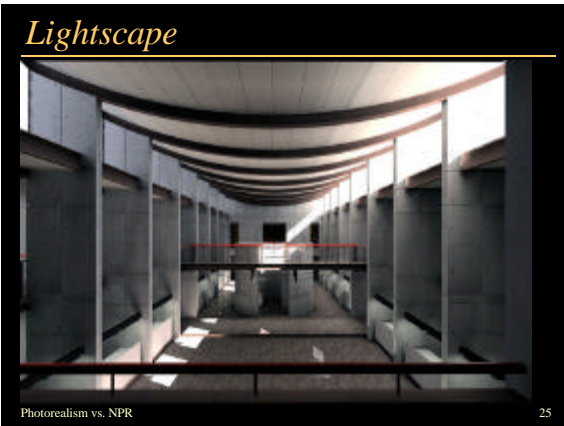
23

Lightscape



Photorealism vs. NPR

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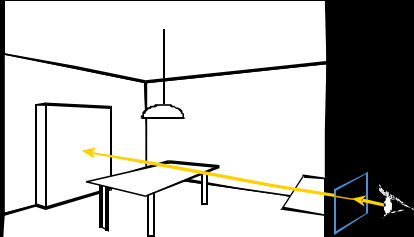
- Monte-Carlo ray-tracing*
- E.g. Radiance (by Greg Ward-Larson), Mental Ray
 - Probabilistic sampling approach
- Photorealism vs. NPR 28

- Monte-Carlo computation of p*
- Take a square
 - Take a random point (x,y) in the square
 - Test if it is inside the $\frac{1}{4}$ disc ($x^2+y^2 < 1$)
 - The probability is $\pi / 4$
-
- Photorealism vs. NPR 29

- Monte-Carlo computation of p*
- The probability is $\pi / 4$
 - Count the inside ratio $n = \# \text{ inside} / \text{total} \# \text{ trials}$
 - $\pi \approx n * 4$
 - The error depends on the number of trials
-
- Photorealism vs. NPR 30

Monte-Carlo

- Cast a ray from the eye through each pixel

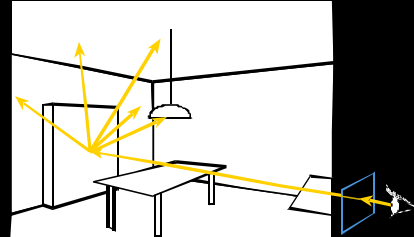


Photorealism vs. NPR

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Monte-Carlo

- Cast a ray from the eye through each pixel
- Cast random rays from the visible point

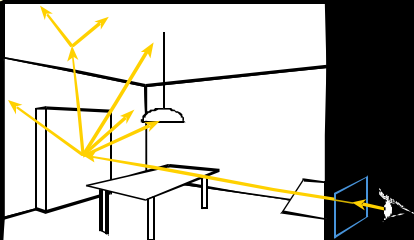


Photorealism vs. NPR

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Monte-Carlo

- Cast a ray from the eye through each pixel
- Cast random rays from the visible point
- Recurse

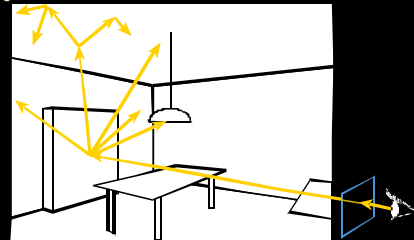


Photorealism vs. NPR

33

Monte-Carlo

- Cast a ray from the eye through each pixel
- Cast random rays from the visible point
- Recurse

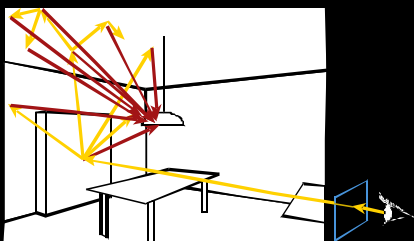


Photorealism vs. NPR

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Monte-Carlo

- Systematically sample primary light

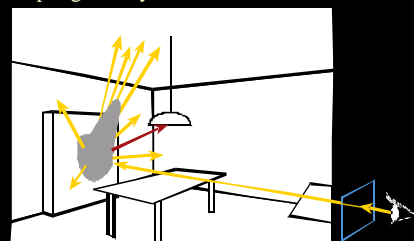


Photorealism vs. NPR

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Monte-Carlo

- Take BRD into account
 - Multiply incoming light
 - Sampling density

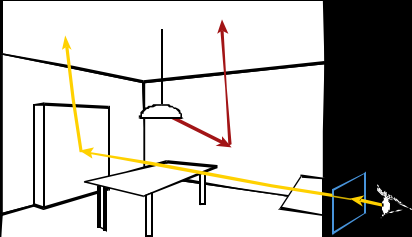


Photorealism vs. NPR

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Monte-Carlo

- Bi-directional
- Cast rays from the eye and from light

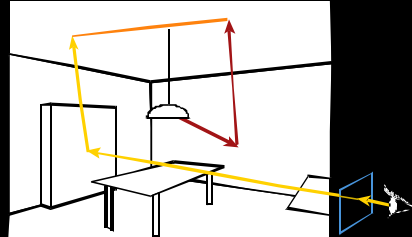


Photorealism vs. NPR

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Monte-Carlo

- Bi-directional
- Cast rays from the eye and from light
- Join

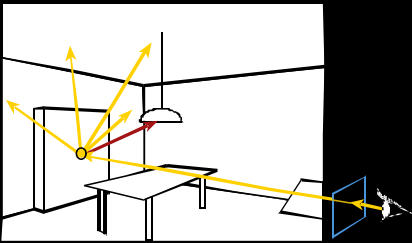


Photorealism vs. NPR

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Radiance cache

- Store the indirect illumination

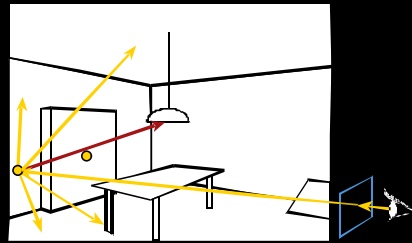


Photorealism vs. NPR

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Radiance cache

- Store the indirect illumination

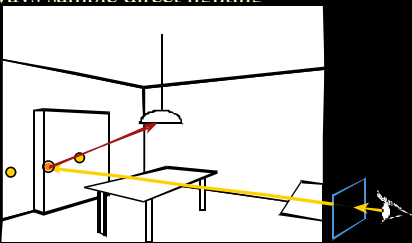


Photorealism vs. NPR

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Radiance cache

- Store the indirect illumination
- Interpolate existing cached values
- Always sample direct lighting



Photorealism vs. NPR

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Monte-Carlo & Radiance

- Pros
 - Can treat any scene and any BRDF
 - The Radiance system is free!
- Cons
 - View-dependent
 - Costly
 - Can be noisy (because of sampling)

Photorealism vs. NPR

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Radiance



Photorealism vs. NPR

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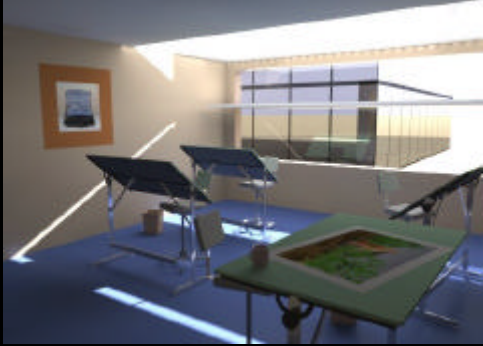
Radiance



Photorealism vs. NPR

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Radiance



Photorealism vs. NPR

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Radiance



Photorealism vs. NPR

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Radiance



Photorealism vs. NPR

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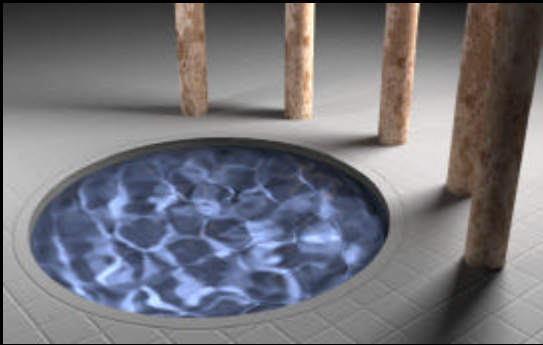
Radiance



Photorealism vs. NPR

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Monte-Carlo ray-tracing



Photorealism vs. NPR

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Non Photorealistic Rendering

- Stanislaw Ulam
 - The study of non-linear physics is like the study of non-elephant biology
 - (quoted by Craig Reynolds)

Photorealism vs. NPR

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Painting with numbers

- [Haeberli 1990]
- Reference photo for color
- Interactive painting with brushes

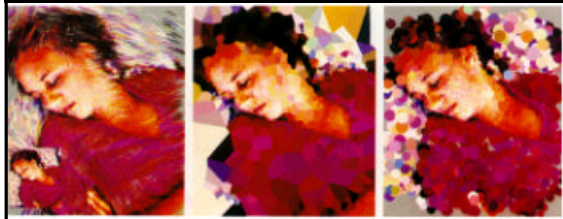


Photorealism vs. NPR

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Painting with numbers

- [Haeberli 1990]
- Reference photo for color
- Interactive painting with brushes



Photorealism vs. NPR

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Painting with numbers

- Direction control



Figure 6. Using a gradient image to control brush stroke direction.

Photorealism vs. NPR

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Painting with numbers

- Direction control using gradient

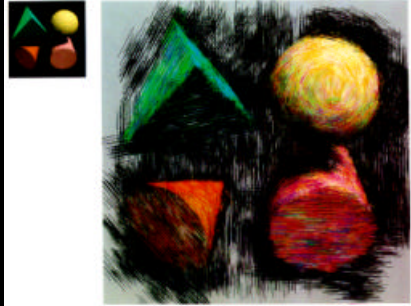


Photorealism vs. NPR

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Painting with numbers

- From 3D geometry



Photorealism vs. NPR

55

Painting with number

- Automatic optimization of brush placement

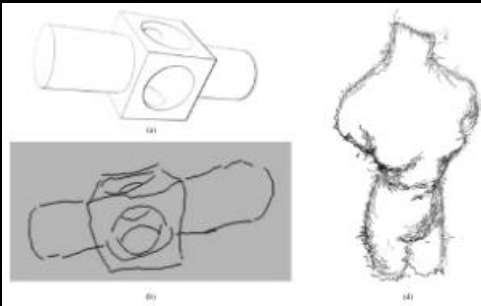


Photorealism vs. NPR

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Line drawing

- [Markosian et al. 97]



Photorealism vs. NPR

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Line drawing

- [Hertzman and Zorin 2000]



Photorealism vs. NPR

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Line drawing

- [Hertzman and Zorin 2000]



Figure 8: Direction fields on the Venus. (a) Silhouettes alone do not convey the interior shape of the surface. (b) Raw principle curvature directions produce an overly-complex hatching pattern. (c) Smooth cross field produced by optimization. Reliable principal curvature directions are left unchanged. Optimization is motivated by the principal curvatures. (d) Hatching with the smooth cross field. (e) Very smooth cross field produced by optimizing all directions. (f) Hatching from the very smooth field.

Photorealism vs. NPR

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Watercolor

- [Curtis et al. 1997]
- Physical simulation of watercolor-paper interaction

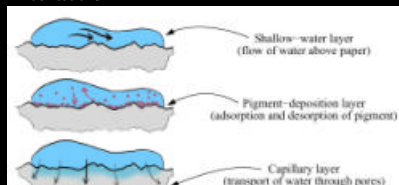


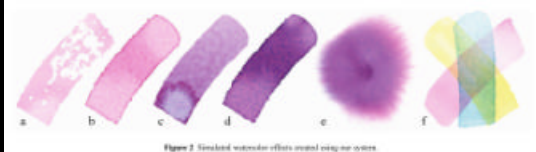
Figure 3 The three-layer fluid model for a watercolor wash.

Photorealism vs. NPR

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Watercolor

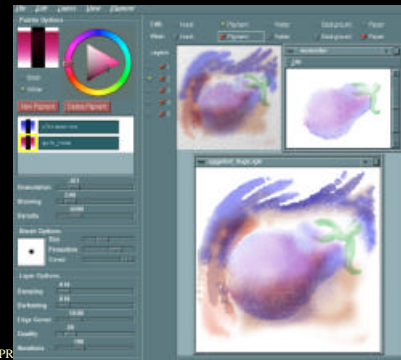
- [Curtis et al. 1997]
- Physical simulation of watercolor-paper interaction
- Very costly (not interactive)



Photorealism vs. NPR

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Watercolor



Photorealism vs. NPR

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Watercolor



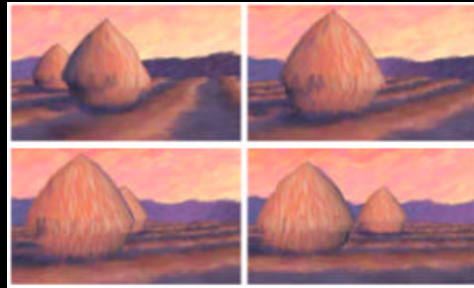
Figure 18: An automatic watercolorization (left) of a fruit still-life scene captured using a probability volume camera (right). The shaded surface is the volume of the camera, using a total of 1750 particles of the simulation, rendered as a collection of 4000 pixels on a Canon CR-1 (1.3 MPx 3CCD) digital camera.

Photorealism vs. NPR

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Painterly animation

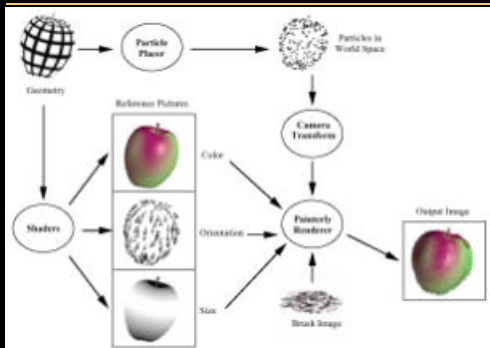
- [Meier 1996]



Photorealism vs. NPR

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Painterly animation

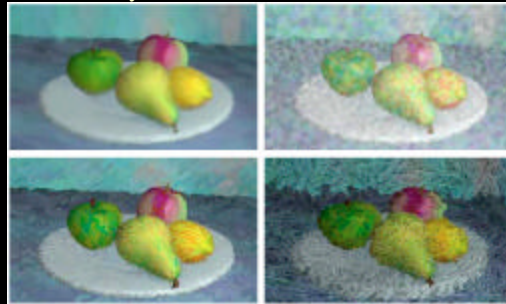


Photorealism vs. NPR

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Painterly animation

- Different styles

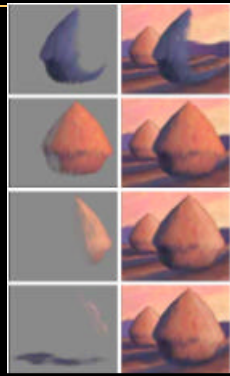


Photorealism vs. NPR

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Painterly animation

- Use of different layers



Photorealism vs. NPR

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Brushes of multiple sizes

- [Hertzman 1998]



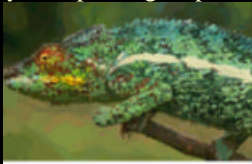
Photorealism vs. NPR

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Brushes of multiple sizes

- Different styles depending on parameters

“Impressionist”



“Expressionist”



Photorealism vs. NPR

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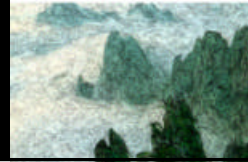
Brushes of multiple sizes

- Different styles depending on parameters

“Impressionist”



“Expressionist”



Photorealism vs. NPR

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Style and soul

- Icon painting, Expressionism

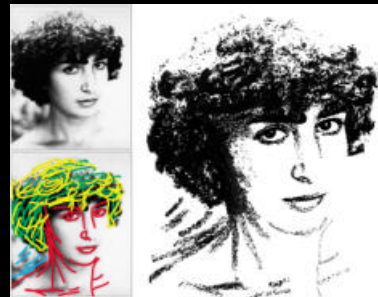


Photorealism vs. NPR

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Interactive assisted drawing

- [Durand, Ostromoukhov et al.]

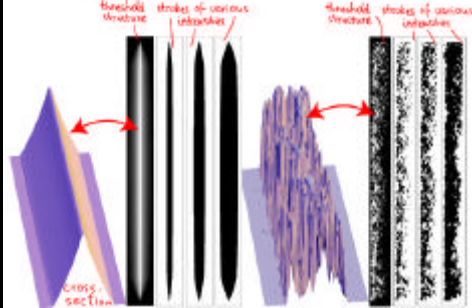


Photorealism vs. NPR

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Interactive assisted drawing

- Thresholding

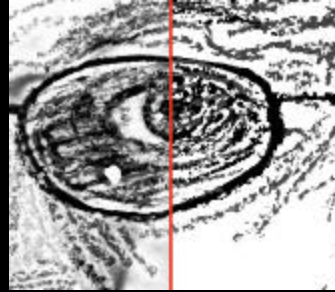


Photorealism vs. NPR

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Interactive assisted drawing

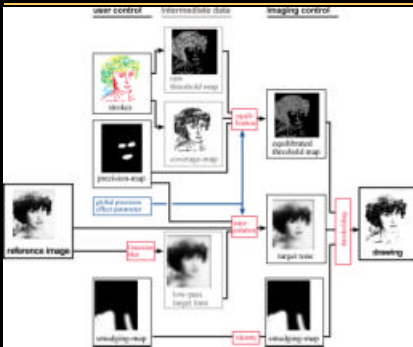
- Smudging



Photorealism vs. NPR

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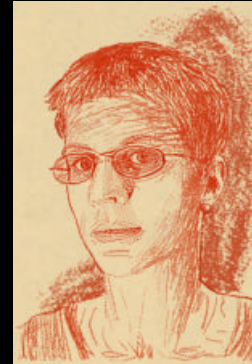
Interactive assisted drawing



Photorealism vs. NPR

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Interactive assisted drawing



Photorealism vs. NPR

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Interactive assisted drawing



Photorealism vs. NPR

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NPR: fuzzy issues

- No systematic classification of techniques
 - Mainly by medium and interactive/full 3D
- No clear issues
 - What are we trying to solve?
- No inter-operability of techniques
 - No clear input and output
- Mainly out-of-the-blue full systems with overlap

Photorealism vs. NPR

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Some issues in NPR

- Medium simulation
- Animation and coherence
- Line drawing, hatching
- Shading
- Style
- Perspective
- User interface

Photorealism vs. NPR

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Can visual art and psychology help?

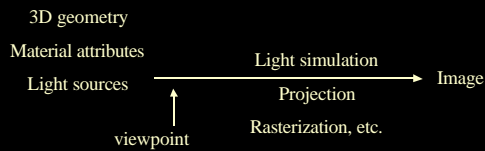
- Understand underlying and “universal” pictorial issues
 - Limitations and compensation
 - Different modes
 - Texture, color, shape
 - Composition, color harmony
- Coarse-grain classification of issues in picture-making
 - Drawing
 - Denotation
 - Tone and Color
 - Physical realization through marks

Photorealism vs. NPR

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A one-way pipeline

- Mechanical and deterministic projection from 3D to 2D
- Input is purely 3D (world space)

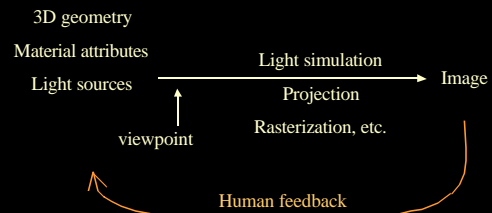


Photorealism vs. NPR

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A one-way pipeline

- Mechanical and deterministic projection from 3D to 2D
- Input is purely 3D (world space)



Photorealism vs. NPR

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Mixed 2D/3D specification

- We should be able to specify “properties” and constraints directly in 2D
 - E.g. color harmony, composition, style
- Still edit the image after rendering
 - E.g. shadows, lighting, colors, compensations

Photorealism vs. NPR

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Pictures for dummy

- Help non-artists produce nice images
- The “gorgeous image” button in your CAD software
- The “digital photo beautifier”
- Realistic or Non-Photorealistic
- Digital assistant that finds problems

Photorealism vs. NPR

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Style

- Coarse-grain style
 - Different categories of drawing, denotation, tone
- Finer-grain
- Local style
- Parameterization
- Capture
 - Automatically deduce style from 3D renderings
 - (semi)-Automatically capture style from image(s)



Photorealism vs. NPR

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Convergence of games and movies

- Game industry is now as big as movie industry
- Graphics accelerator permit stunning 3D graphics
- Cinema quality is not far
- However, games are interactive, “unpredictable”
- How can we transform the art and craft of cinema into algorithmic games
- E.g. Lighting, camera control, editing

Photorealism vs. NPR

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