

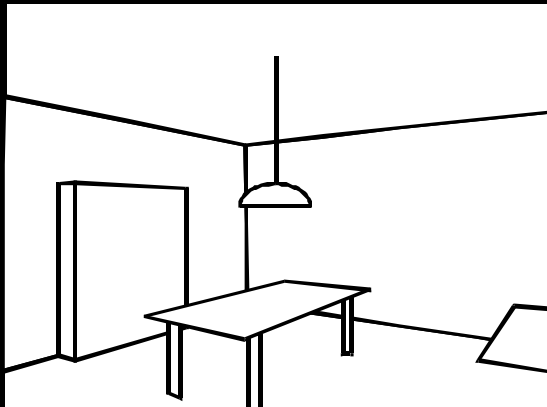
The Art and Science of Depiction

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

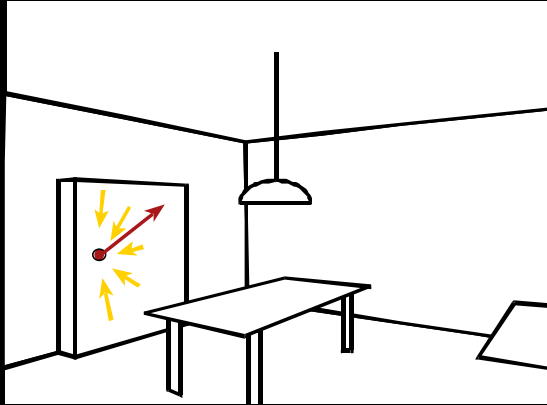


Photorealism vs. NPR

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

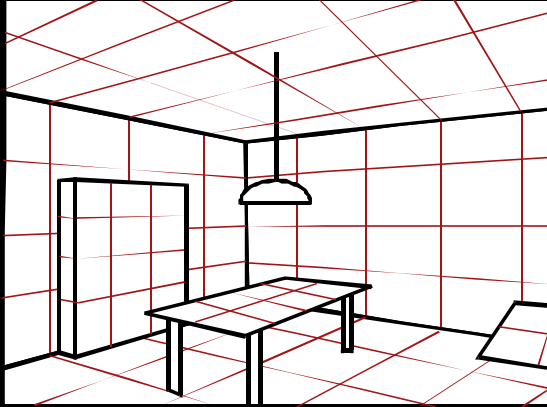
- E.g. Lightscape
- Assume surfaces diffuse (independent of direction)

Photorealism vs. NPR

4

Radiosity

- Subdivide the scene into discrete elements

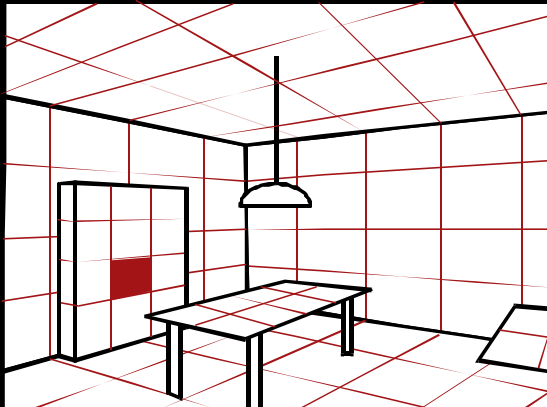


Photorealism vs. NPR

5

Radiosity

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

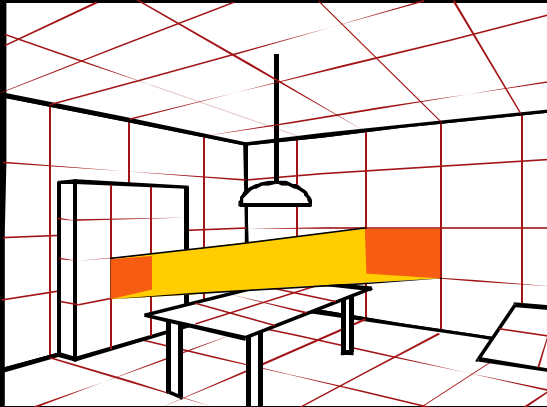


Photorealism vs. NPR

6

Radiosity

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

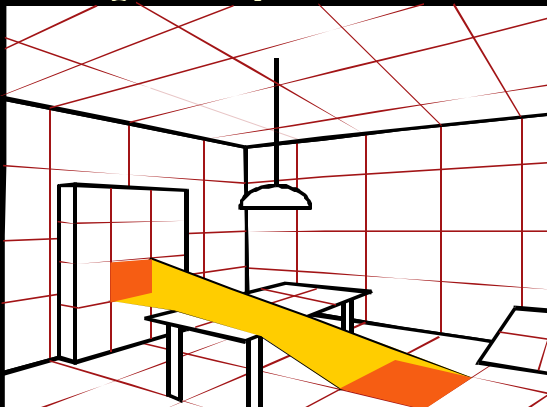


Photorealism vs. NPR

7

Radiosity

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

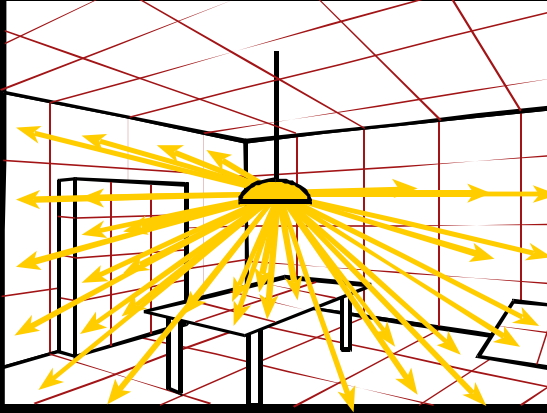


Photorealism vs. NPR

8

Radiosity

- Iterative solution
- Shoot light from the most luminous source

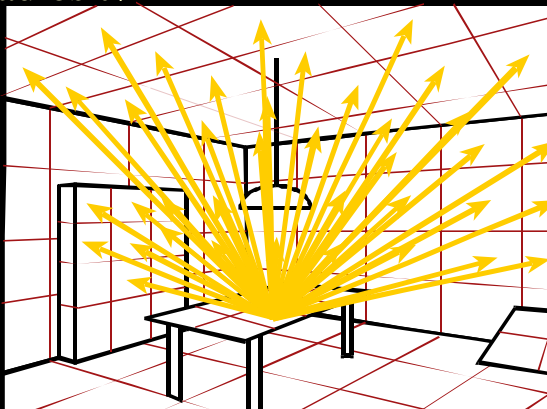


Photorealism vs. NPR

9

Radiosity

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

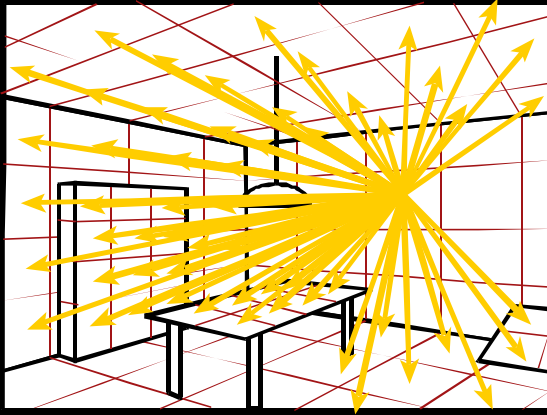


Photorealism vs. NPR

10

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

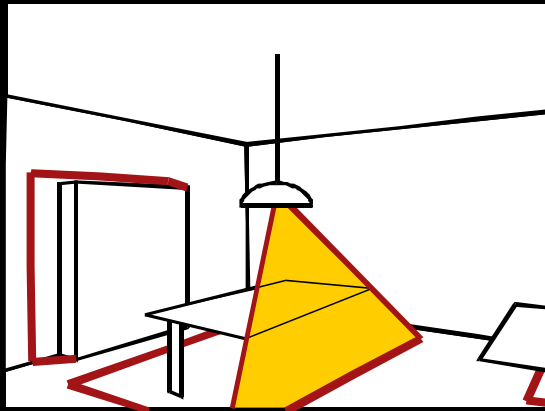
12

Radiosity

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

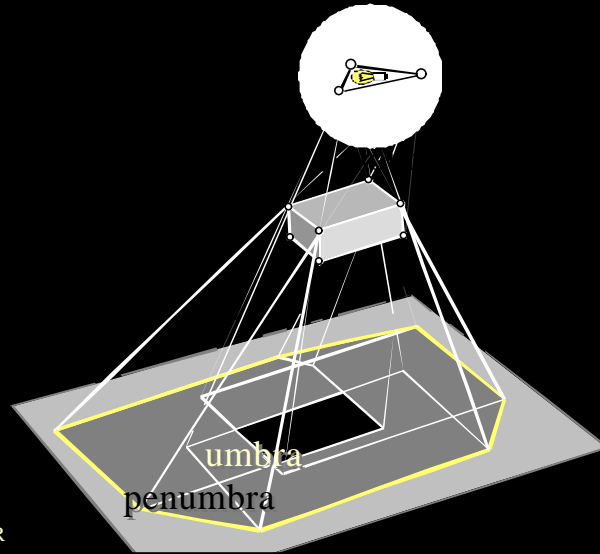
Discontinuity meshing

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



Discontinuity meshing

- Limits of umbra and penumbra



Photorealism vs. NPR

15

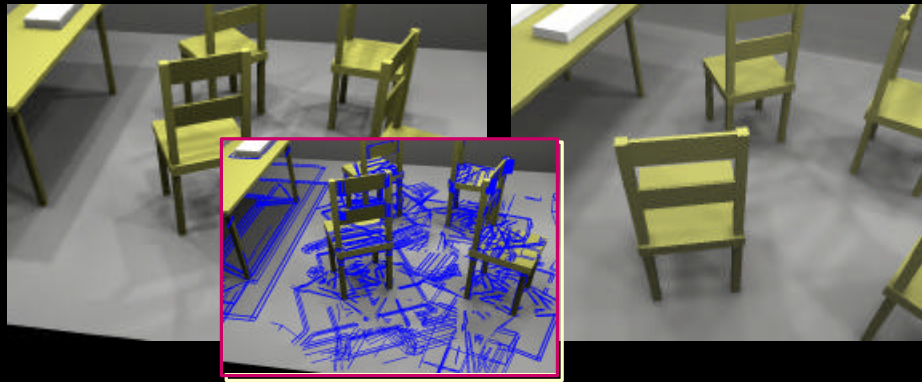
Discontinuity meshing



Photorealism vs. NPR

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Comparison



With skeleton

10 minutes 23 seconds

Photorealism vs. NPR

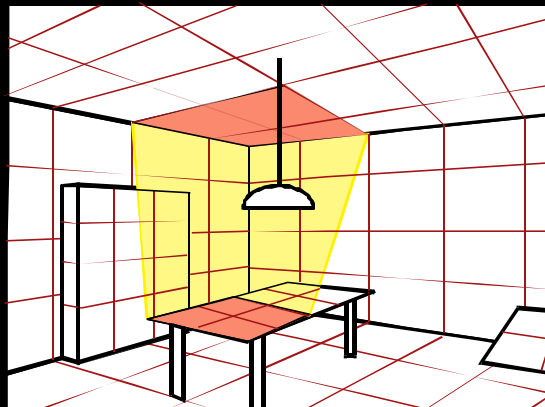
[Gibson 96]

1 hour 57 minutes

17

Hierarchical approach

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



Photorealism vs. NPR

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Lightscape



Rendered using the Lightscape Visualization System.
Courtesy of and copyright (c) 1998 Design Visualization Partners (Santa Monica, CA)

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

22

Lightscape



Photorealism vs. NPR

23

Lightscape

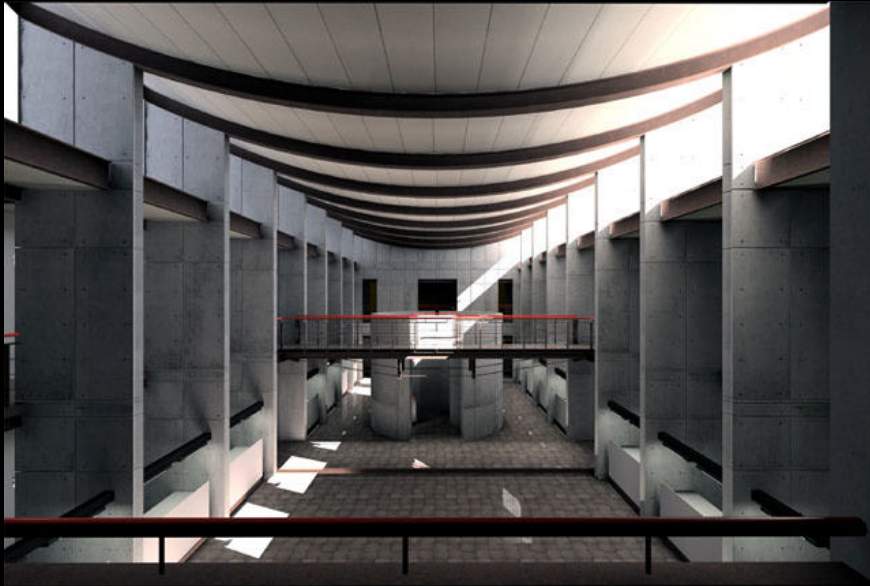


Rendered using the Lightscape Visualization System.
Courtesy of and copyright (c) 1998 Design Visualization Partners (Santa Monica, CA)

Photorealism vs. NPR

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Lightscape



Photorealism vs. NPR

25

Lightscape



Photorealism vs. NPR

26

Lightscape



Photorealism vs. NPR

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Monte-Carlo ray-tracing

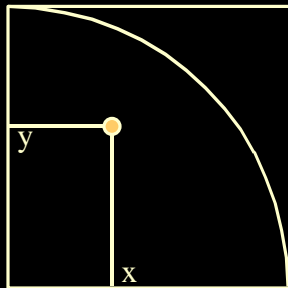
- E.g. Radiance (by Greg Ward-Larson), Mental Ray
- Probabilistic sampling approach

Photorealism vs. NPR

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Monte-Carlo computation of π

- 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 $\pi / 4$

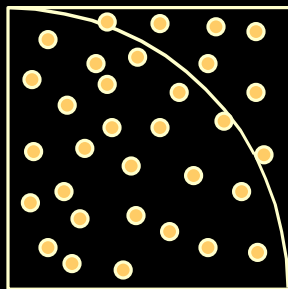


Photorealism vs. NPR

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Monte-Carlo computation of π

- 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 or trials

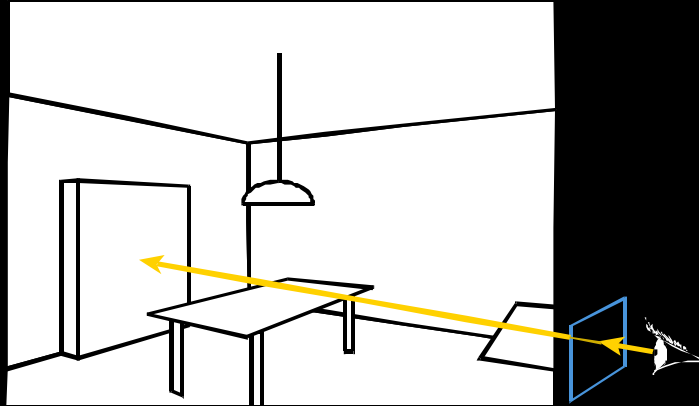


Photorealism vs. NPR

30

Monte-Carlo

- Cast a ray from the eye through each pixel

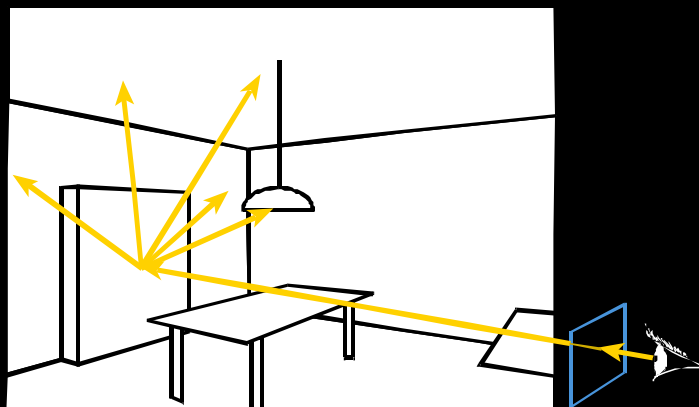


Photorealism vs. NPR

31

Monte-Carlo

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

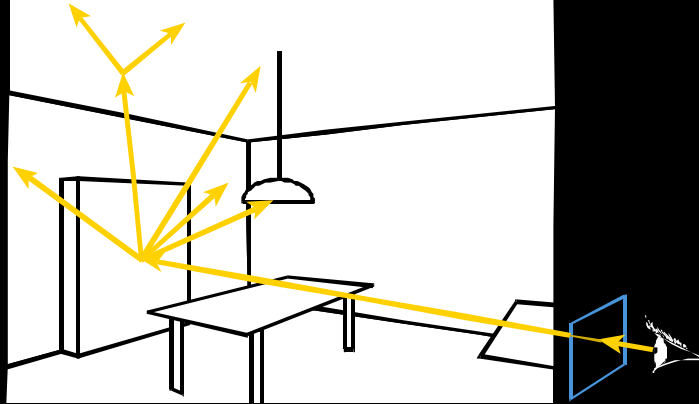


Photorealism vs. NPR

32

Monte-Carlo

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

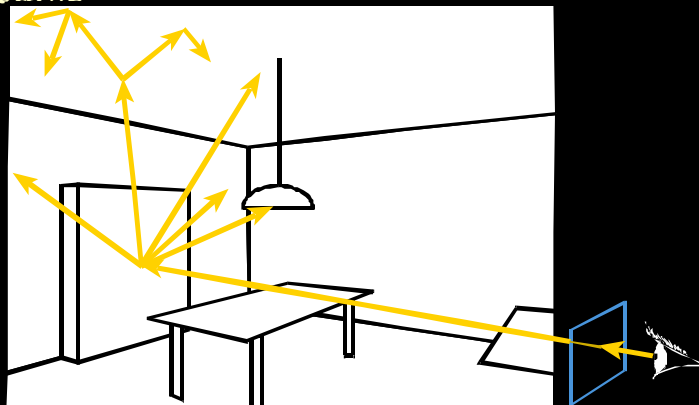


Photorealism vs. NPR

33

Monte-Carlo

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

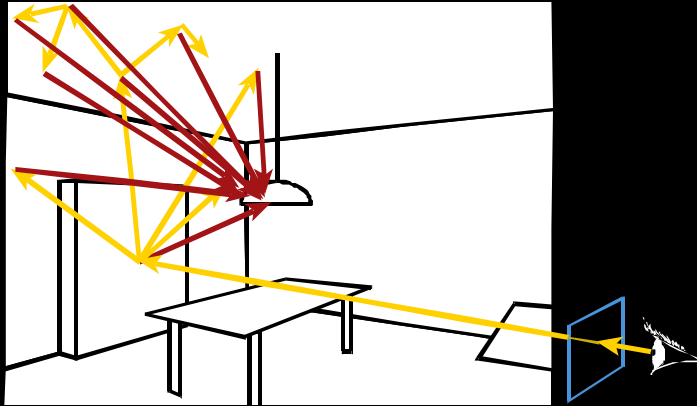


Photorealism vs. NPR

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Monte-Carlo

- Systematically sample primary light

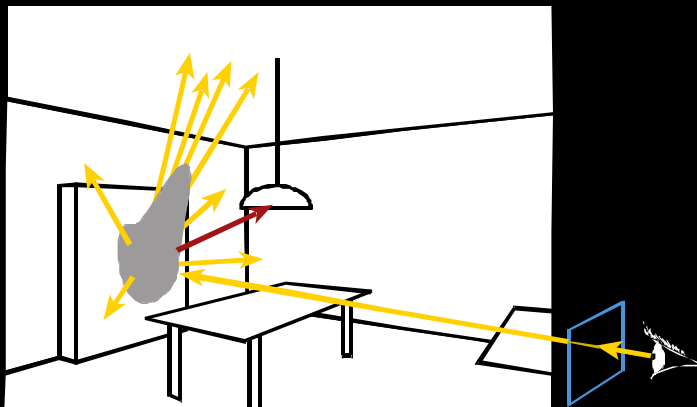


Photorealism vs. NPR

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Monte-Carlo

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

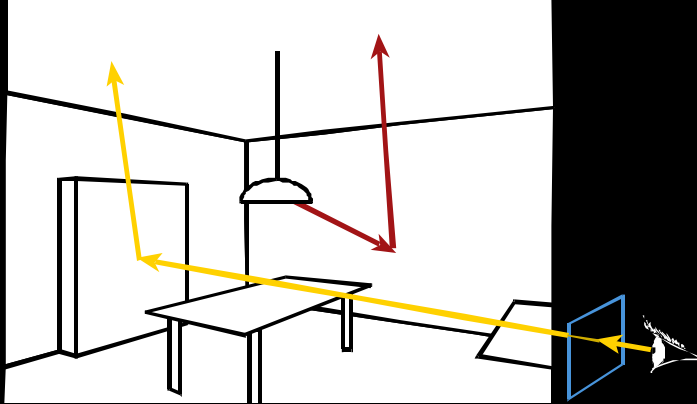


Photorealism vs. NPR

36

Monte-Carlo

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

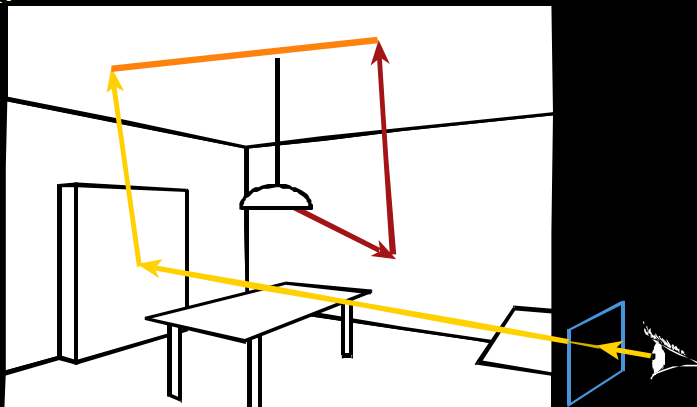


Photorealism vs. NPR

37

Monte-Carlo

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

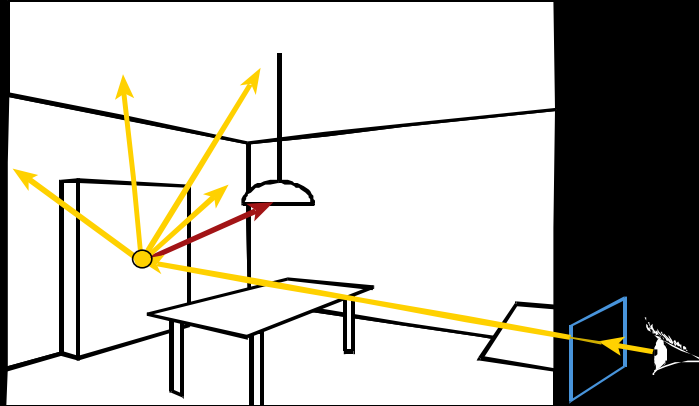


Photorealism vs. NPR

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Radiance cache

- Store the indirect illumination

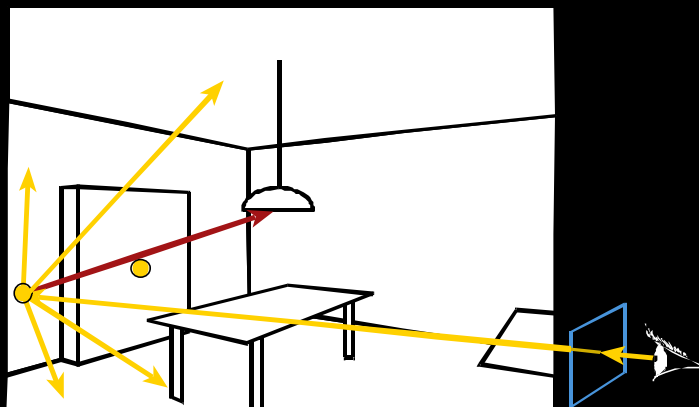


Photorealism vs. NPR

39

Radiance cache

- Store the indirect illumination

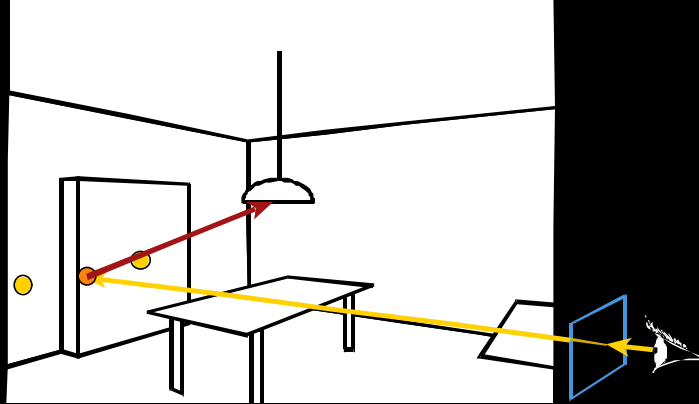


Photorealism vs. NPR

40

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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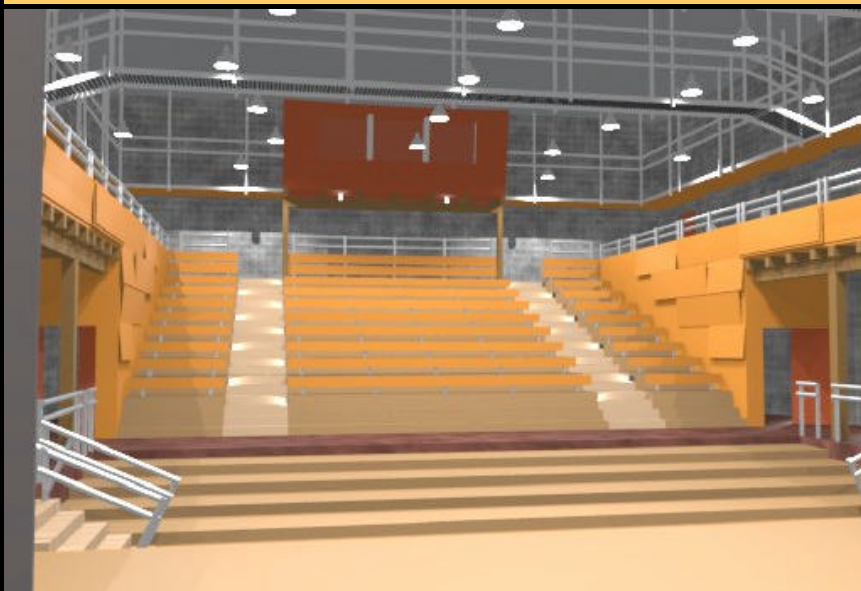
Radiance



Photorealism vs. NPR

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Radiance



Photorealism vs. NPR

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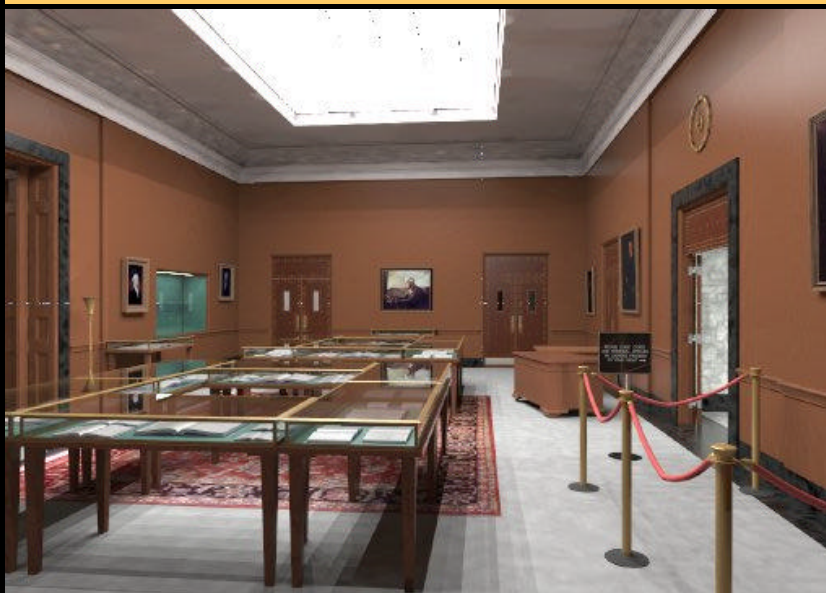
Radiance



Photorealism vs. NPR

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Radiance



Photorealism vs. NPR

46

Radiance



Photorealism vs. NPR

47

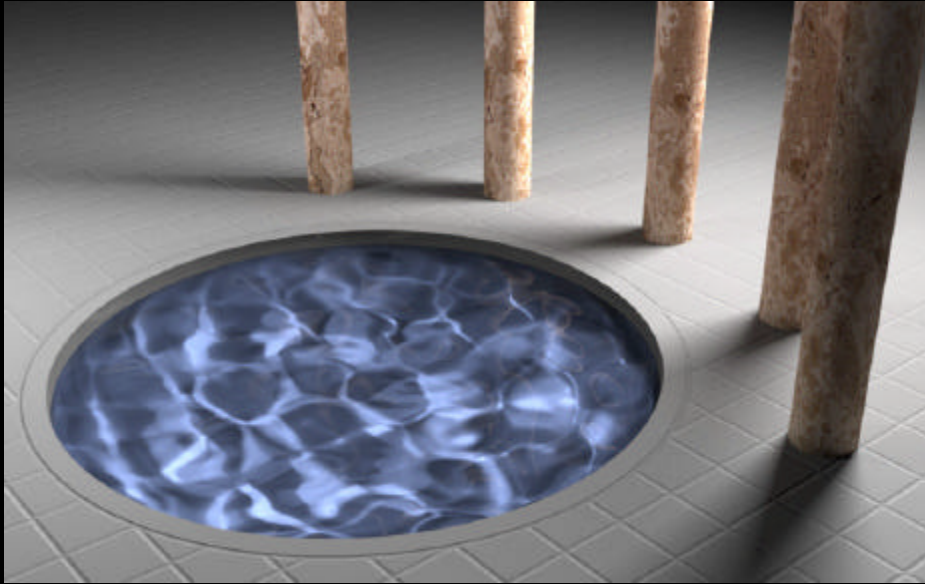
Radiance



Photorealism vs. NPR

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Monte-Carlo ray-tracing



Photorealism vs. NPR

49

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

50

Painting with numbers

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



Photorealism vs. NPR

51

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 second image to control brush stroke direction.

Photorealism vs. NPR

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Painting with numbers

- Direction control using gradient

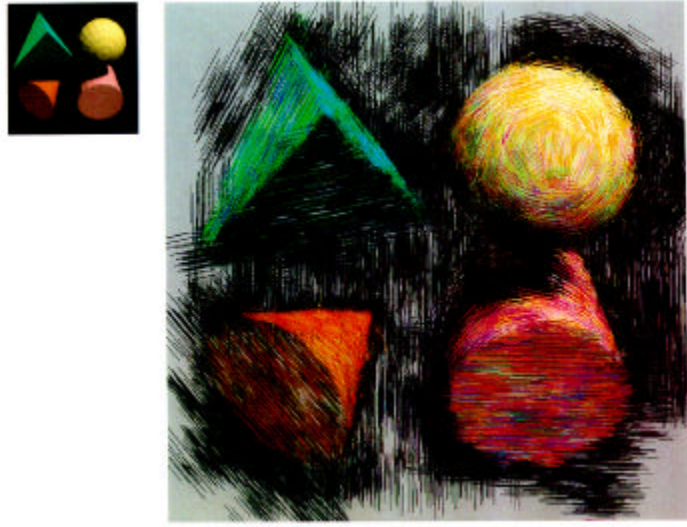


Photorealism vs. NPR

54

Painting with numbers

- From 3D geometry

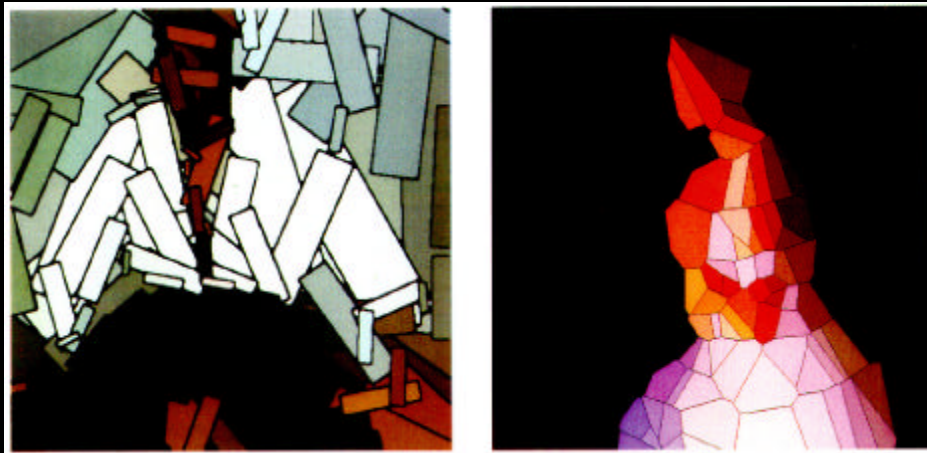


Photorealism vs. NPR

55

Painting with number

- Automatic optimization of brush placement

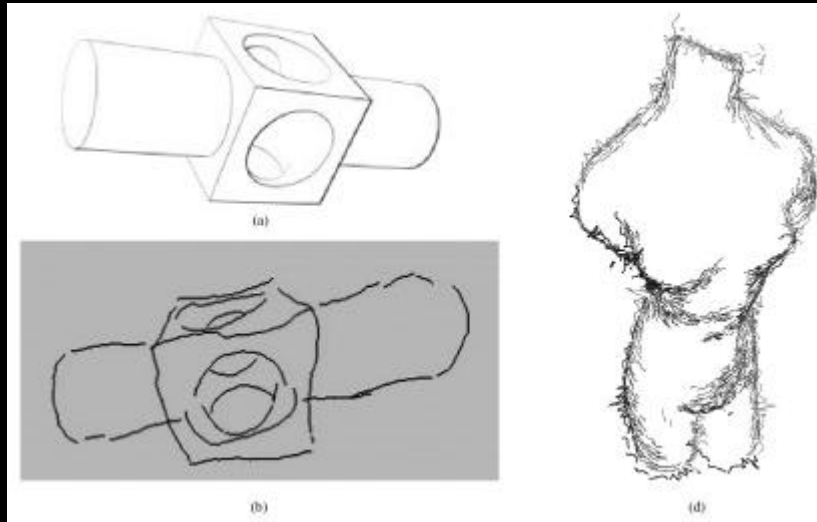


Photorealism vs. NPR

56

Line drawing

- [Markosian et al. 97]

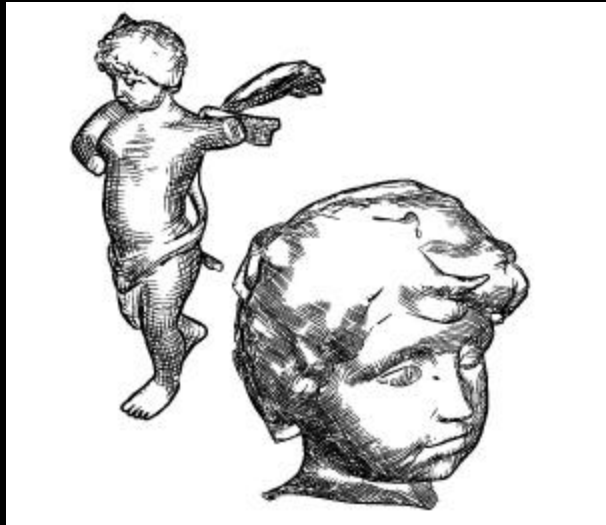


Photorealism vs. NPR

57

Line drawing

- [Hertzman and Zorin 2000]

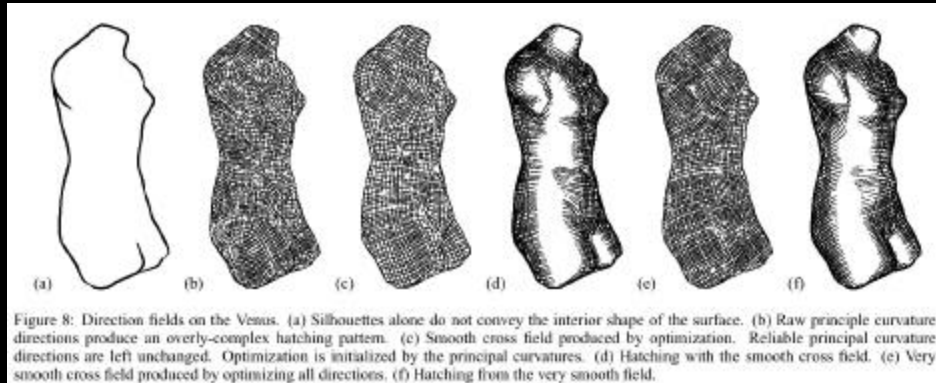


Photorealism vs. NPR

58

Line drawing

- [Hertzman and Zorin 2000]

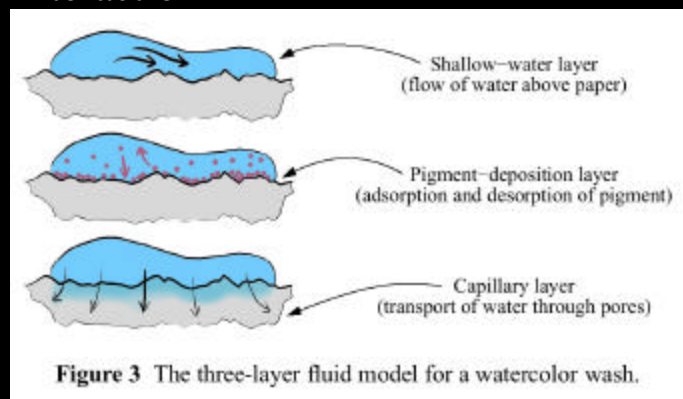


Photorealism vs. NPR

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Watercolor

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



Photorealism vs. NPR

60

Watercolor

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

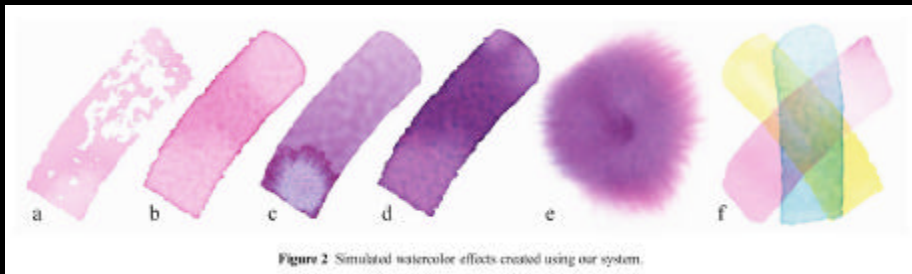
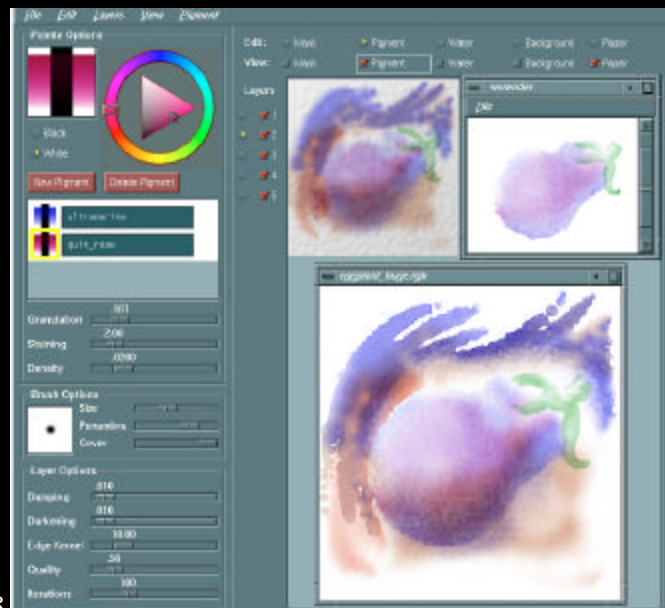


Figure 2 Simulated watercolor effects created using our system.

Photorealism vs. NPR

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Watercolor



Photorealism vs. NPR

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Watercolor



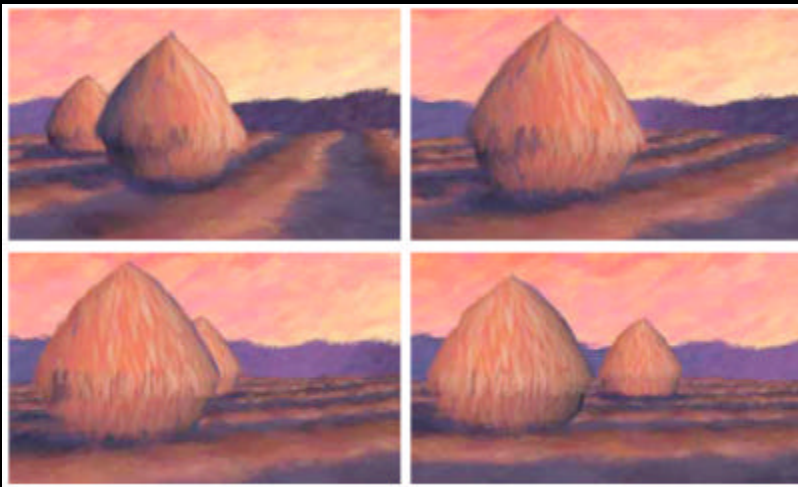
Figure 10 An automatic watercolorization (left) of a low resolution image captured using a poor-quality video camera (above). The finished painting consists of 11 glazes, using a total of 2750 iterations of the simulator, rendered at a resolution of 640 by 480 pixels in 7 hours on a 133 MHz SGI R4600 processor.

Photorealism vs. NPR

63

Painterly animation

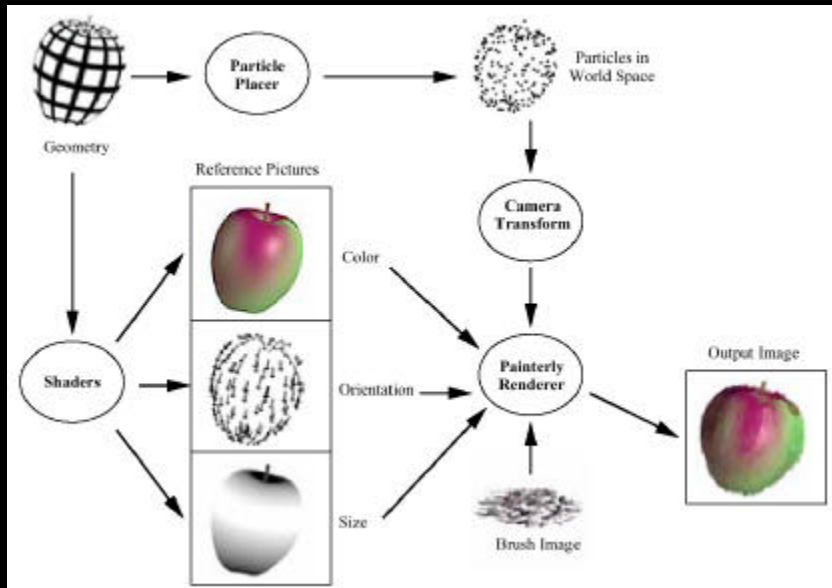
- [Meier 1996]



Photorealism vs. NPR

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Painterly animation

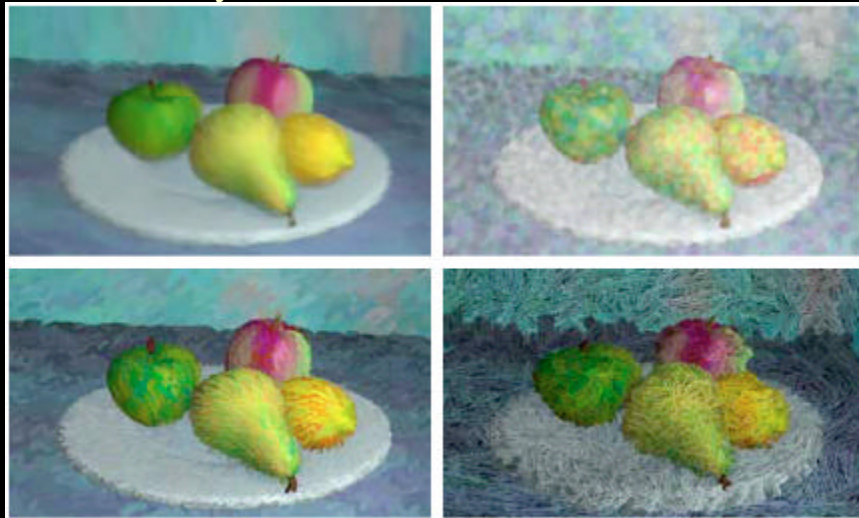


Photorealism vs. NPR

65

Painterly animation

- Different styles

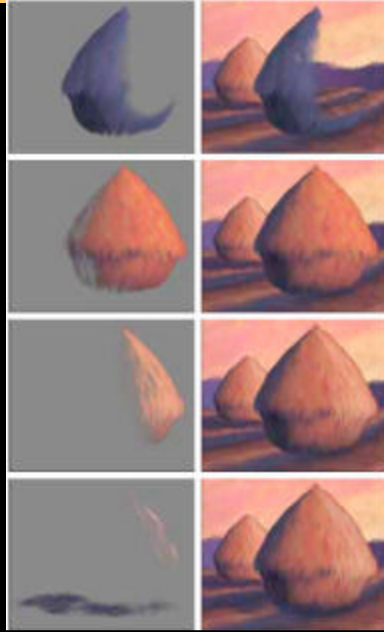


Photorealism vs. NPR

66

Painterly animation

- Use of different layers

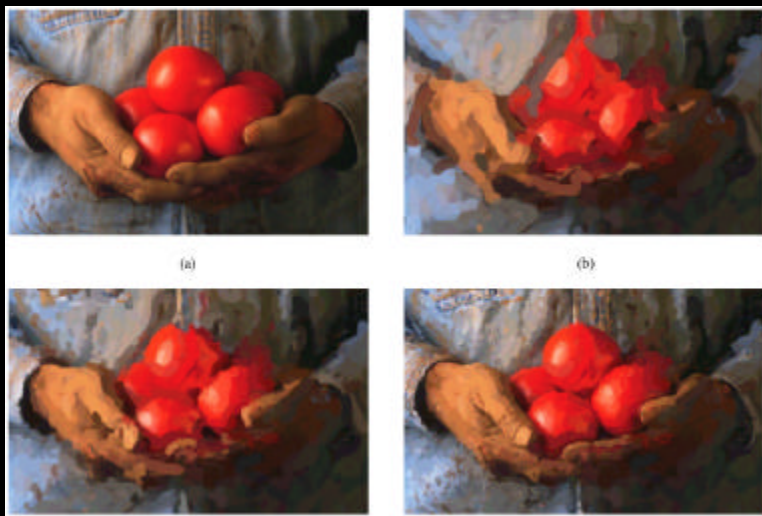


Photorealism vs. NPR

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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

69

Brushes of multiple sizes

- Different styles depending on parameters

“Impressionist”



“Expressionist”

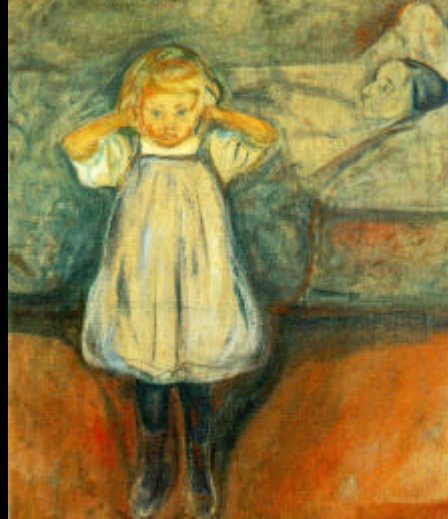


Photorealism vs. NPR

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Style and soul

- Icon painting, Expressionism

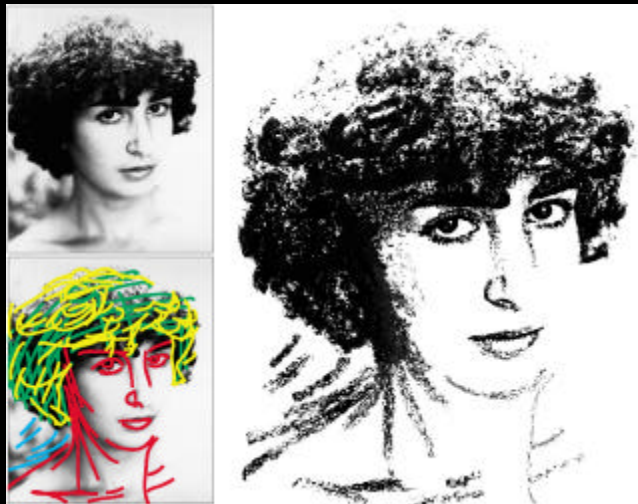


Photorealism vs. NPR

71

Interactive assisted drawing

- [Durand, Ostromoukhov et al.]

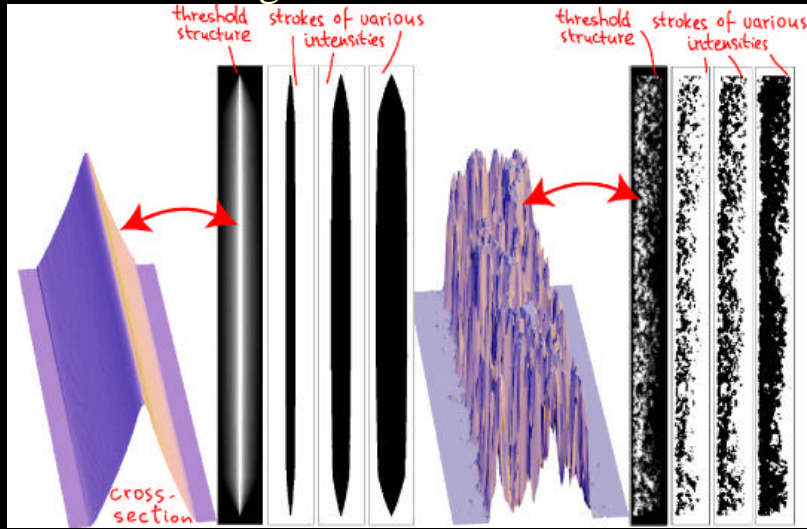


Photorealism vs. NPR

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Interactive assisted drawing

- Thresholding

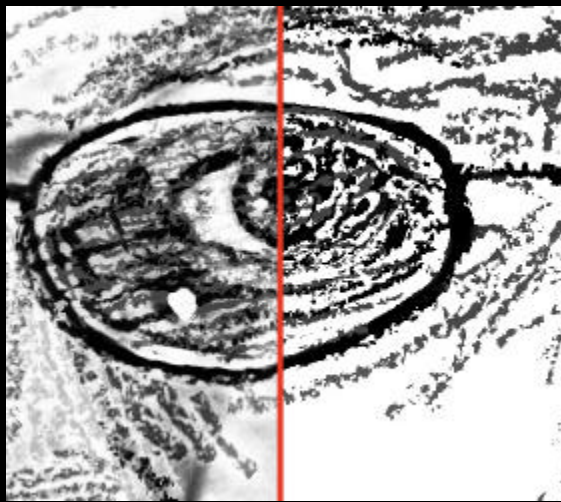


Photorealism vs. NPR

73

Interactive assisted drawing

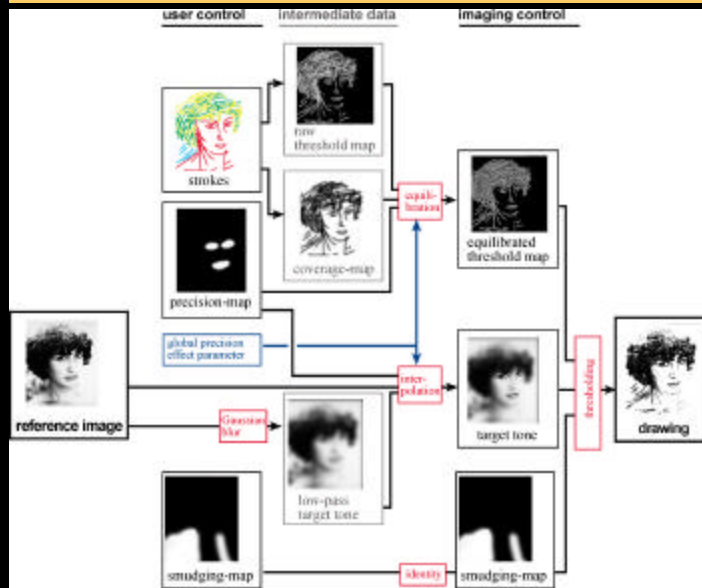
- Smudging



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

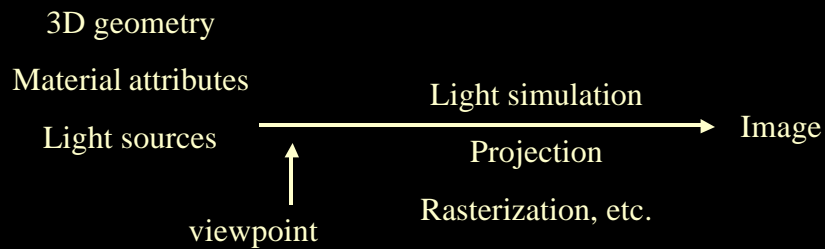
- Medium simulation
- Animation and coherence
- Line drawing, hatching
- Shading
- Style
- Perspective
- User interface

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

A one-way pipeline

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

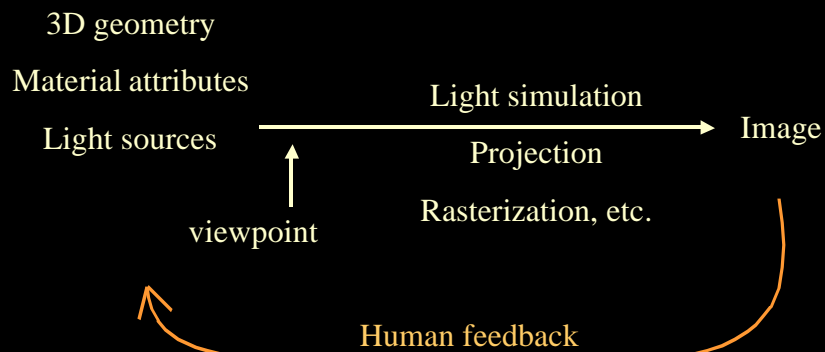


Photorealism vs. NPR

81

A one-way pipeline

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



Photorealism vs. NPR

82

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

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

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)



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