The Art and Science of Depiction

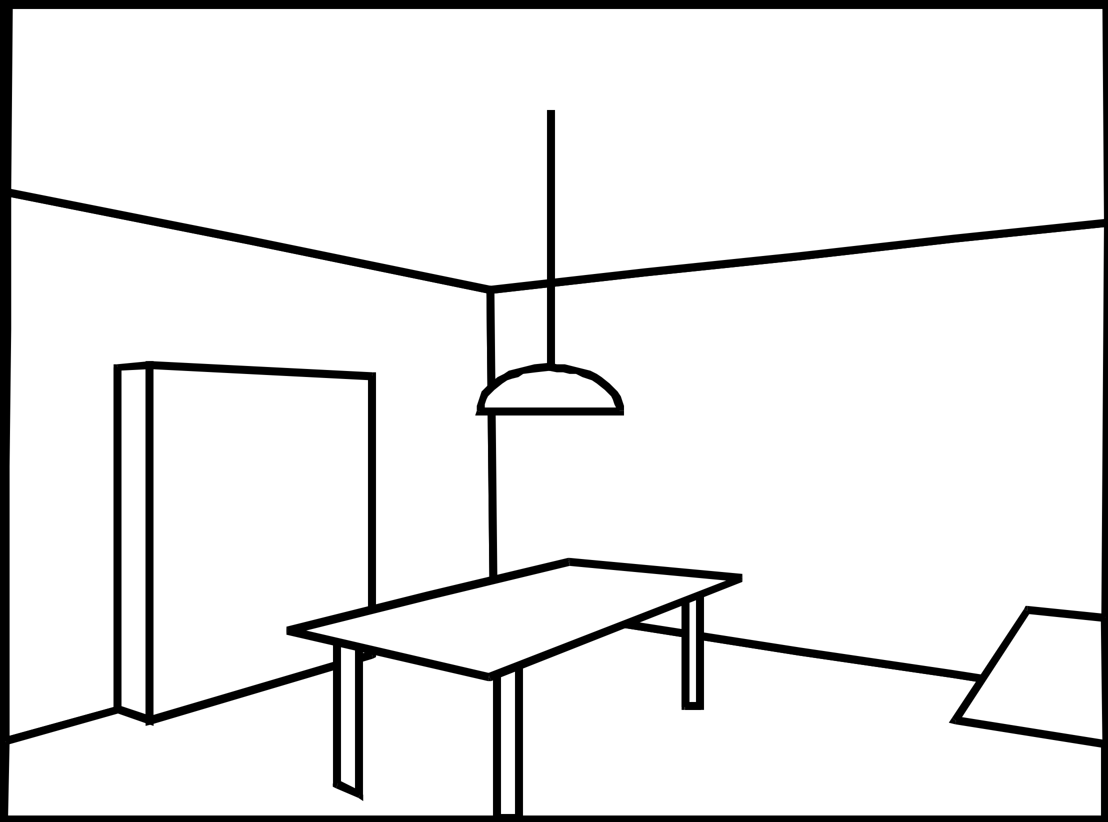
Photorealism vs. Non-Photorealism in Computer Graphics

Fredo Durand

MIT- Lab for Computer Science

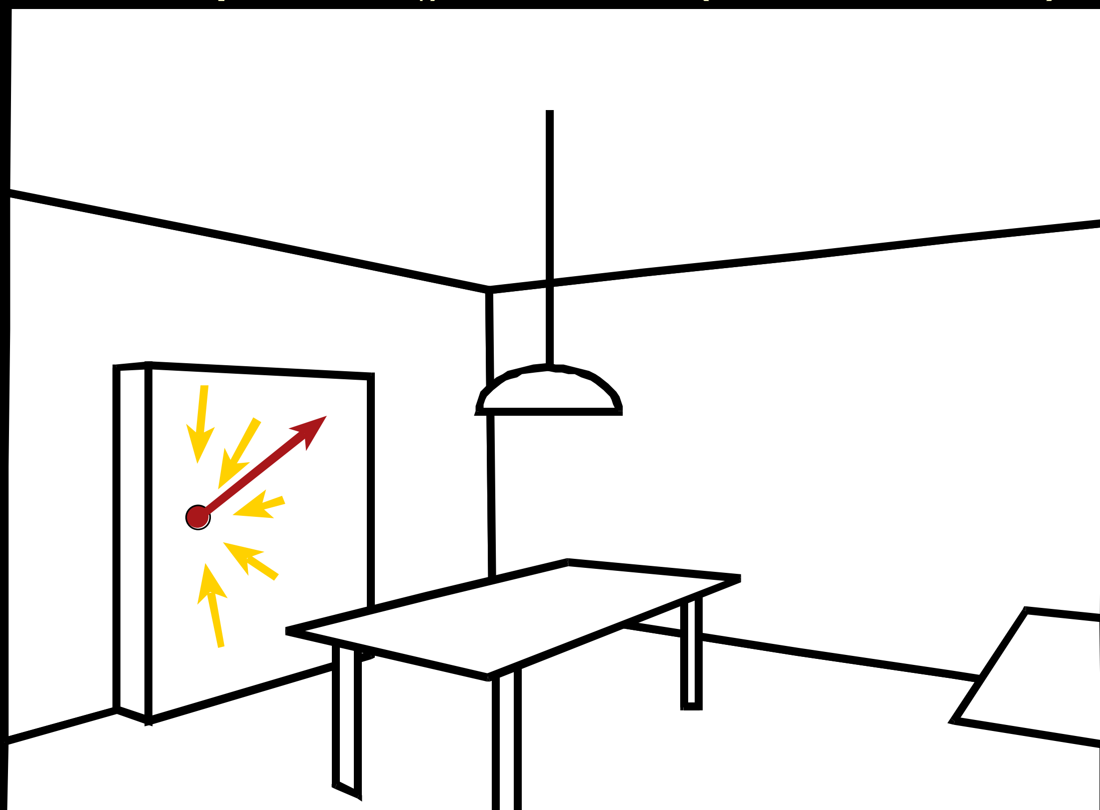
Global illumination

- How to take into account all light inter-reflections



The Rendering equation

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

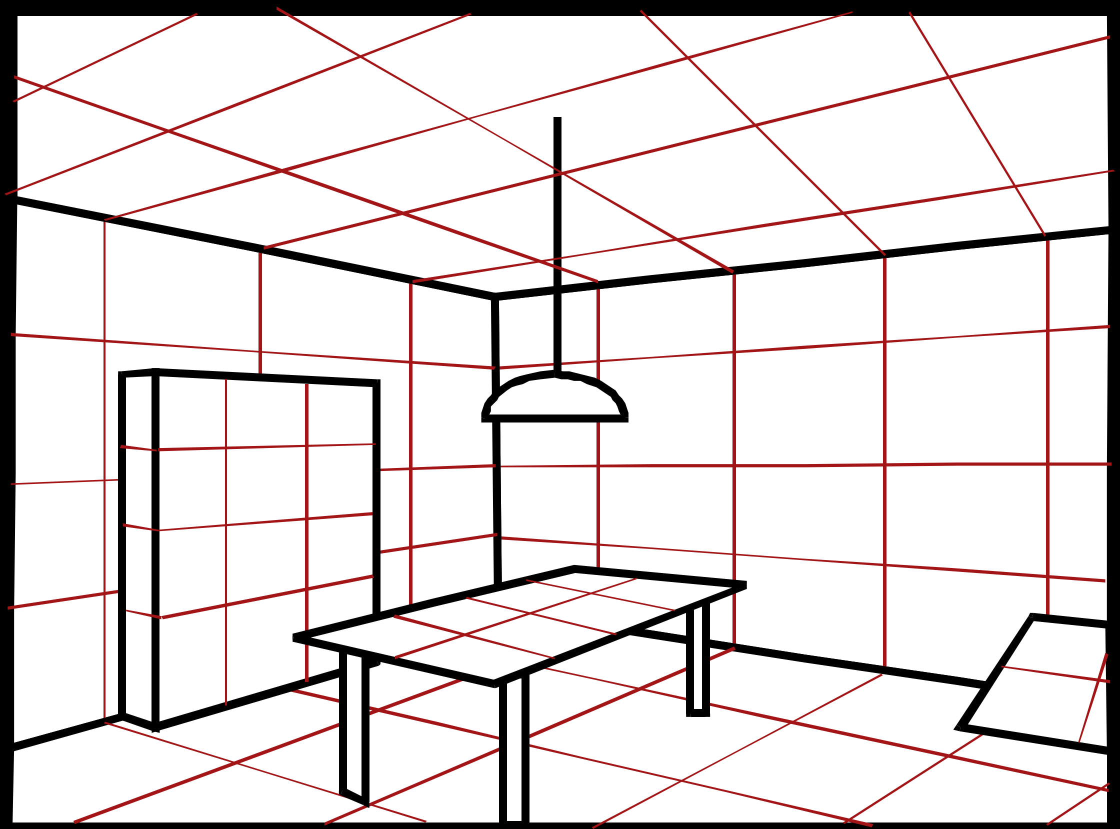


Radiosity

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

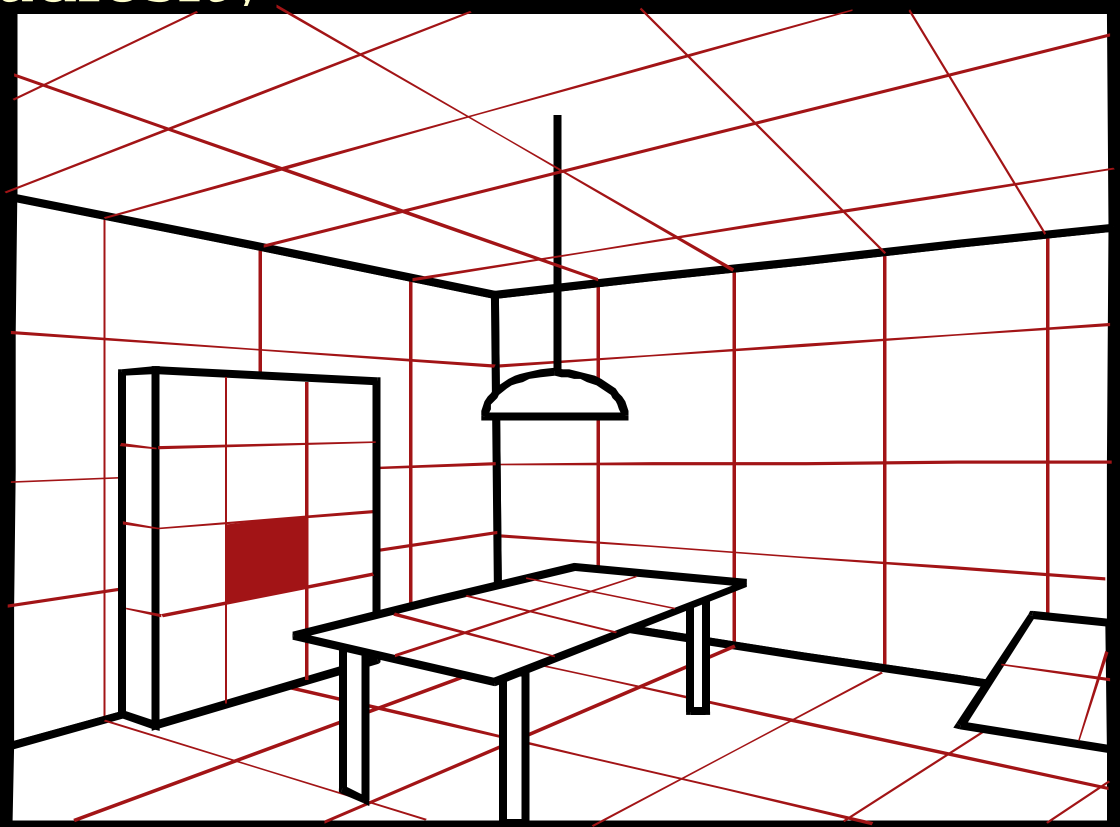
Radiosity

- Subdivide the scene into discrete elements



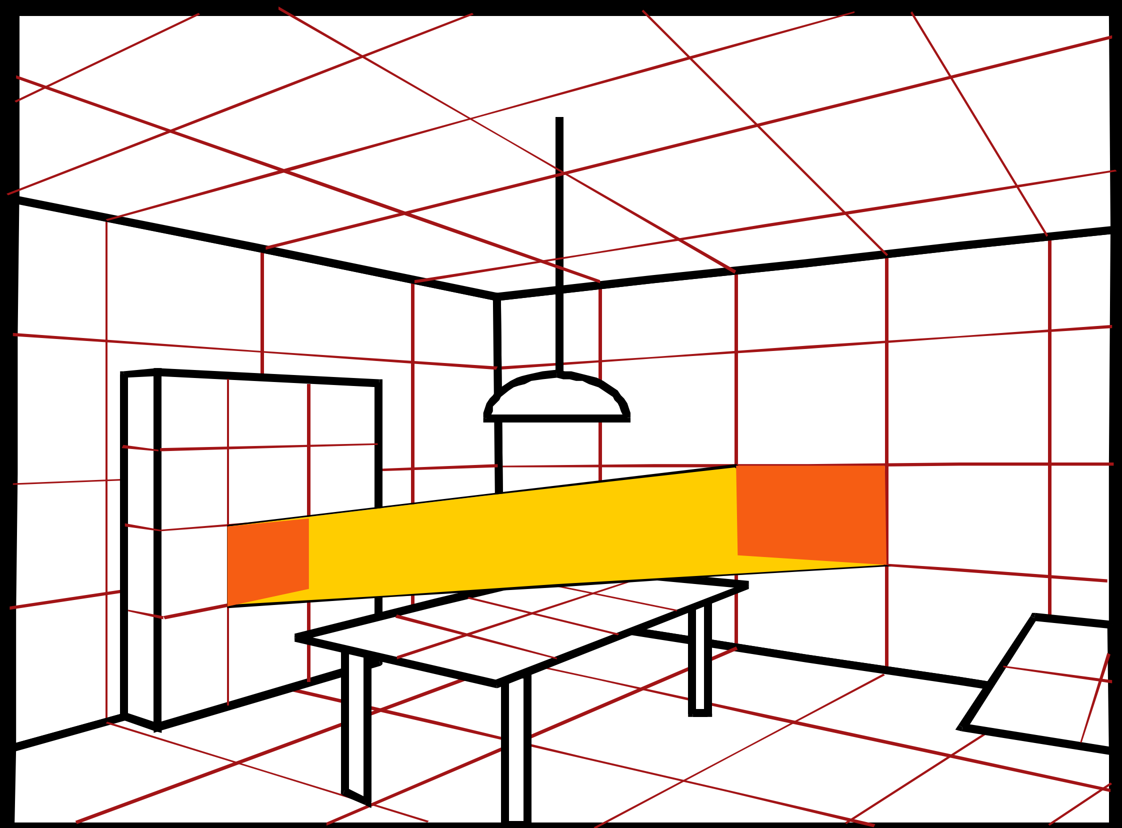
Radiosity

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



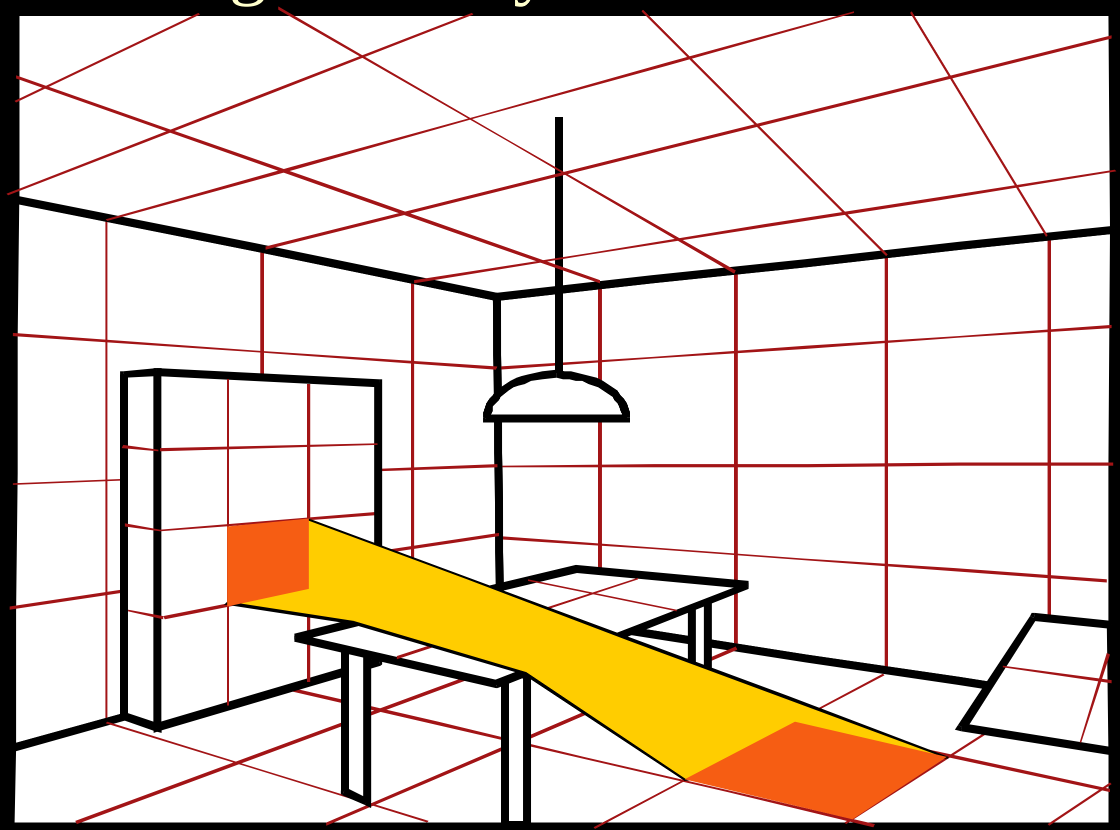
Radiosity

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



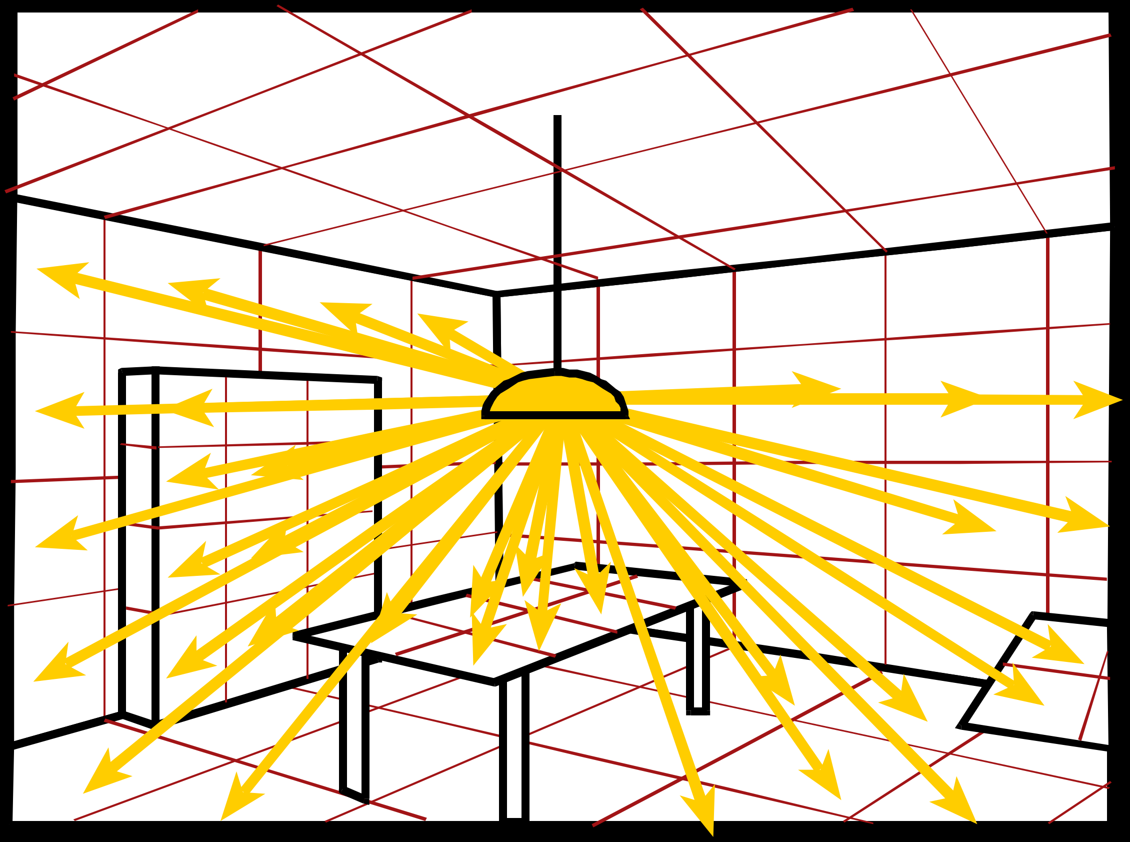
Radiosity

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



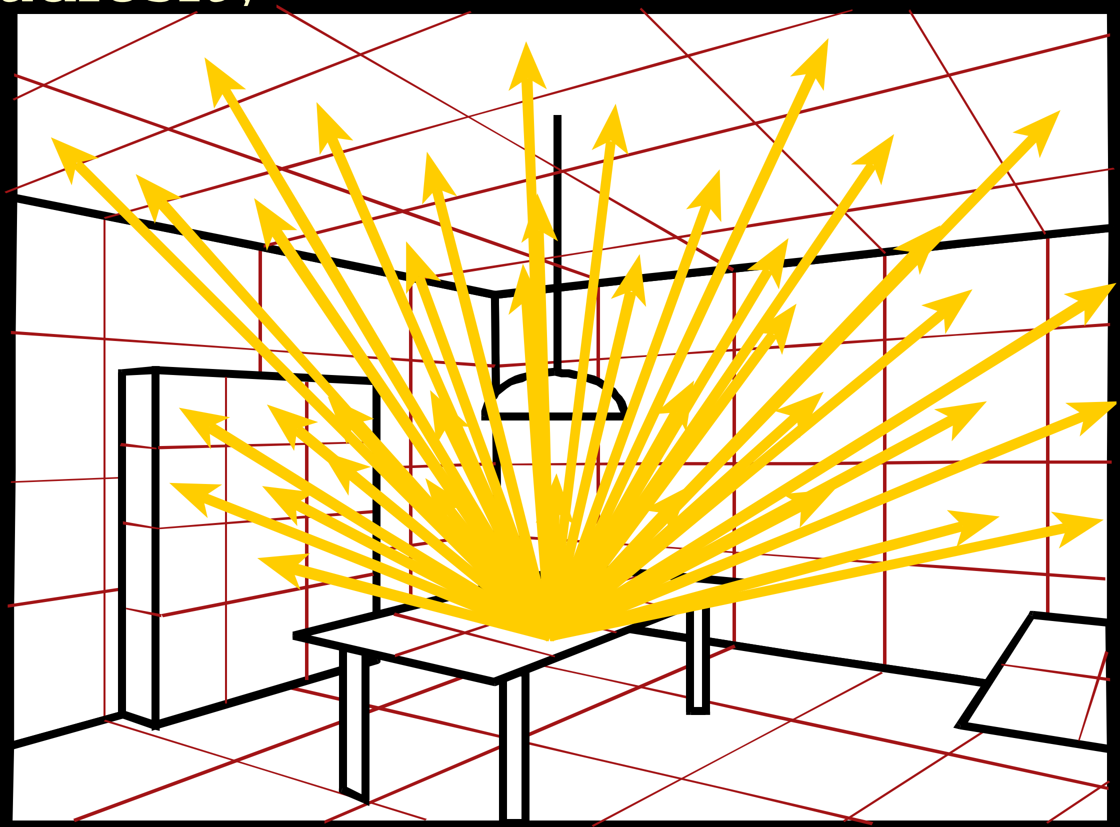
Radiosity

- Iterative solution
- Shoot light from the most luminous source



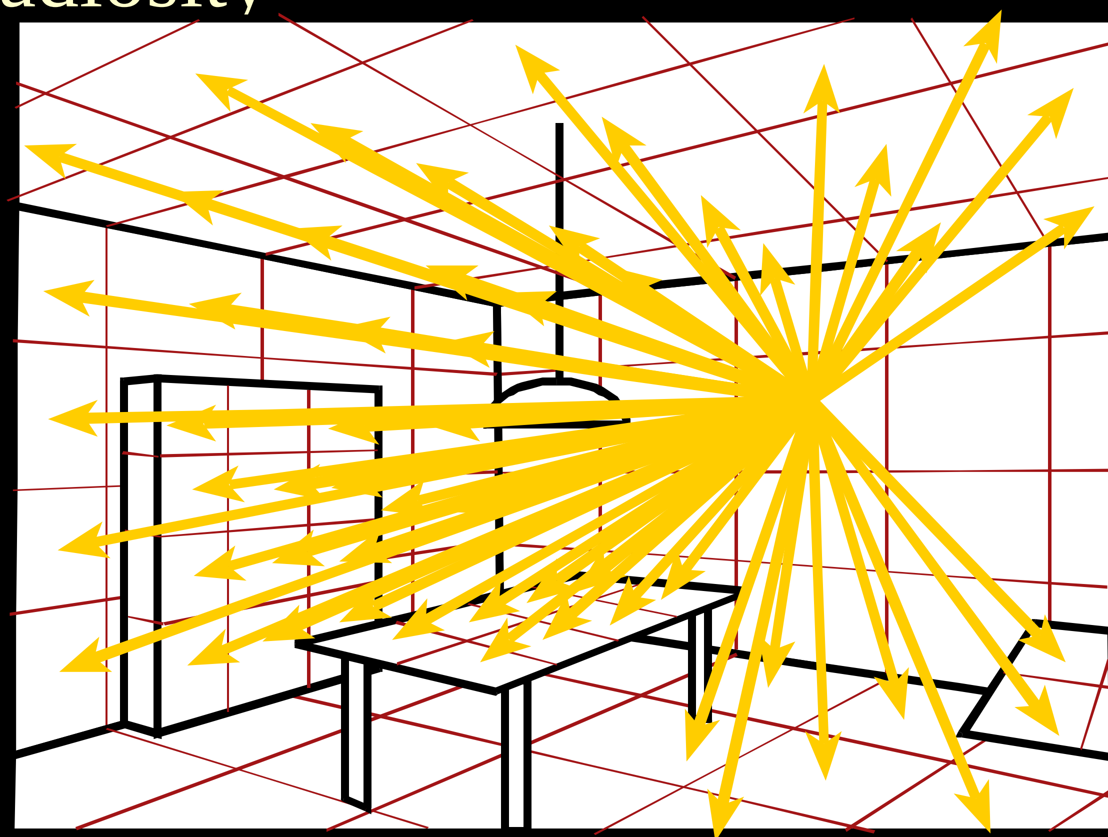
Radiosity

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



Radiosity

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



Radiosity

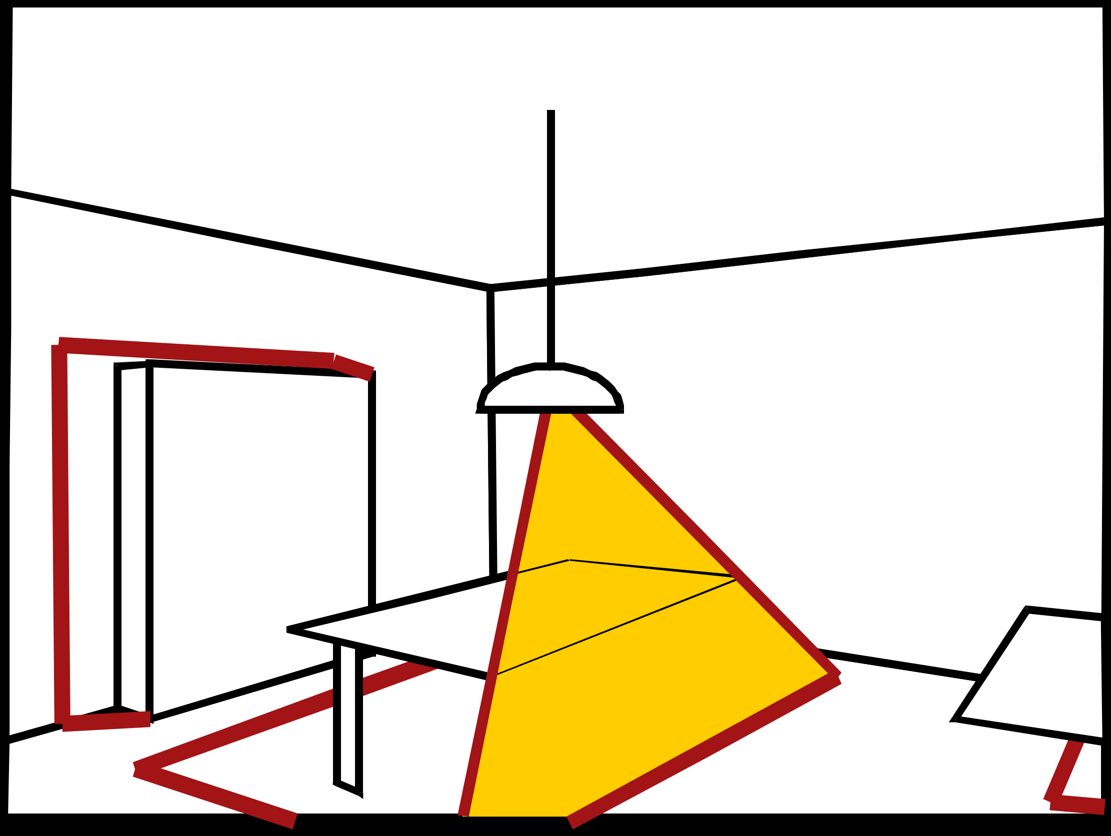
- Smoothing and other gimmicks

Radiosity

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

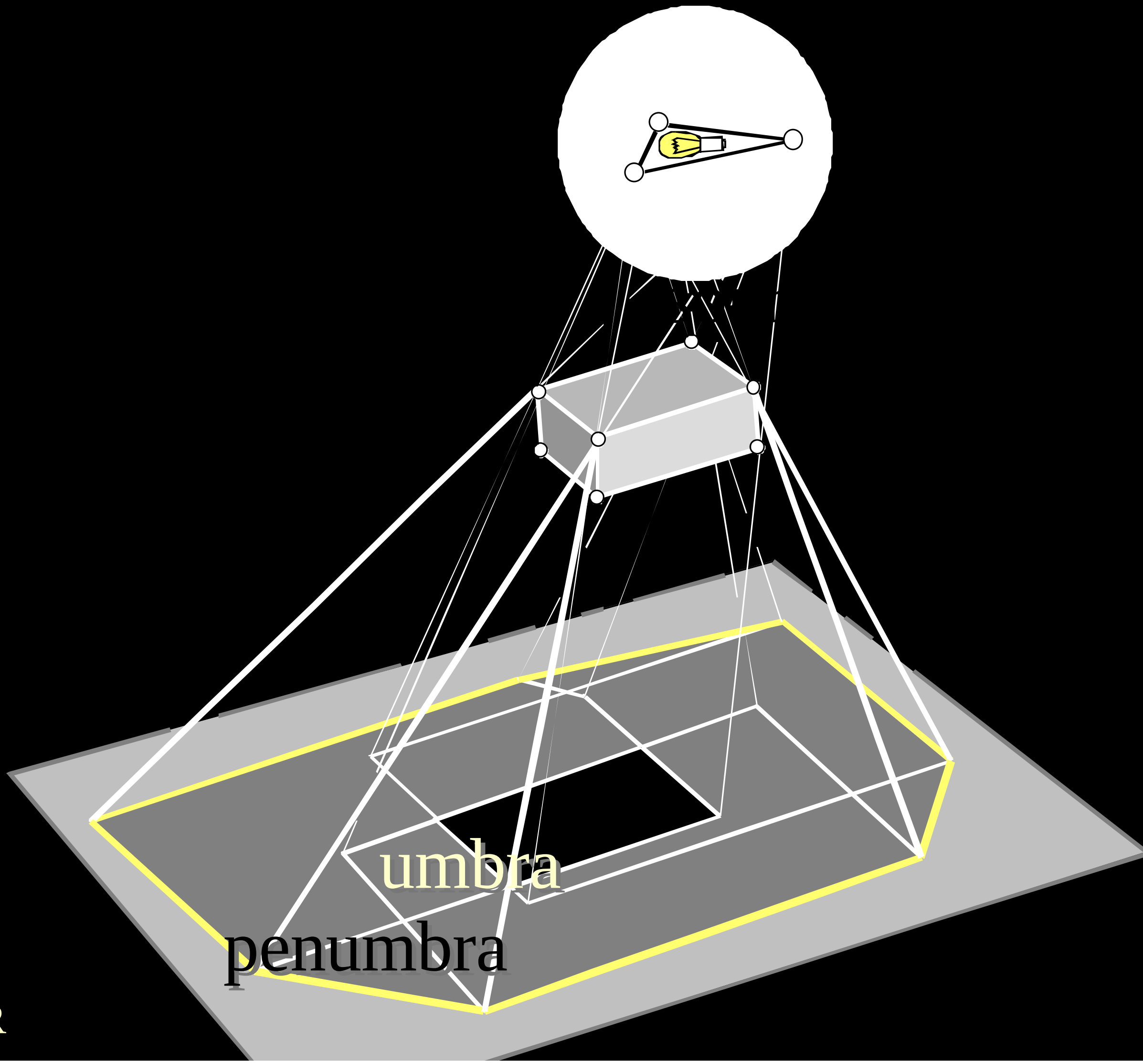
Discontinuity meshing

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

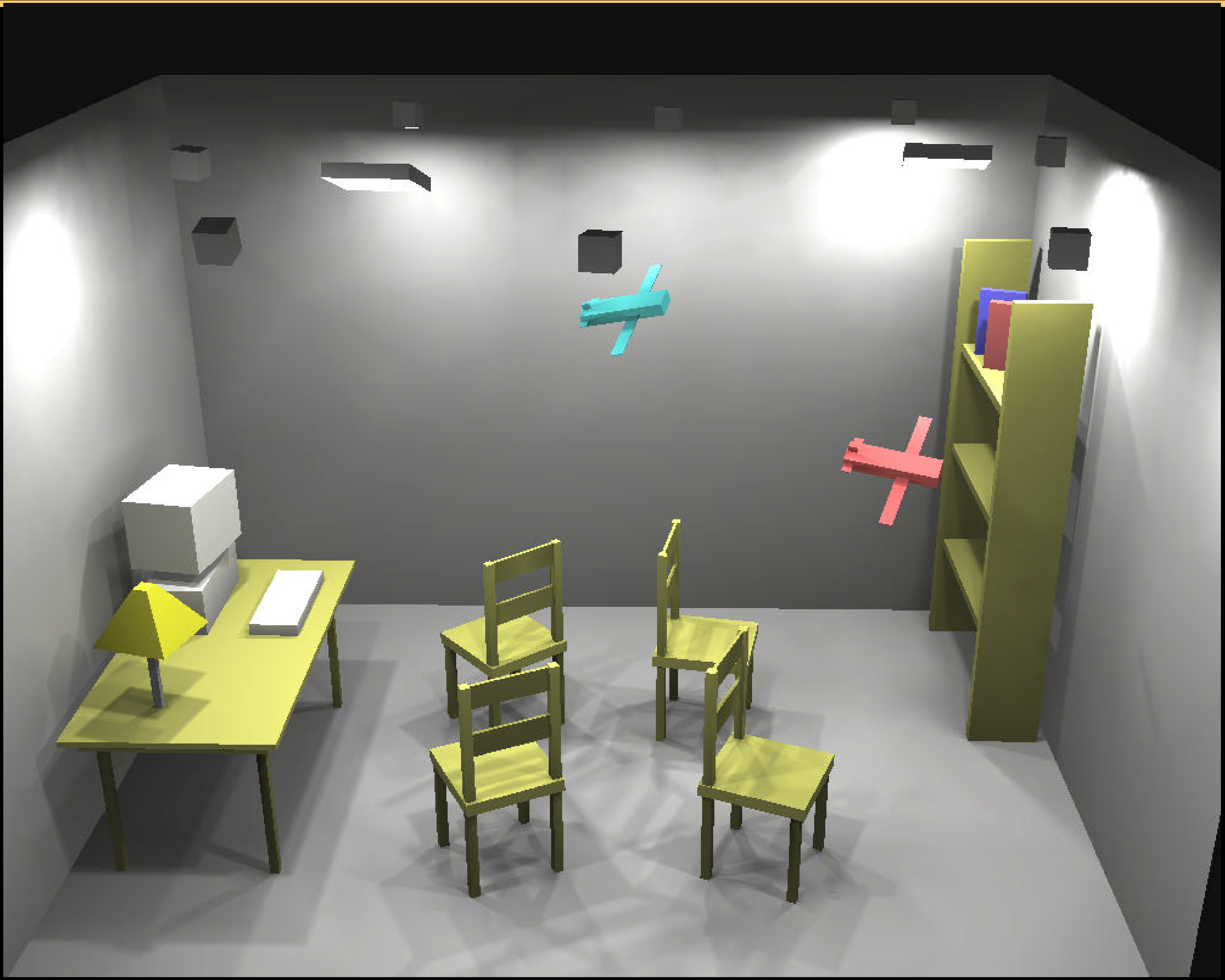


Discontinuity meshing

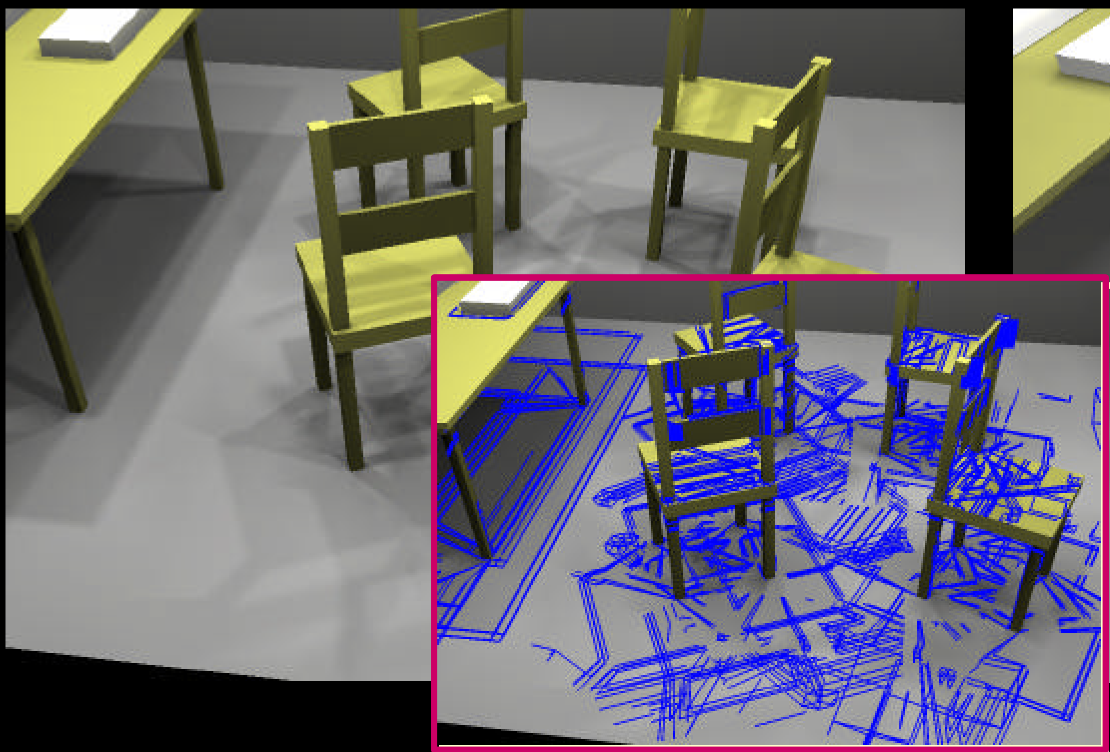
- Limits of umbra and penumbra



Discontinuity meshing



Comparison



With skeleton

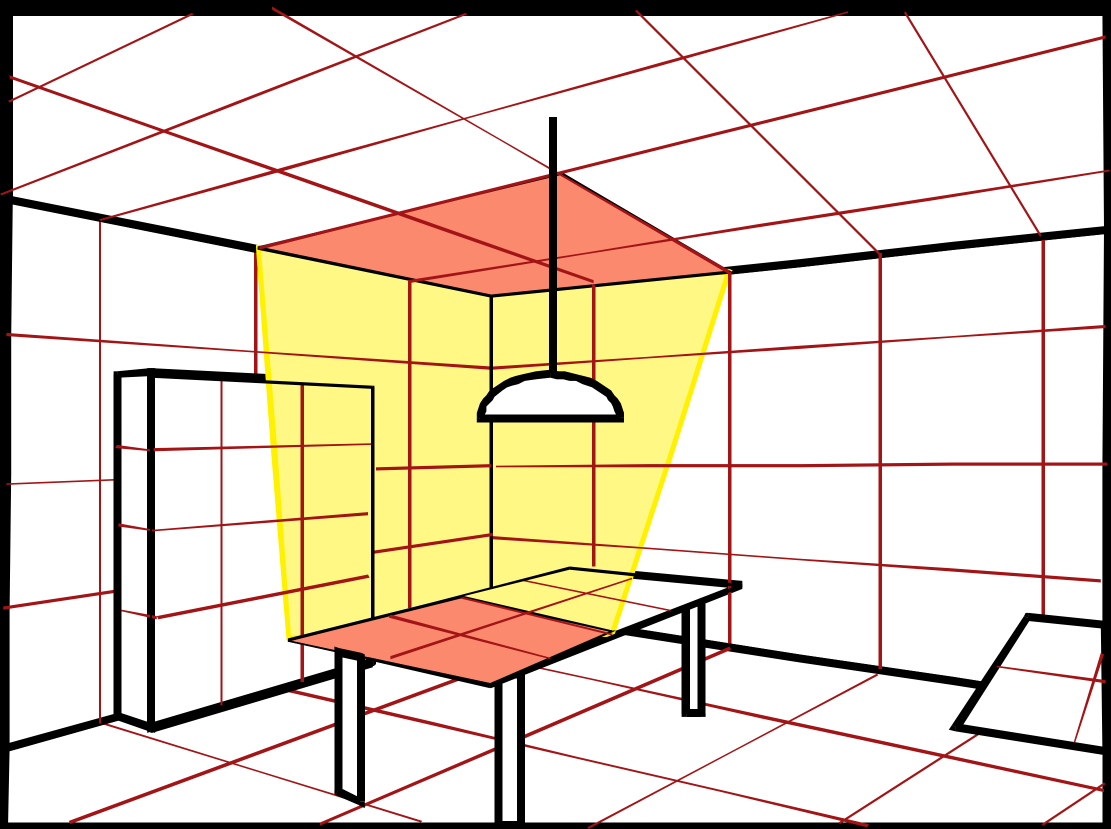
10 minutes 23 seconds

[Gibson 96]

1 hour 57 minutes

Hierarchical approach

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



Lightscape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Lightscape

Lightscape


Rendered using Lightscape
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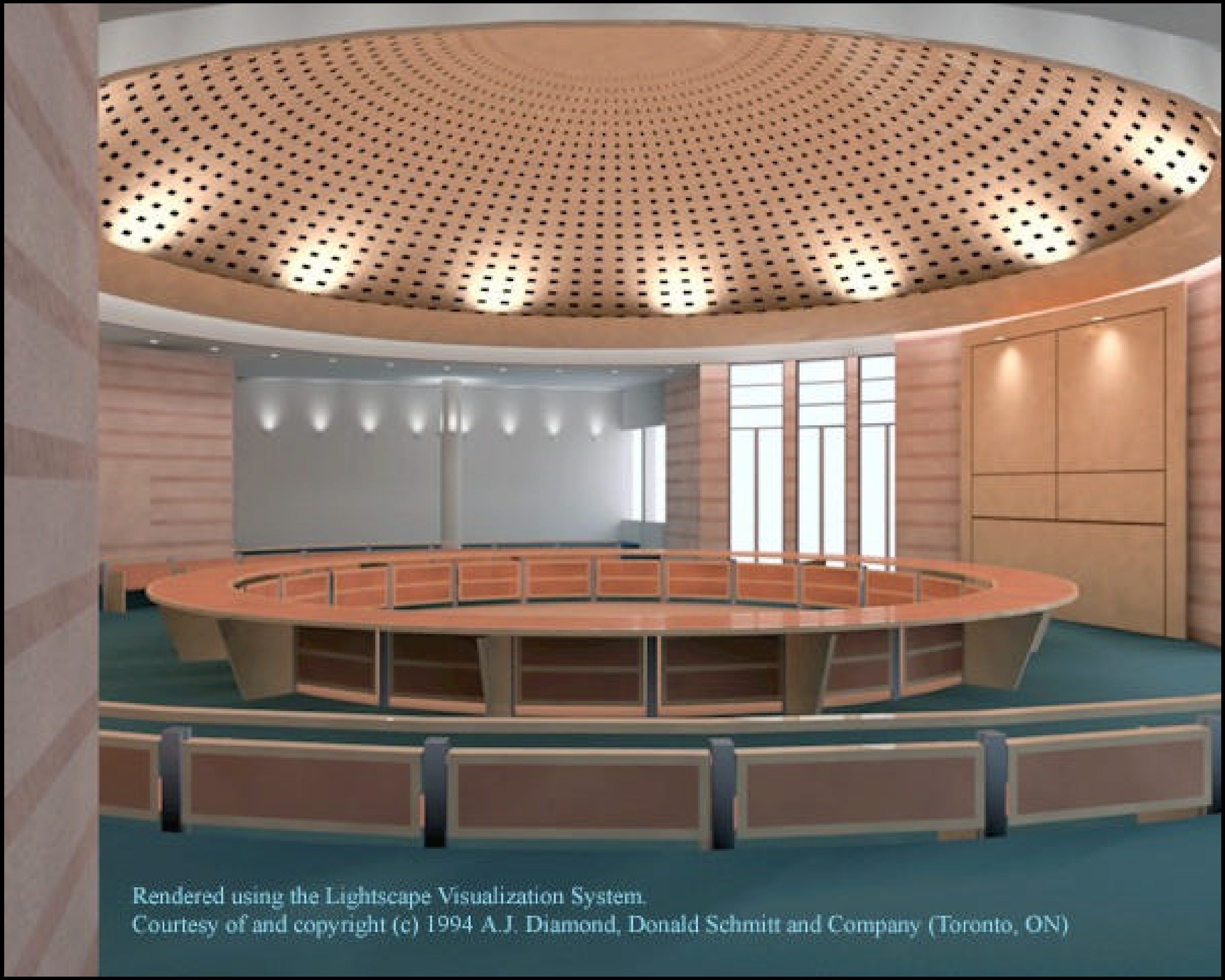
Lightscape


Rendered using the Lightscape Visualization System.
Courtesy of and copyright (c) 1994 A.J. Diamond, Donald Schmitt and Company (Toronto, ON)

Lightscape

Lightscape


Rendered using the Lightscape Visualization System.
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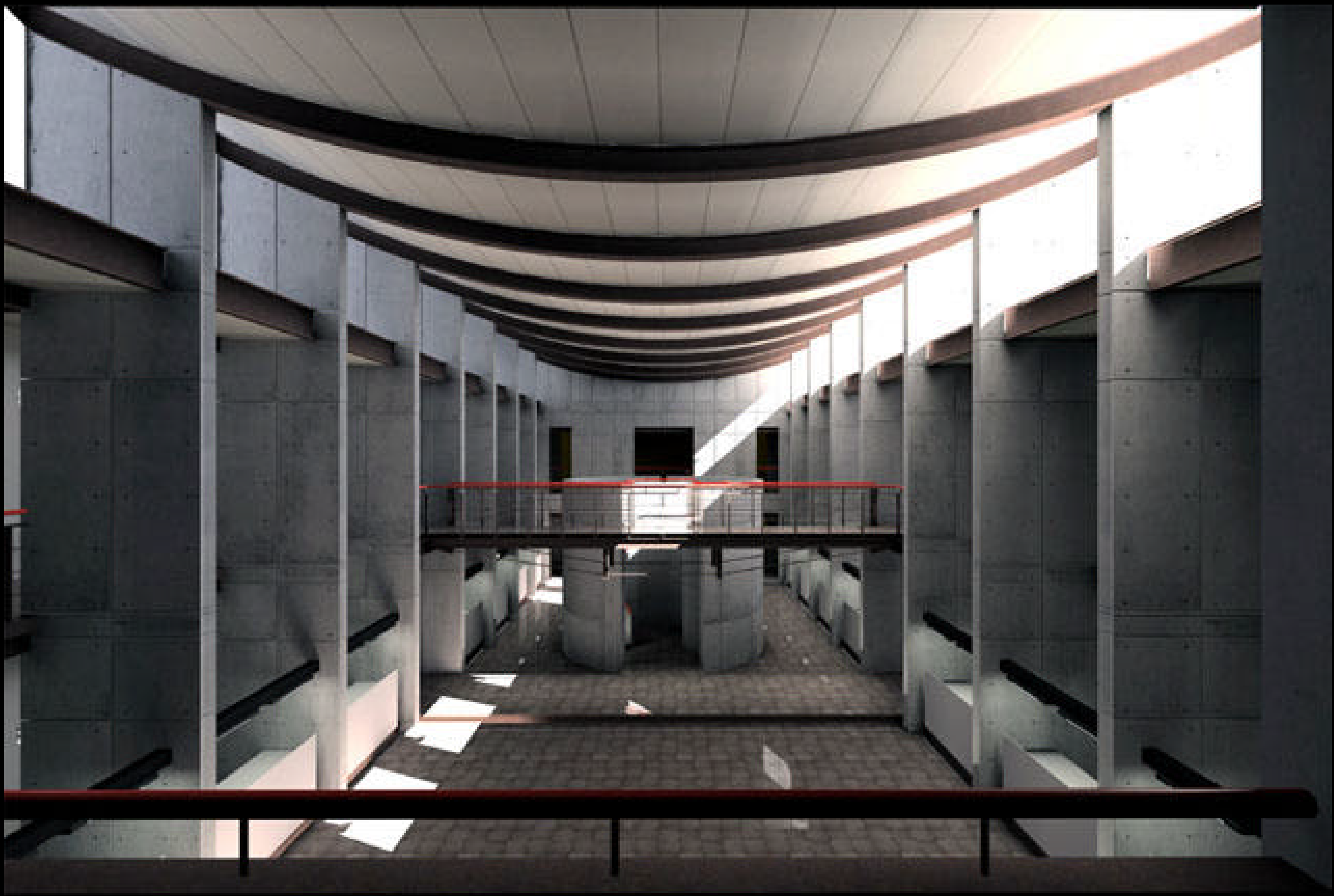
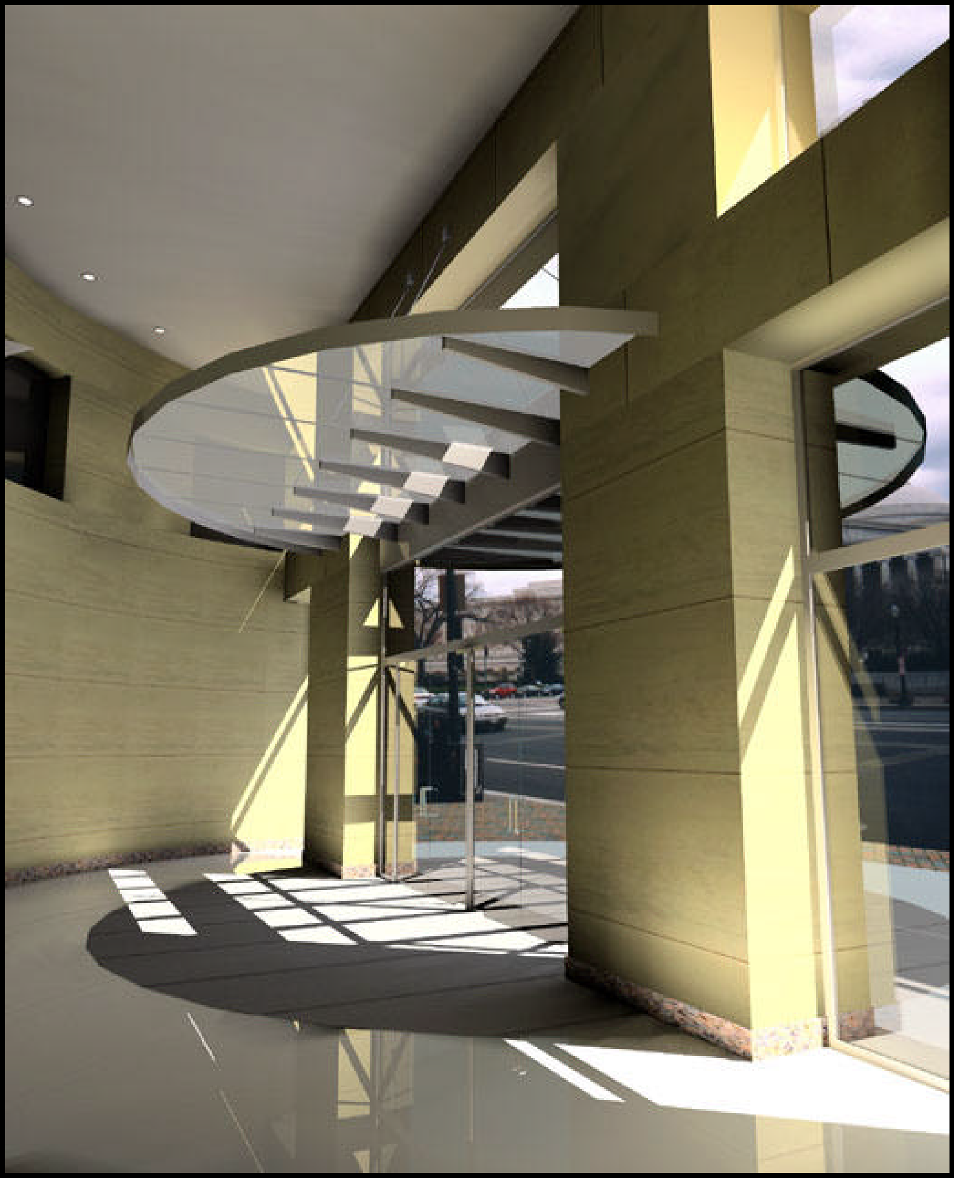
Lightscape



Lightscape



Lightscape


Rendered using the Lightscape Visualization System
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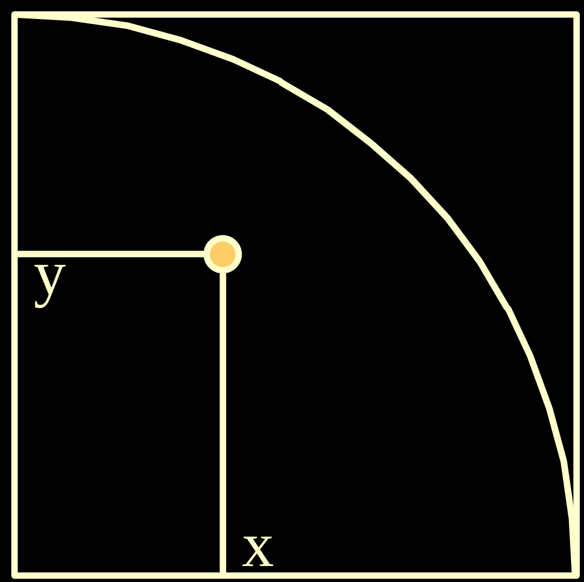
Monte-Carlo ray-tracing

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

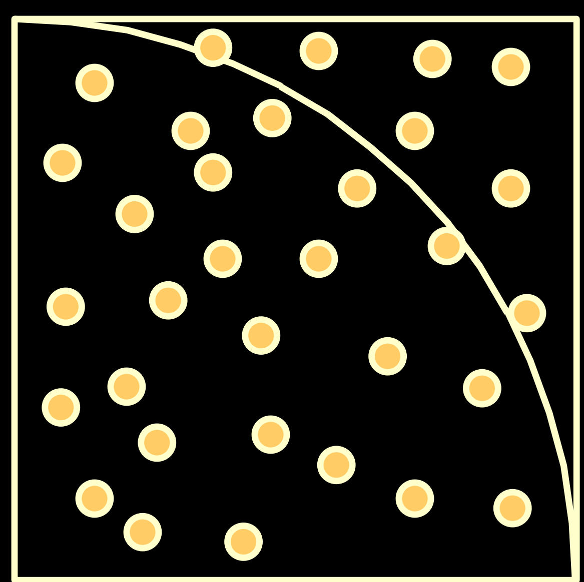
Monte-Carlo computation of p

- Take a square
- Take a random point (x,y) in the square
- Test if it is inside the ¼ disc ($x^2+y^2 < 1$)
- The probability is $\pi /4$



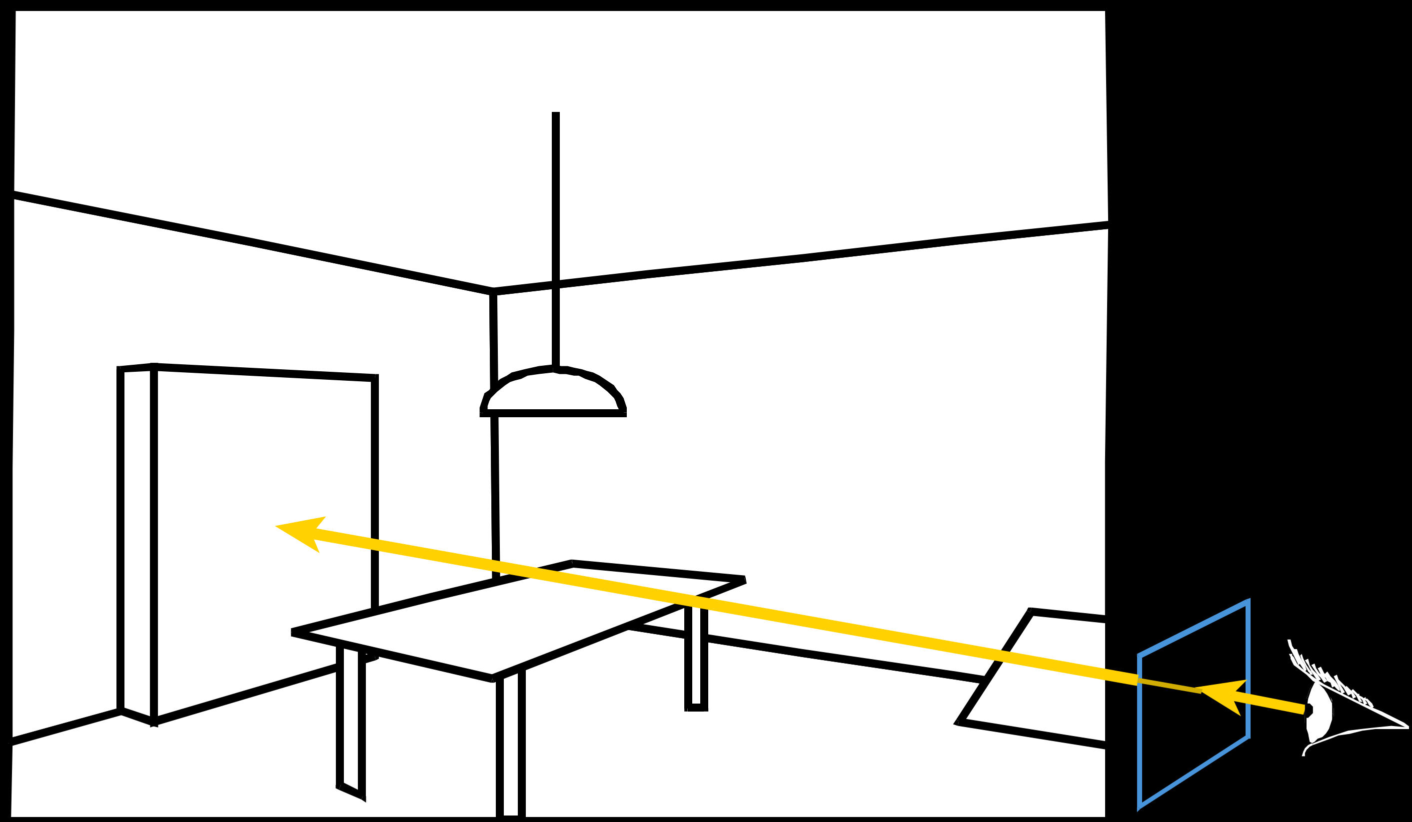
Monte-Carlo computation of p

- The probability is π /4
- Count the inside ratio n = # inside / total # trials
- $\pi \approx n * 4$
- The error depends on the number or trials



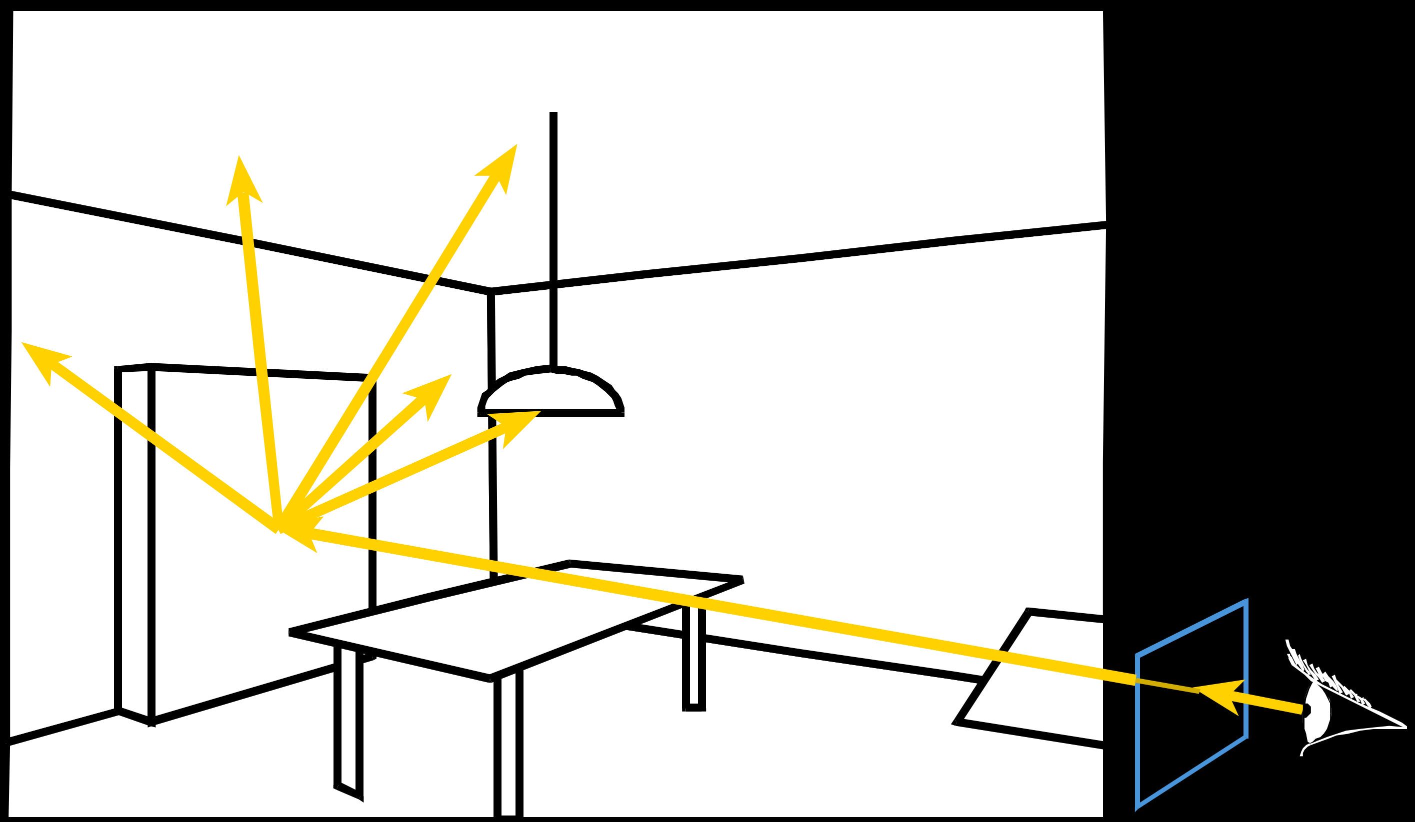
Monte-Carlo

- Cast a ray from the eye through each pixel



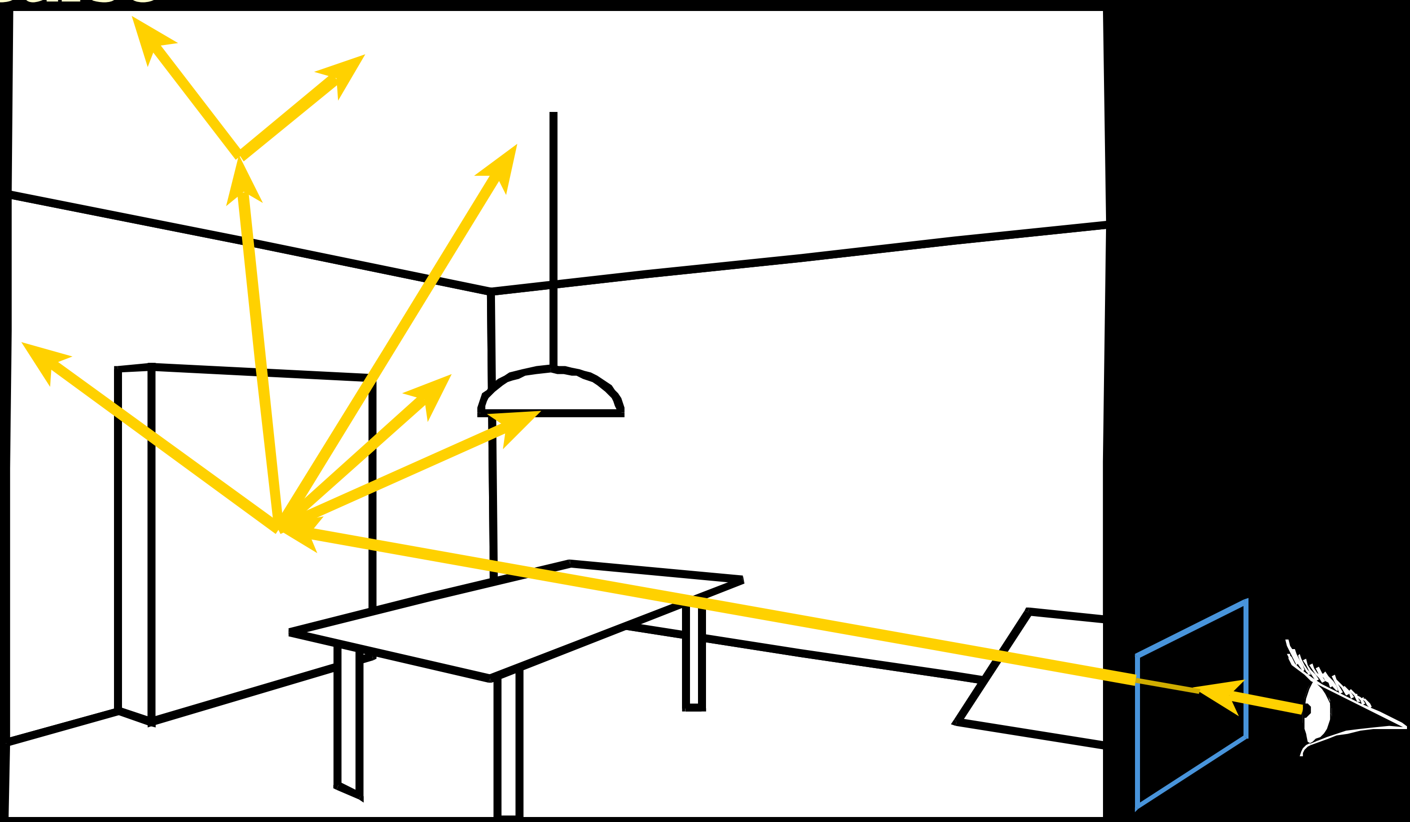
Monte-Carlo

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



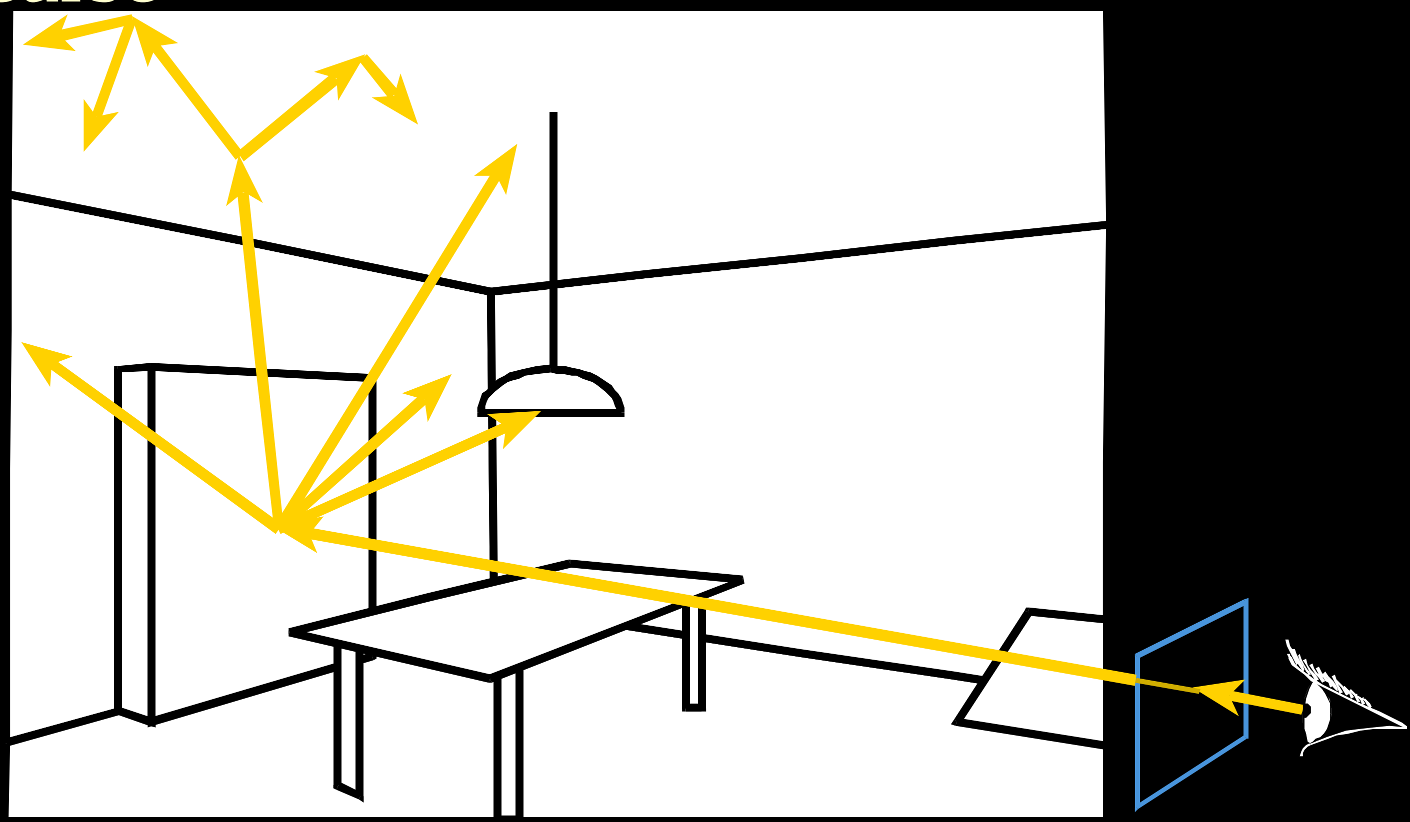
Monte-Carlo

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



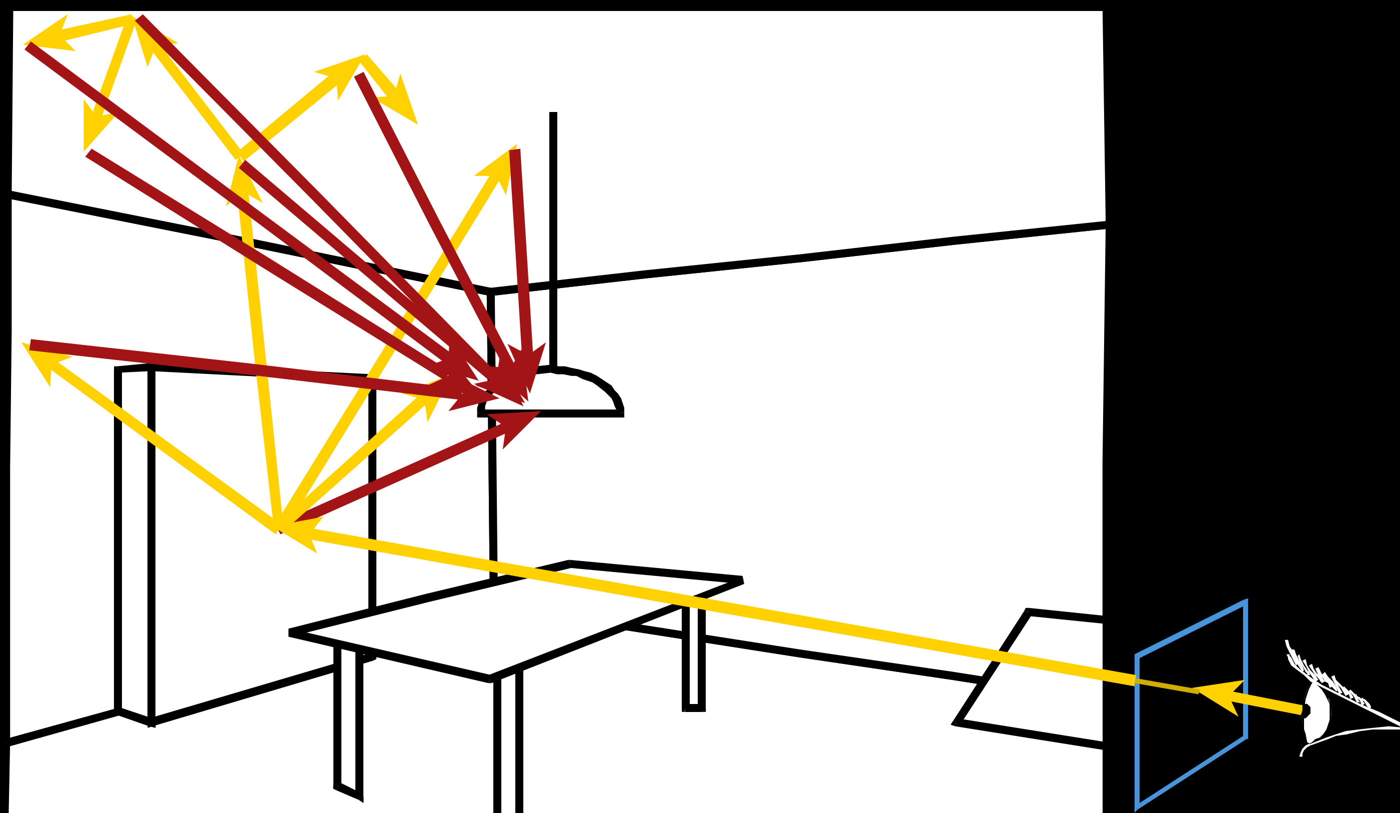
Monte-Carlo

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



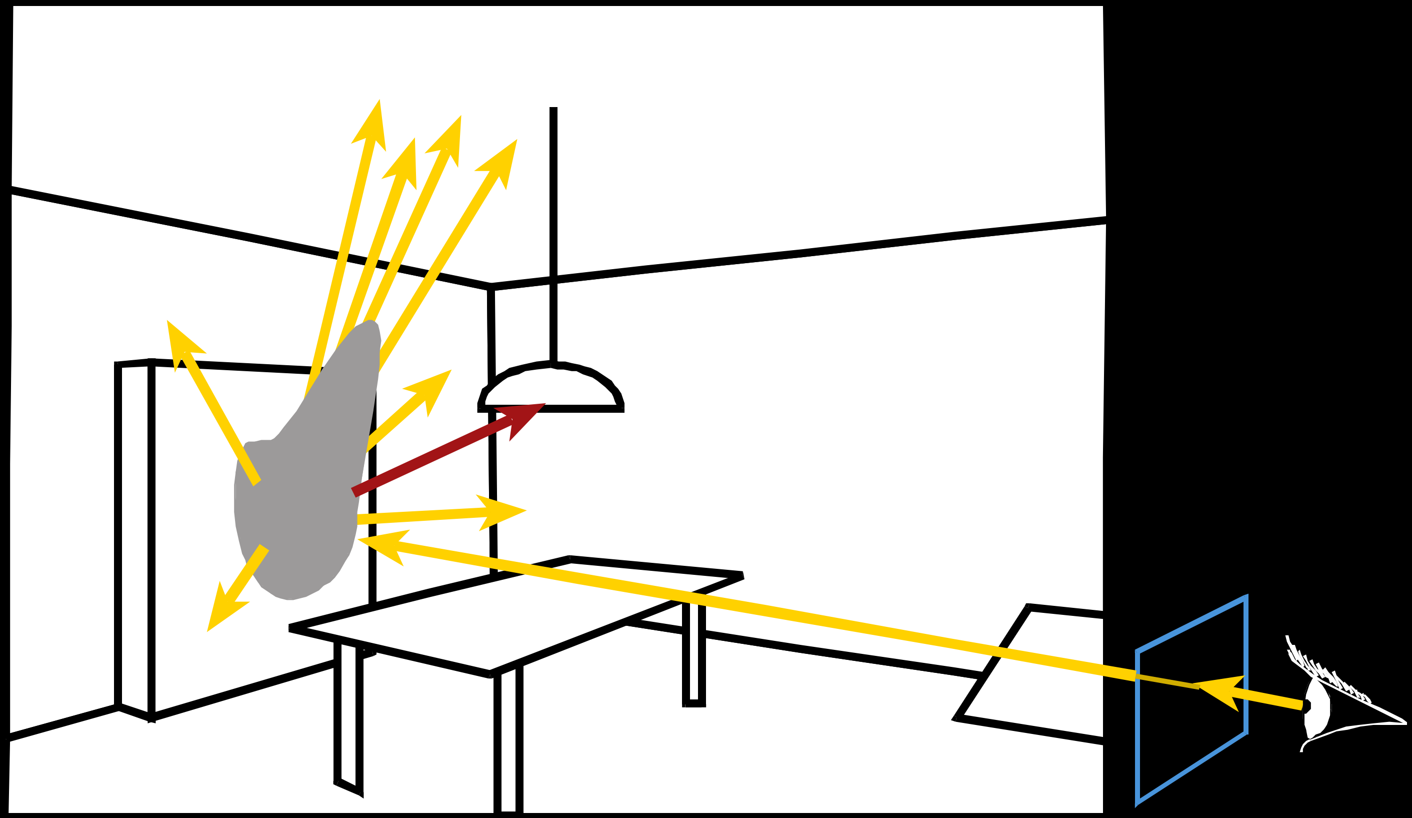
Monte-Carlo

- Systematically sample primary light



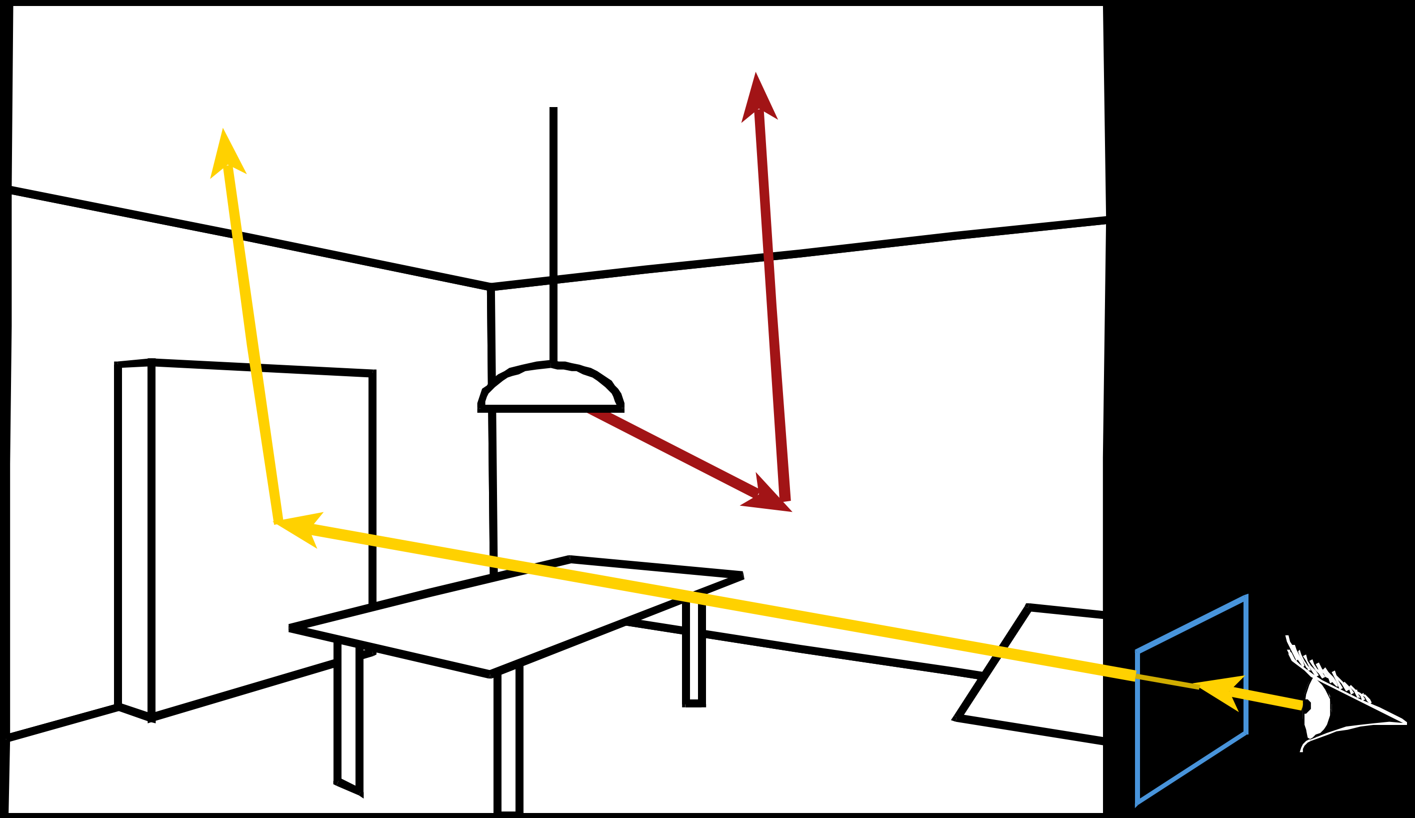
Monte-Carlo

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



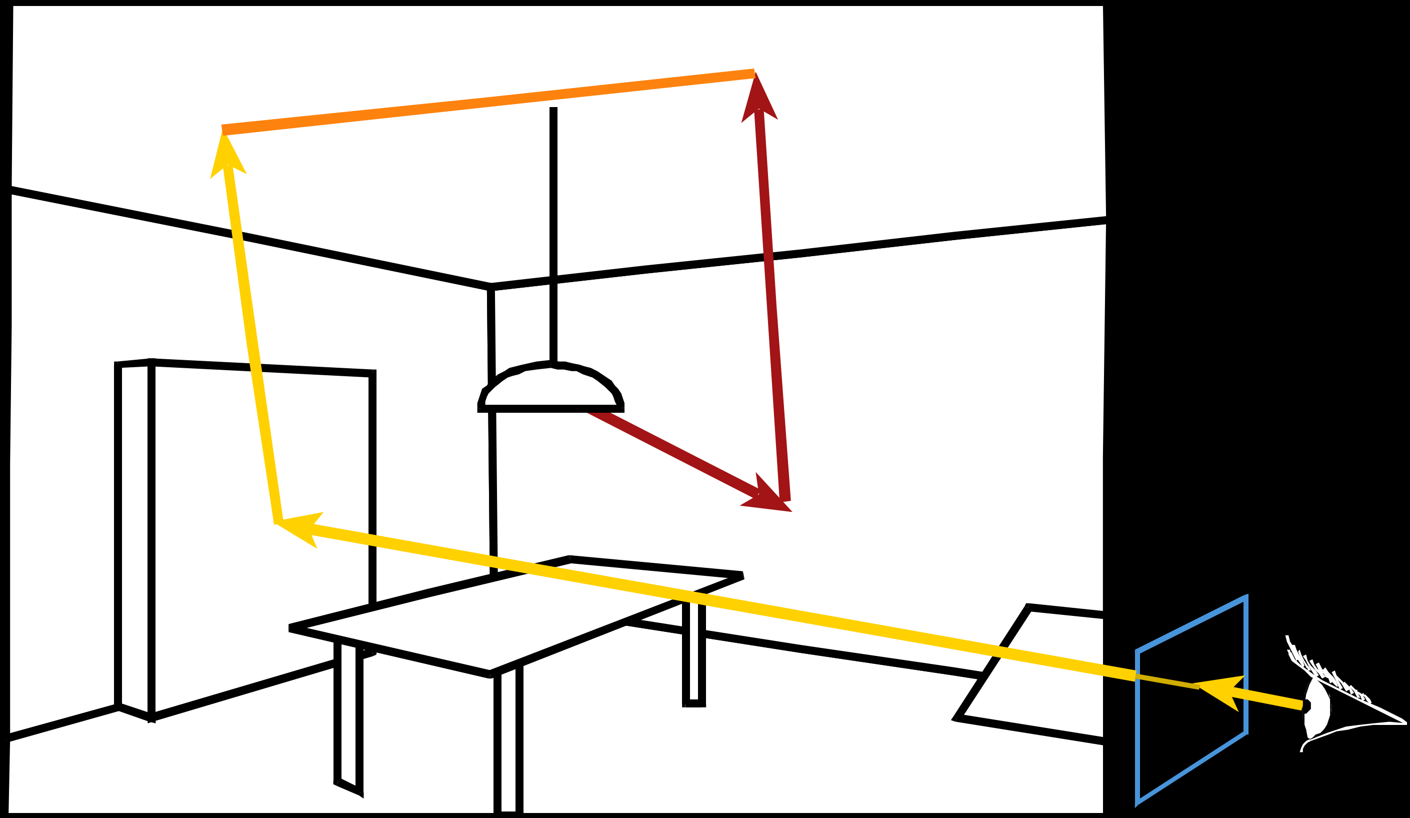
Monte-Carlo

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



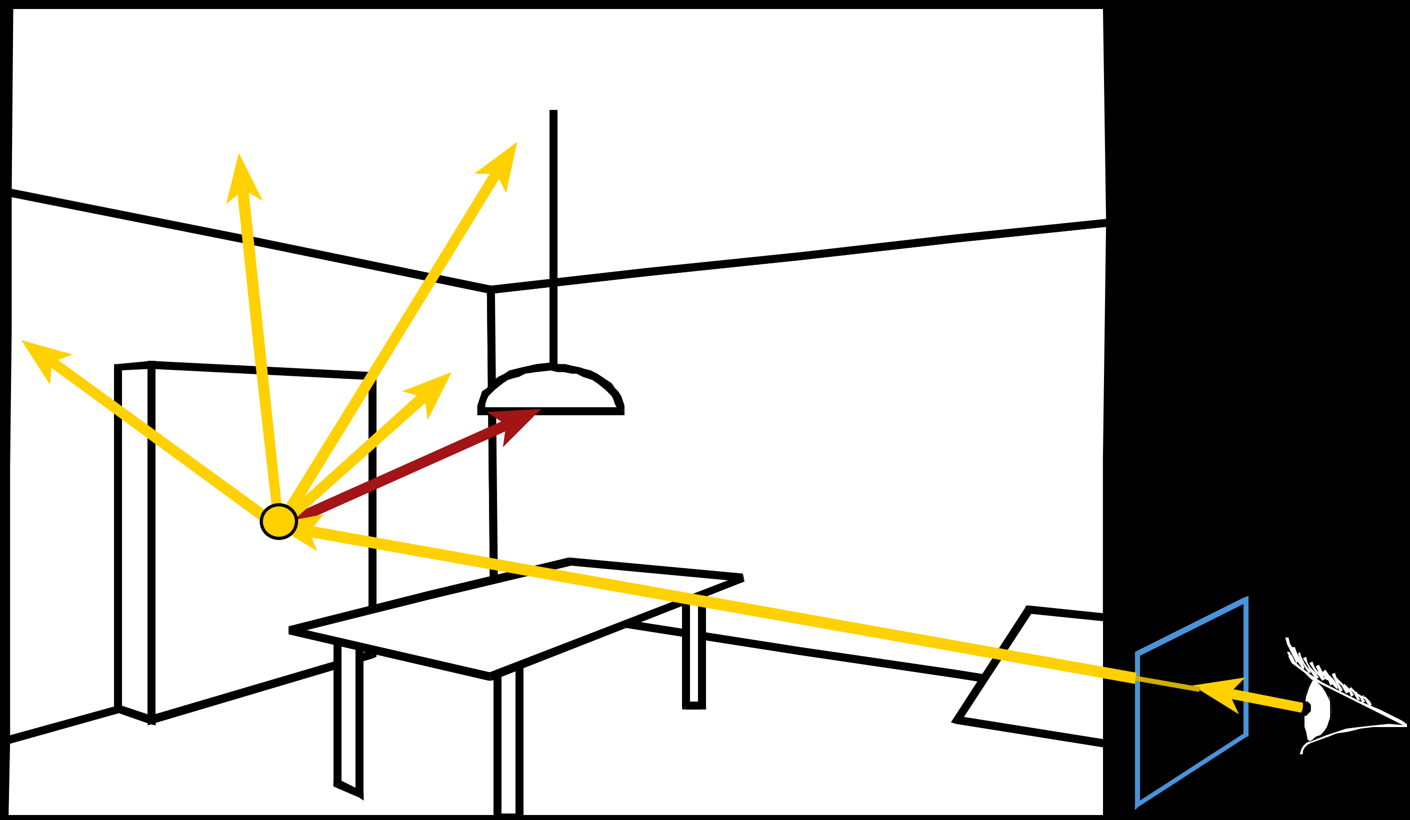
Monte-Carlo

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



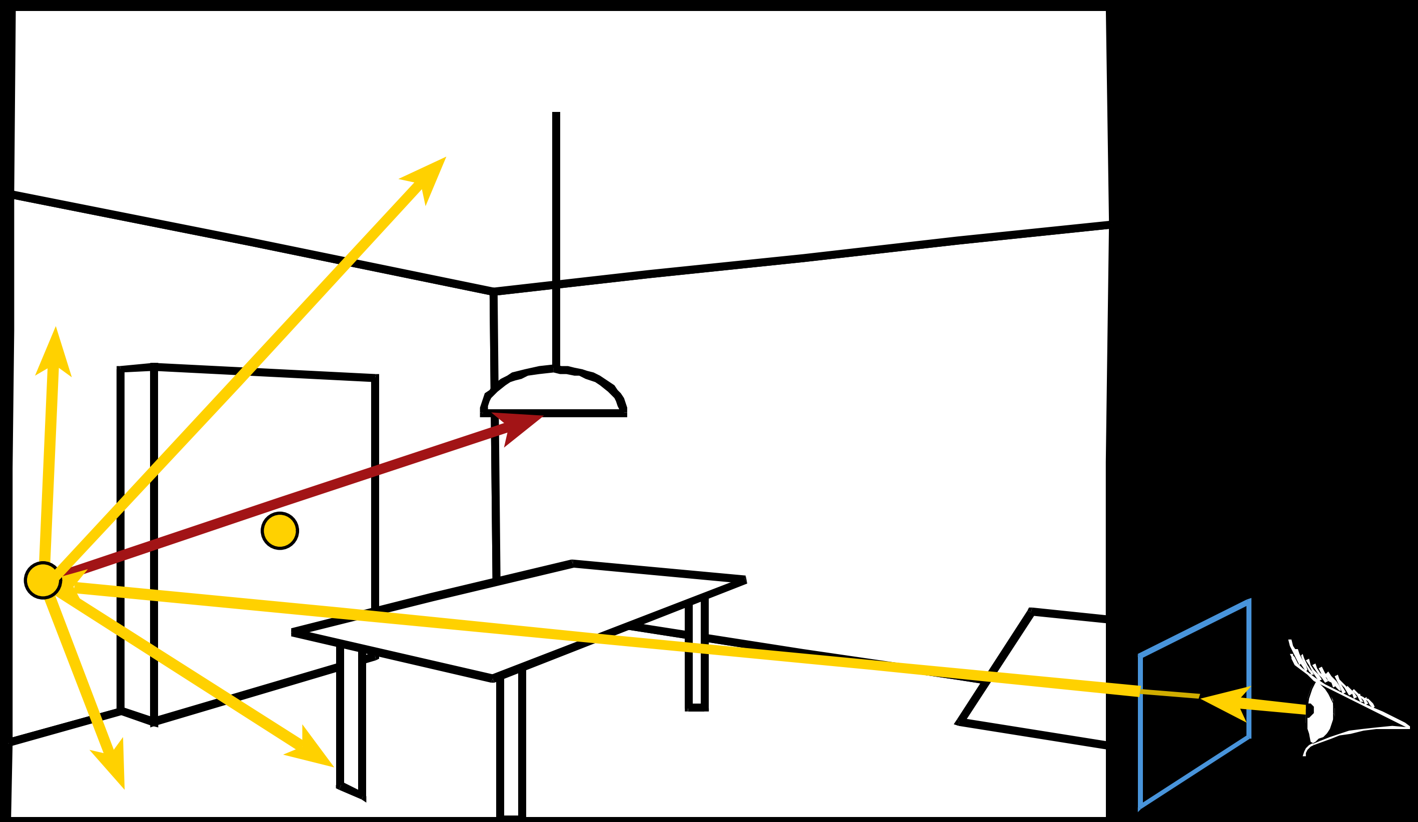
Radiance cache

- Store the indirect illumination



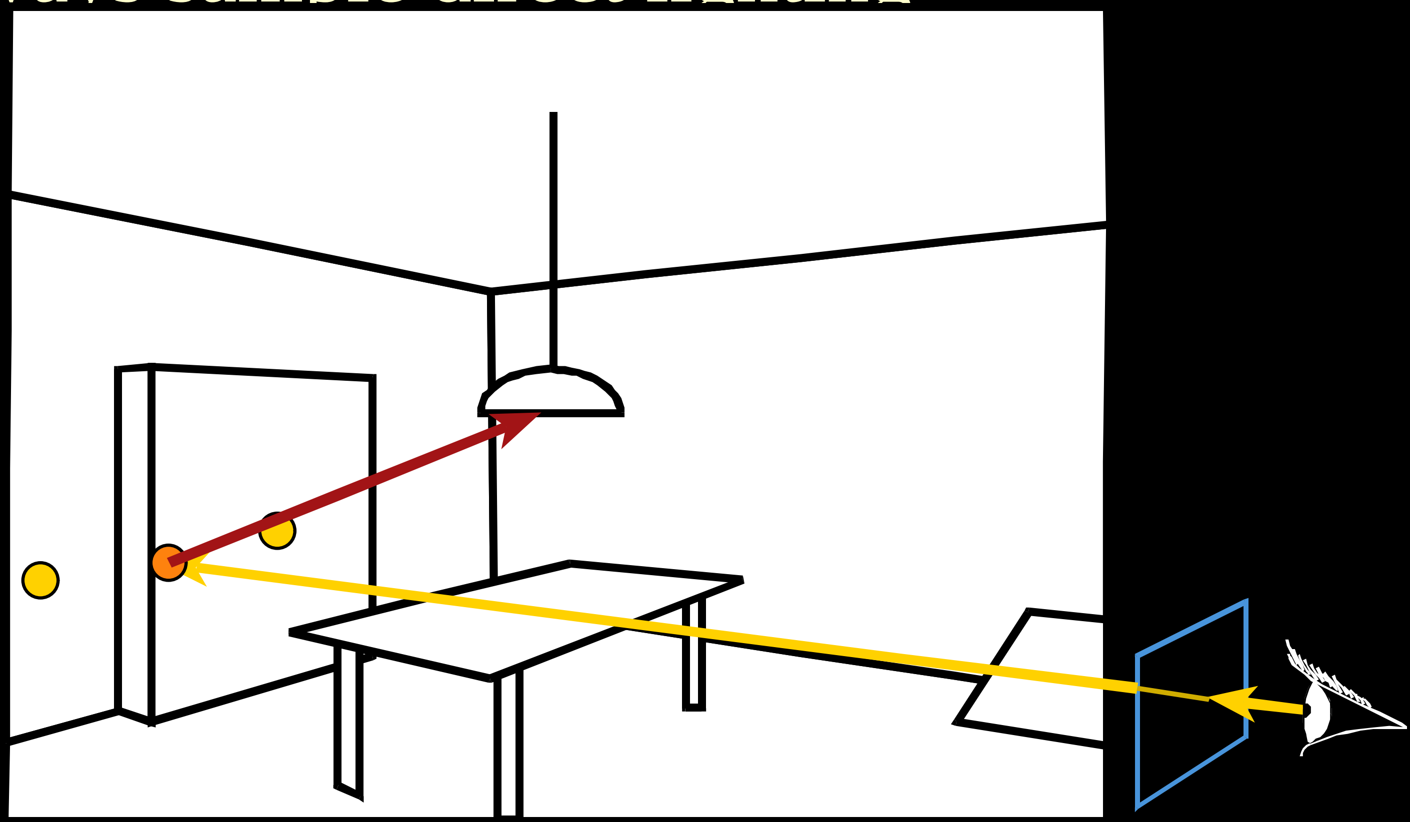
Radiance cache

- Store the indirect illumination



Radiance cache

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

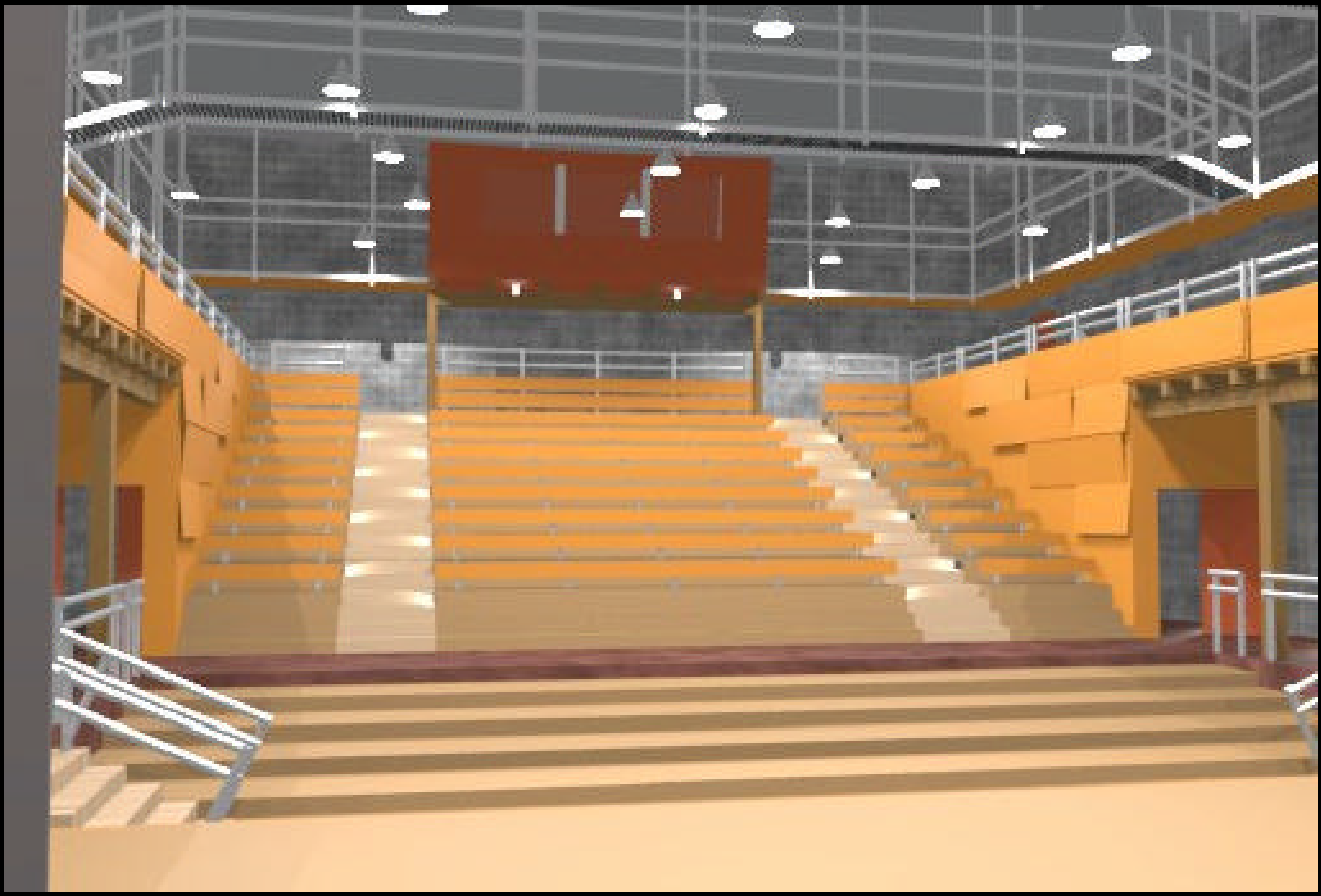


Monte-Carlo & Radiance

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

Radiance

Radiance



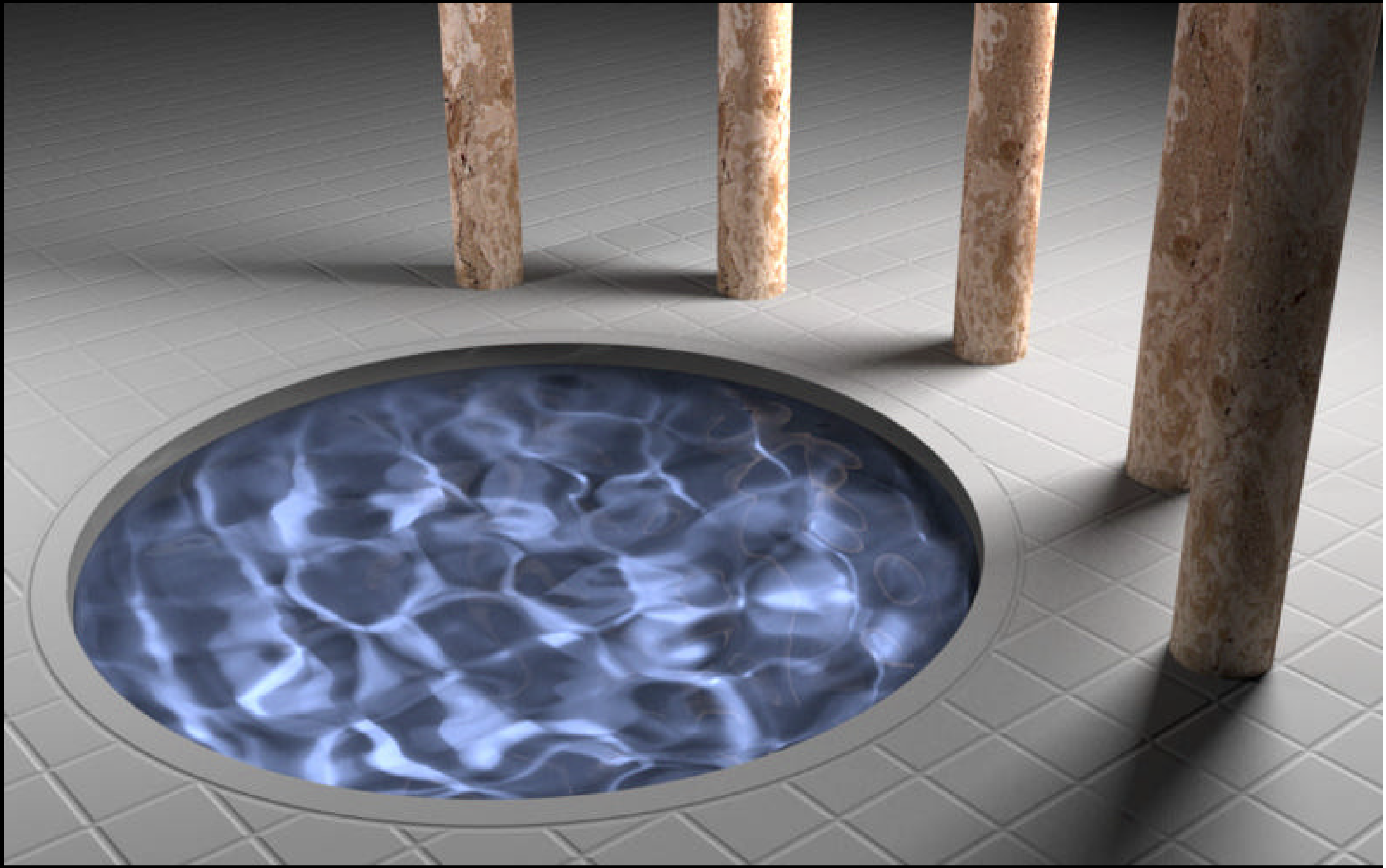
Radiance

Radiance

Radiance

Radiance

Monte-Carlo ray-tracing

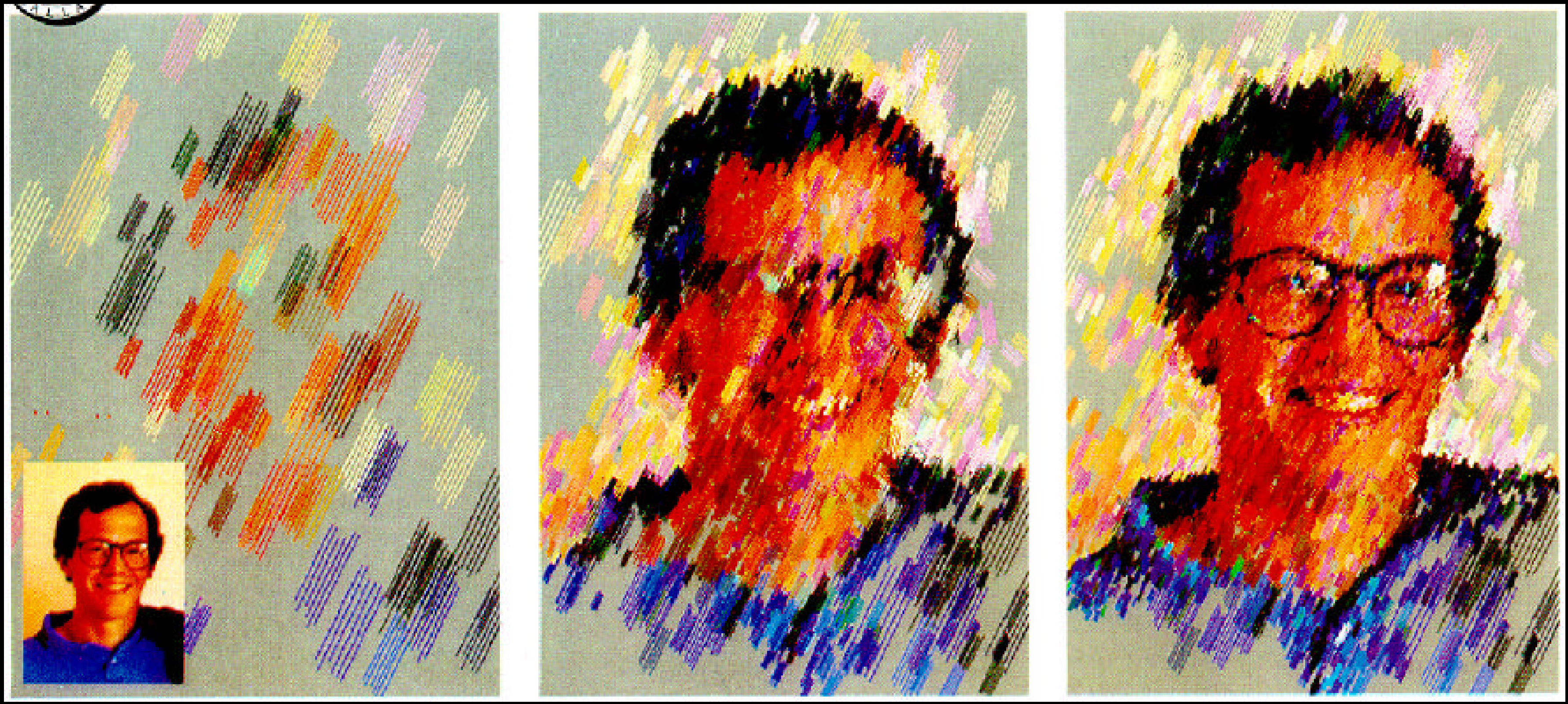


Non Photorealistic Rendering

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

Painting with numbers

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



Painting with numbers

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

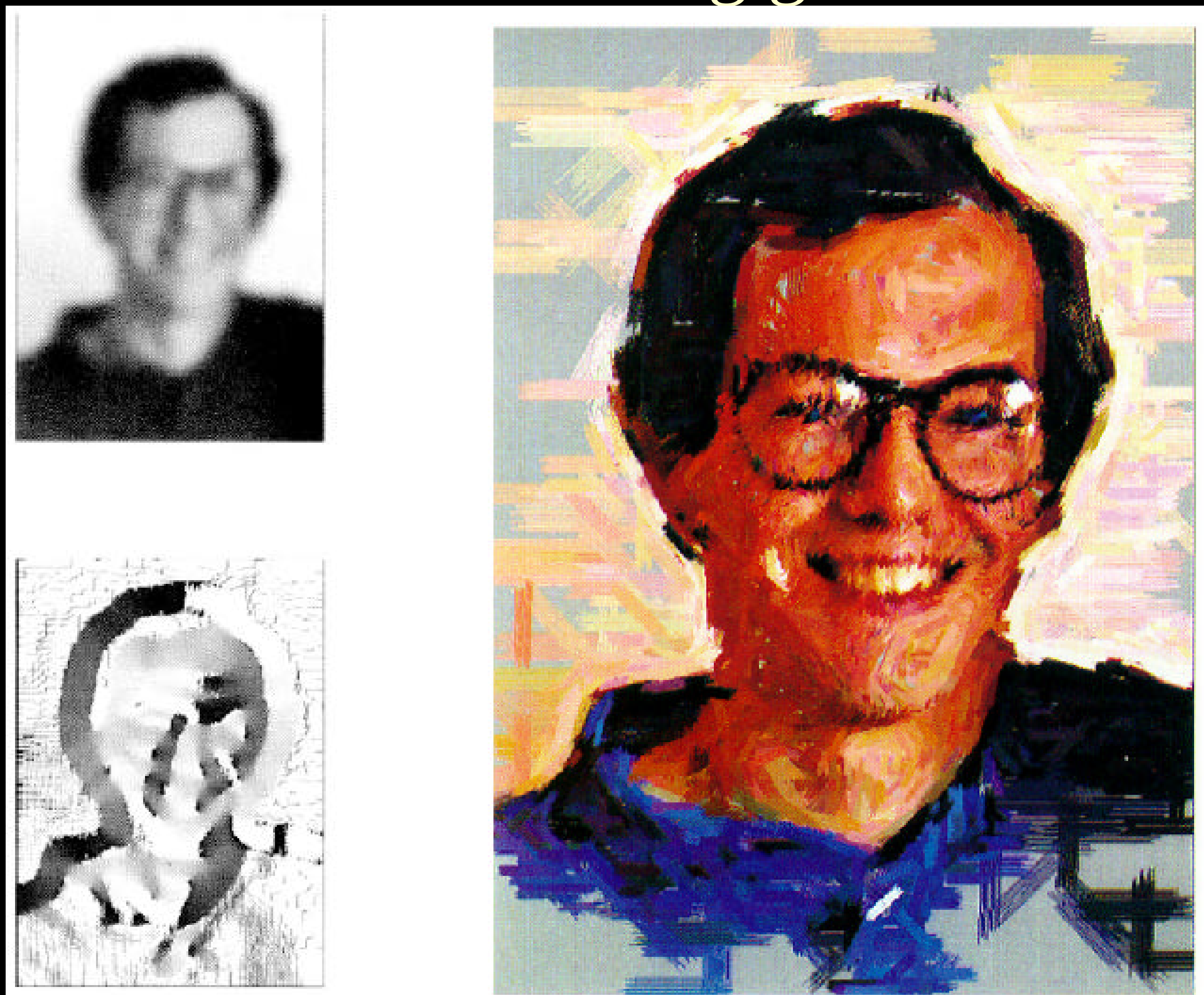
Painting with numbers

- Direction control

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

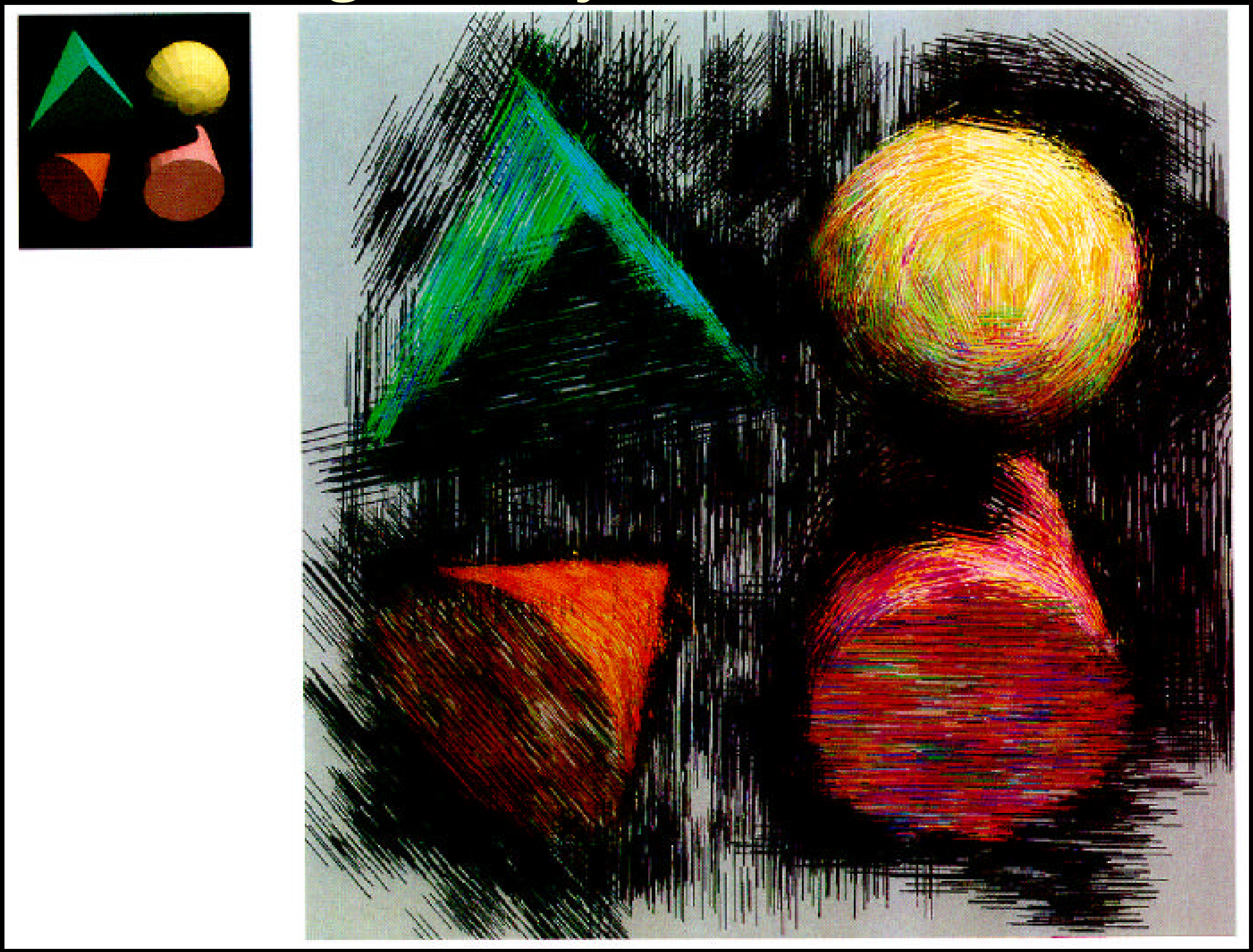
Painting with numbers

- Direction control using gradient



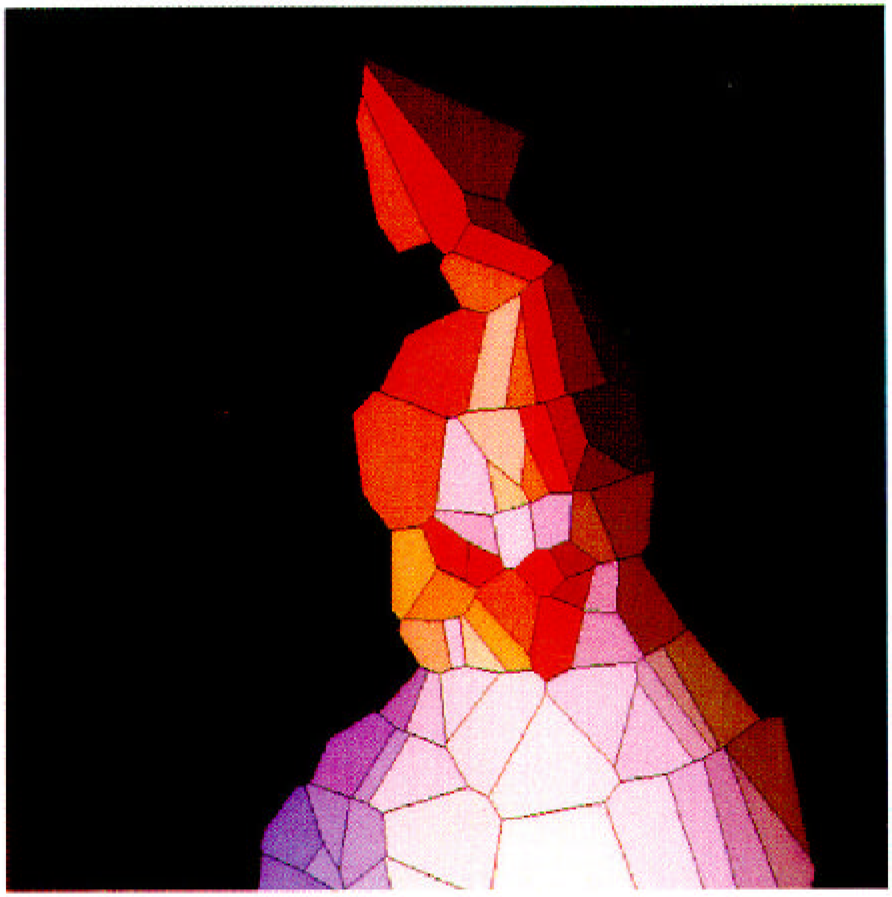
Painting with numbers

- From 3D geometry



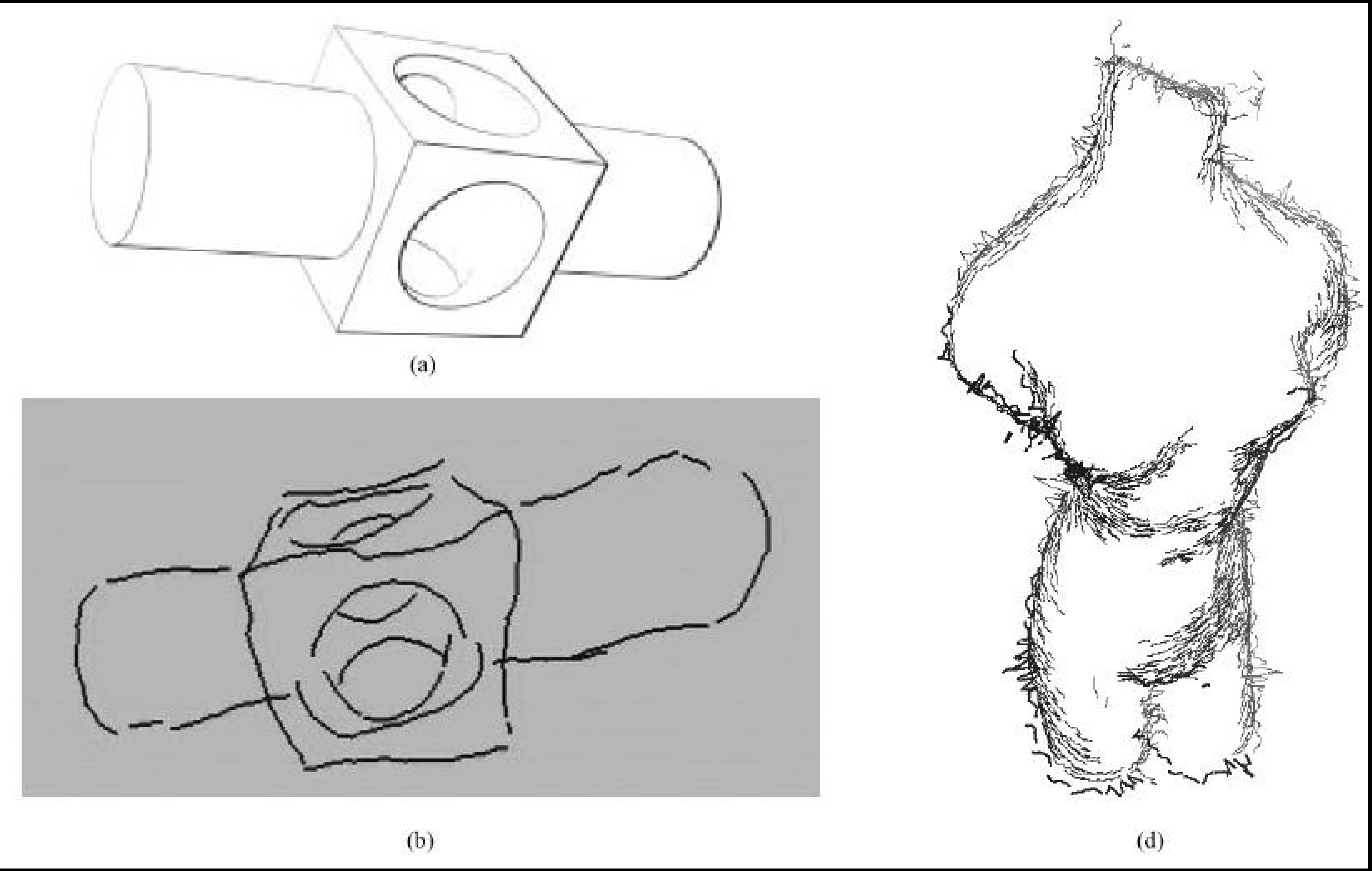
Painting with number

- Automatic optimization of brush placement



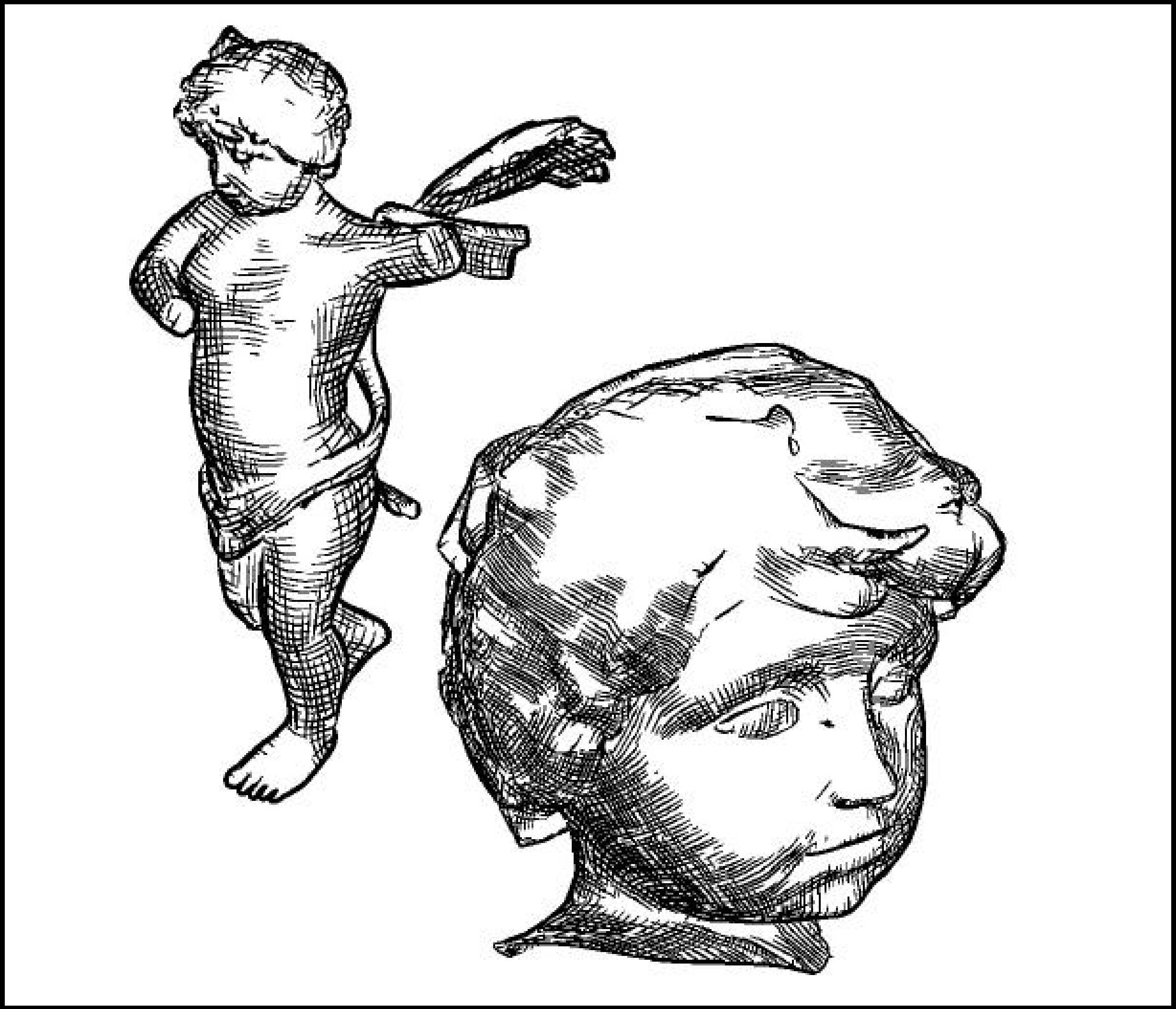
Line drawing

- [Markosian et al. 97]



Line drawing

- [Hertzman and Zorin 2000]



Line drawing

- [Hertzman and Zorin 2000]

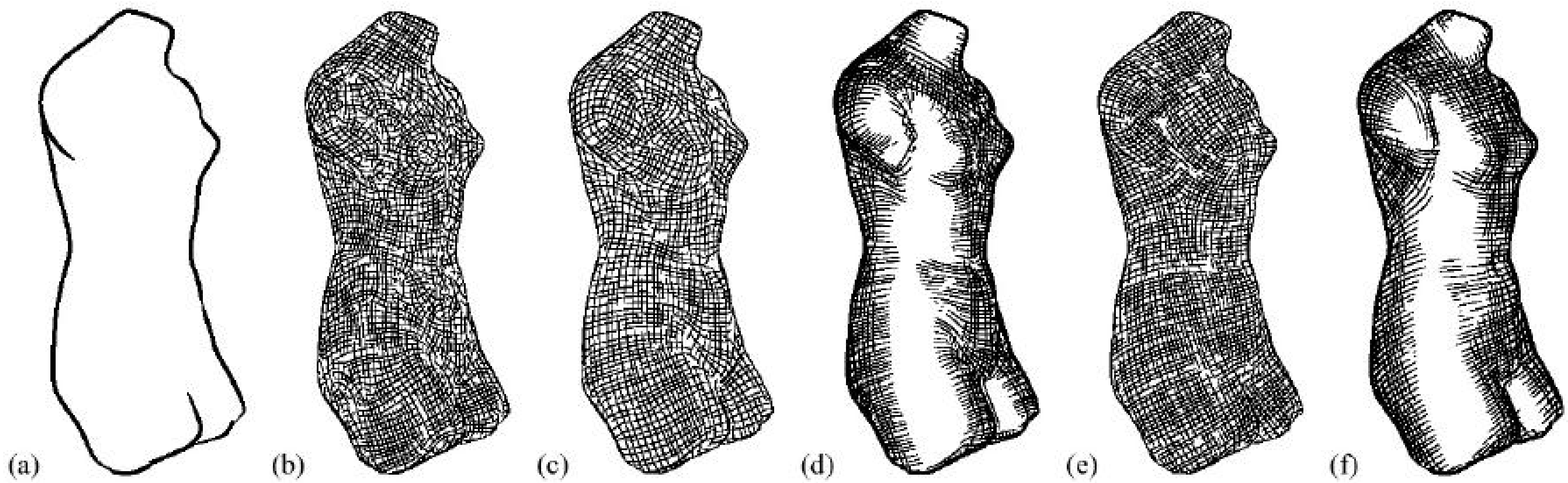


Figure 8: Direction fields on the Venus. (a) Silhouettes alone do not convey the interior shape of the surface. (b) Raw principle curvature directions produce an overly-complex hatching pattern. (c) Smooth cross field produced by optimization. Reliable principal curvature directions are left unchanged. Optimization is initialized 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.

Watercolor

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

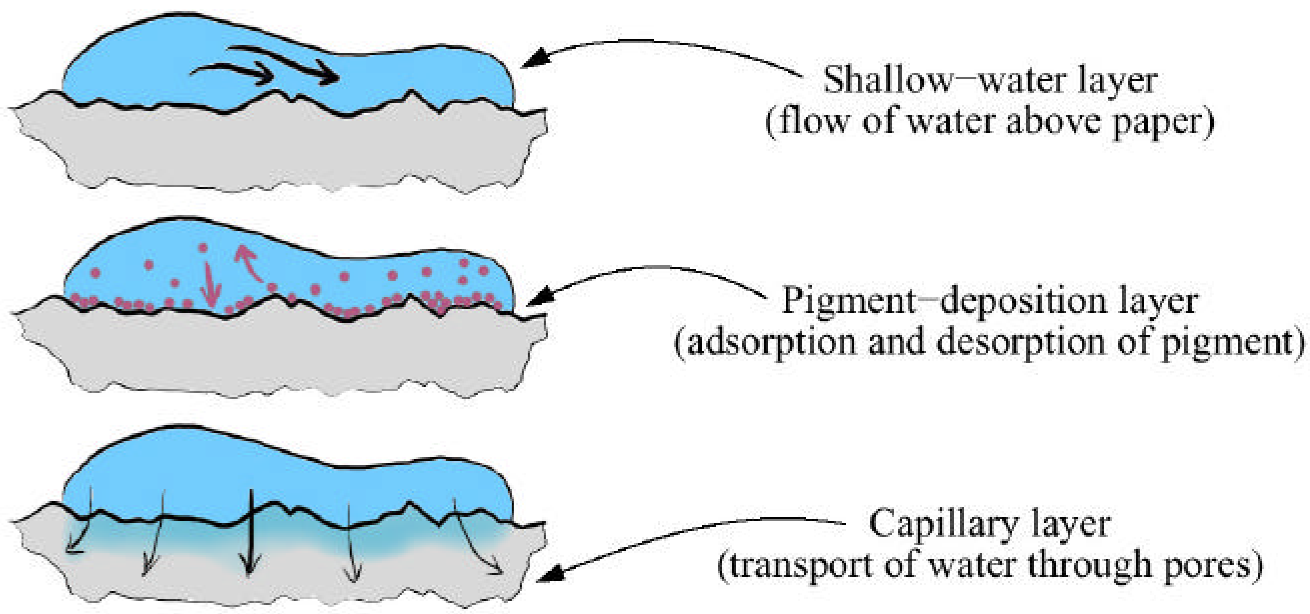


Figure 3 The three-layer fluid model for a watercolor wash.

Watercolor

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

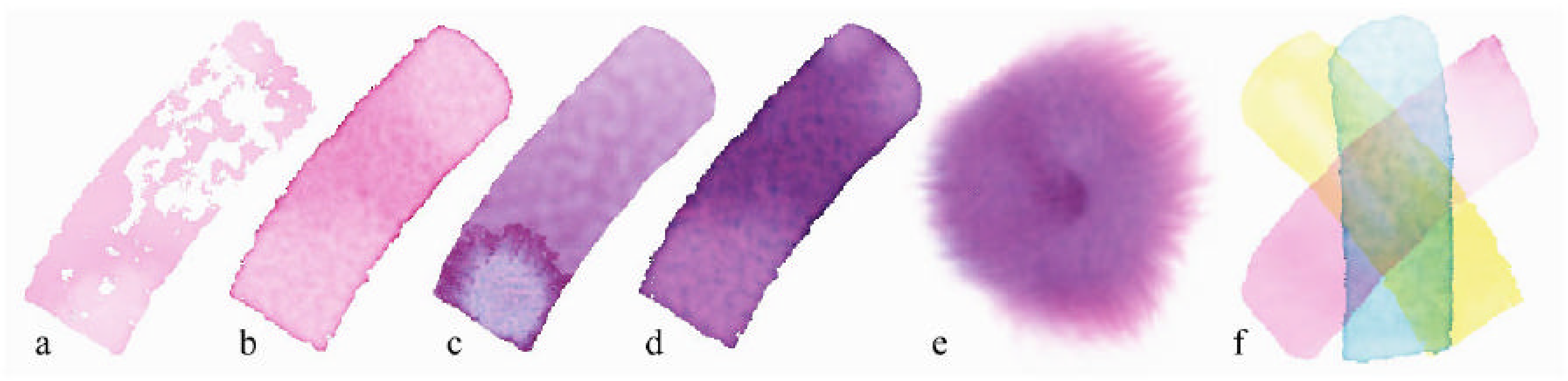
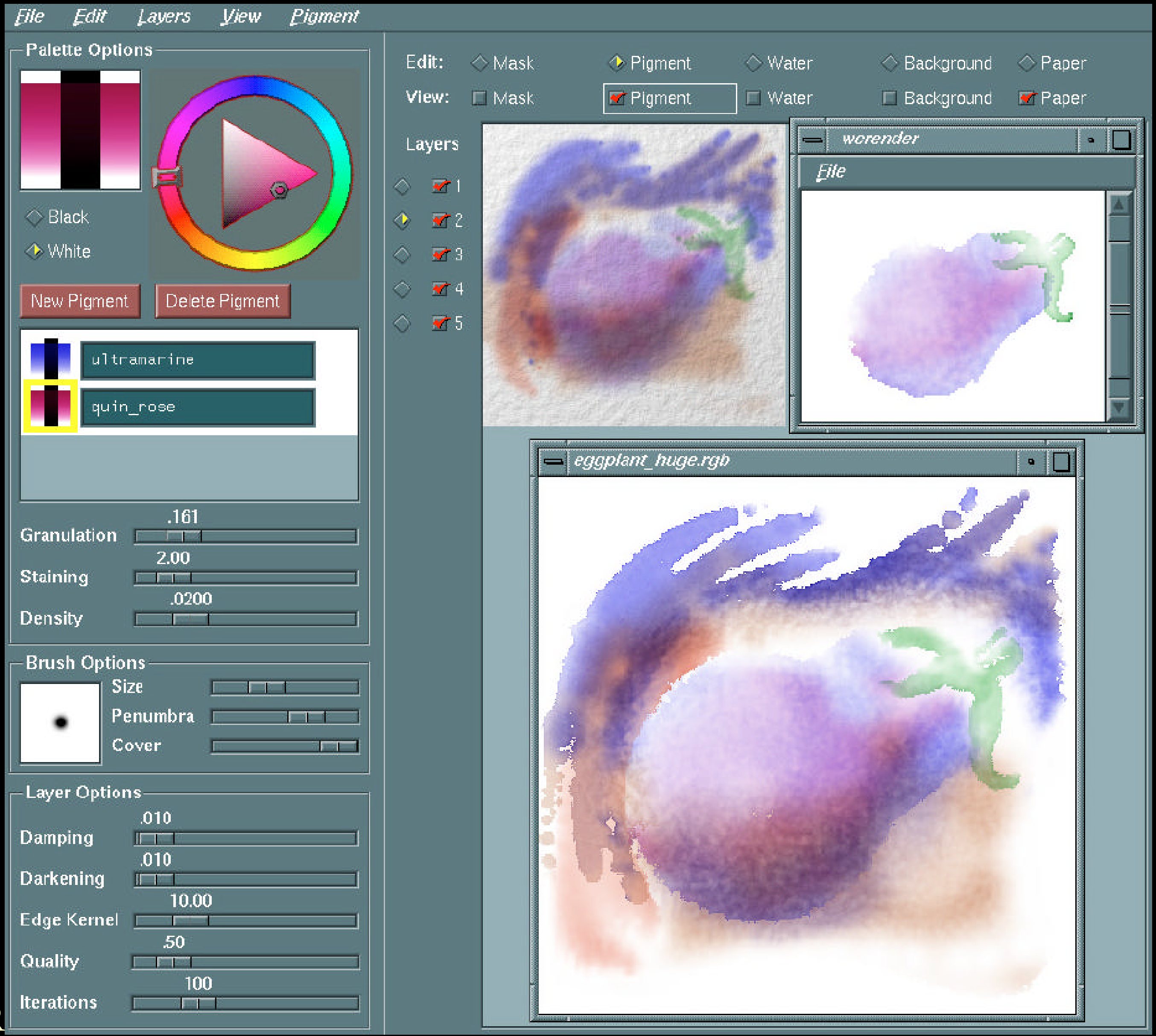


Figure 2 Simulated watercolor effects created using our system.

Watercolor


File Edit Layers View Pigment
Palette Options
Black
White
New Pigment
Delete Pigment
ultramarine
quin_rose
Granulation .161
Staining 2.00
Density .0200
Brush Options
Size
Penumbra
Cover
Layer Options
Damping .010
Darkening .010
Edge Kernel 10.00
Quality .50
Iterations 100
Edit: Mask Pigment Water Background Paper
View: Mask Pigment Water Background Paper
Layers
1
2
3
4
5
wcrender
File
eggplant_huge.rgb

Watercolor

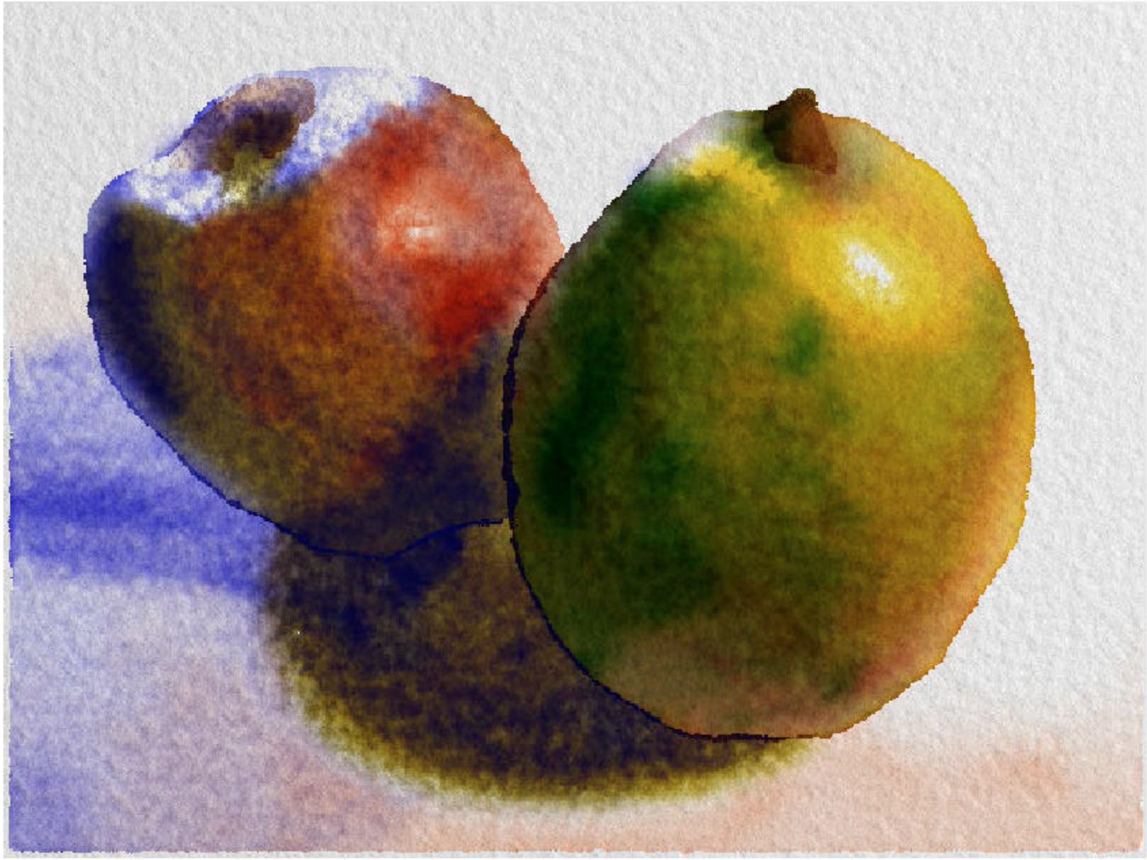
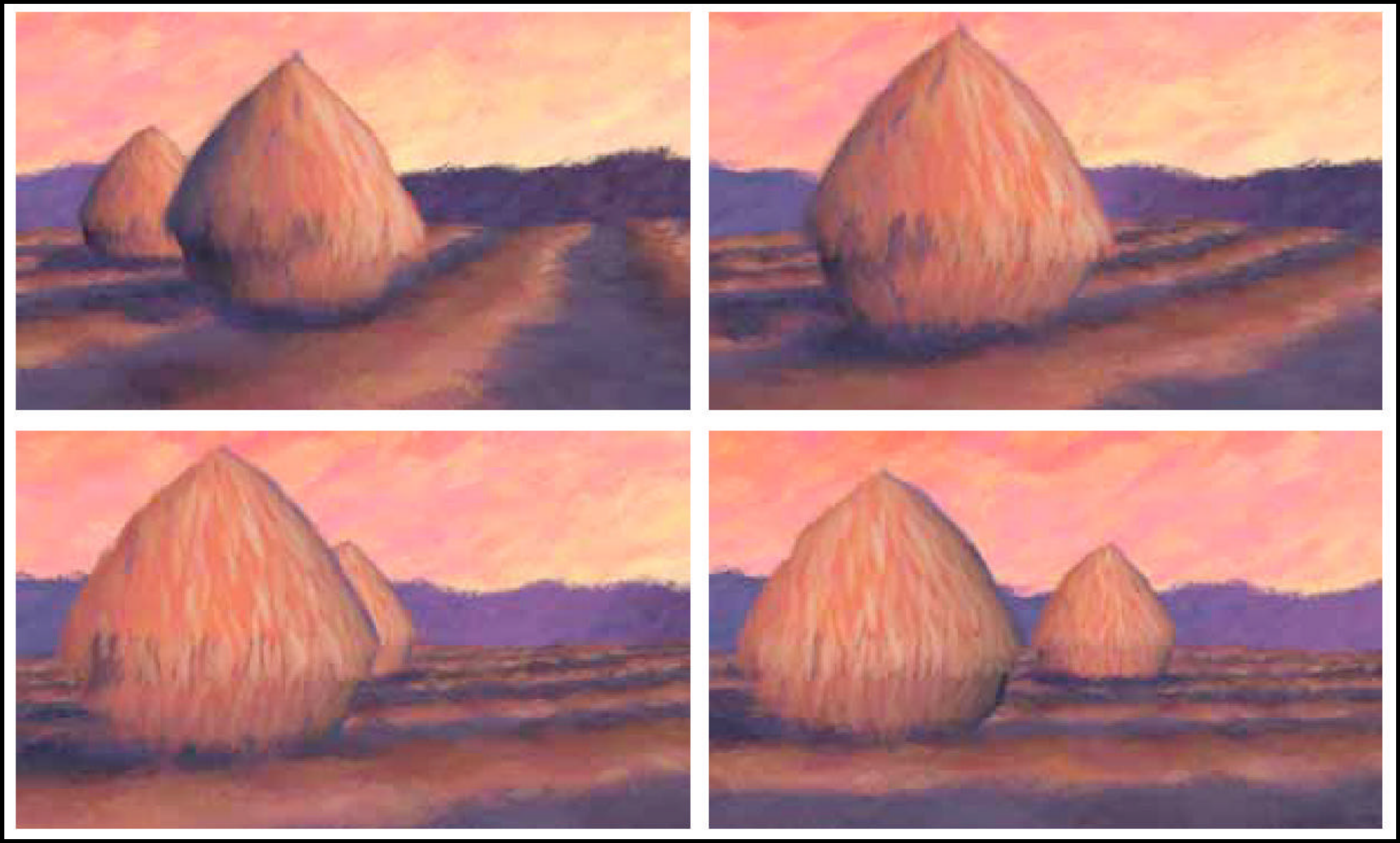


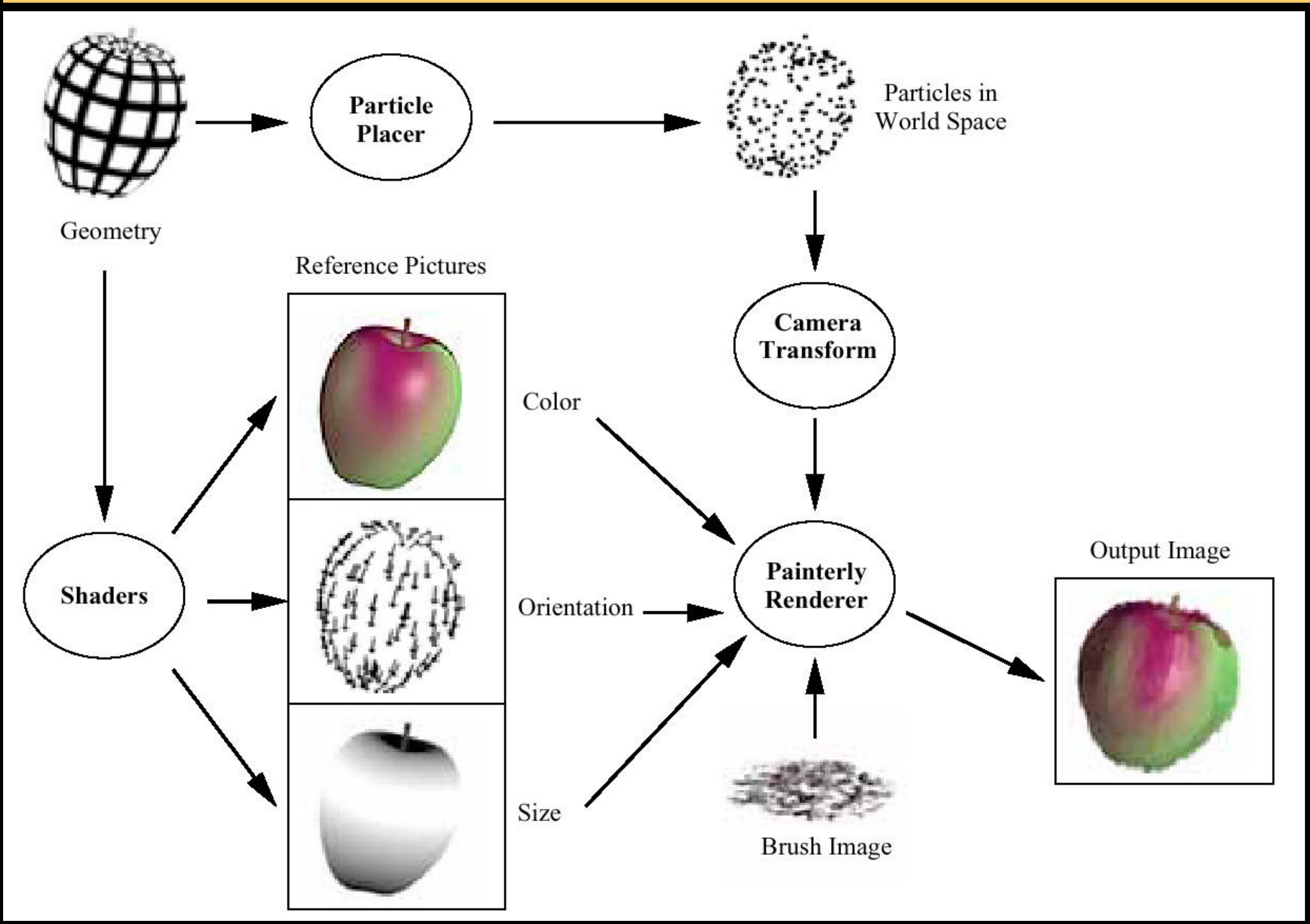
Figure 10 An automatic watercolorization (left) of a low resolution image captured using a poor-quality video camera (above). The finished painting consists of 11 glazes, using a total of 2750 iterations of the simulator, rendered at a resolution of 640 by 480 pixels in 7 hours on a 133 MHz SGI R4600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

Painterly animation

- [Meier 1996]



Painterly animation

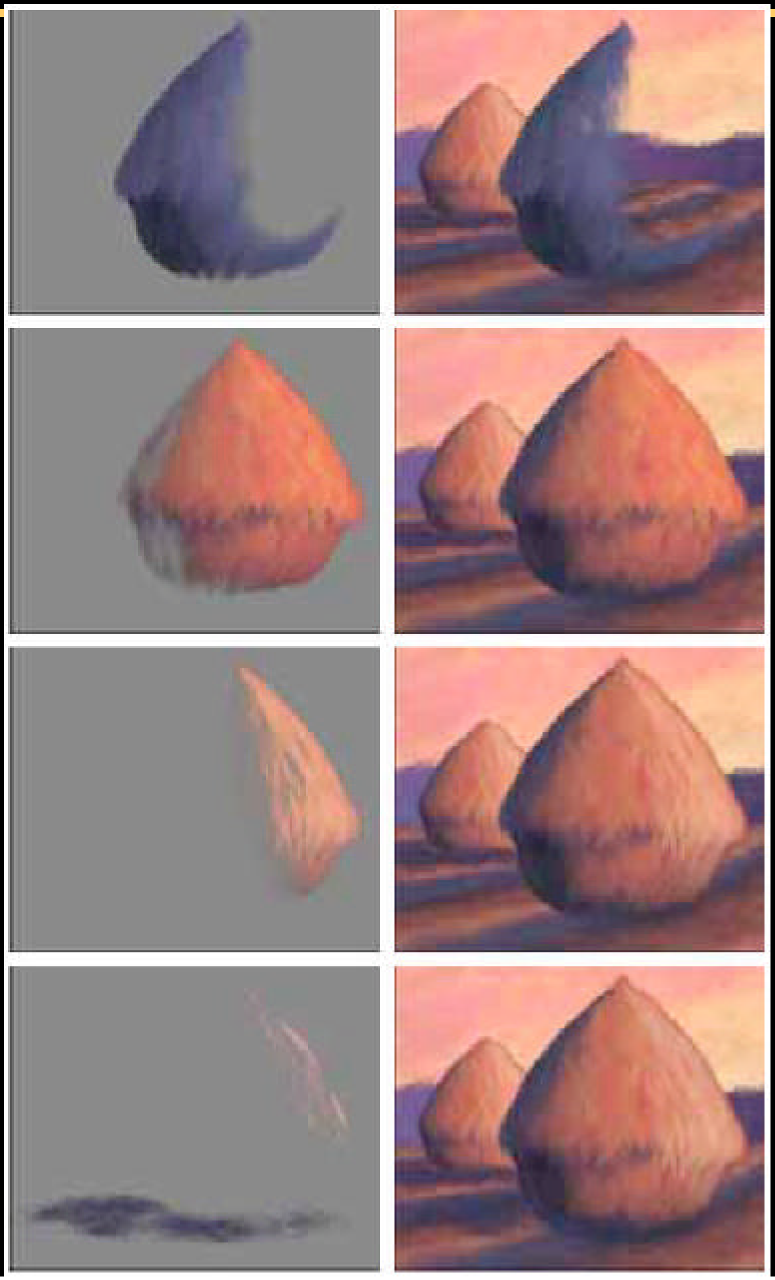


Painterly animation

- Different styles

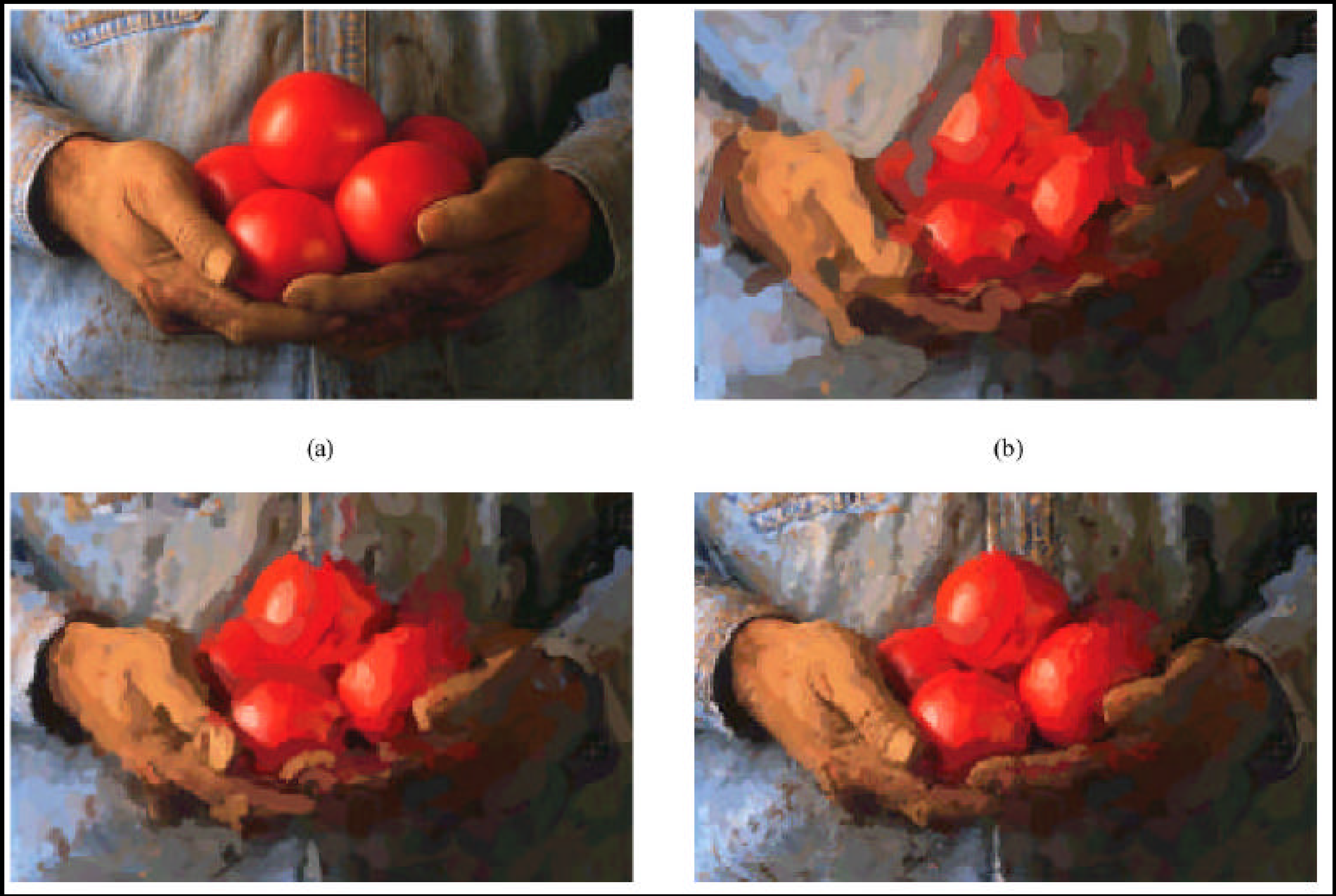
Painterly animation

- Use of different layers



Brushes of multiple sizes

- [Hertzman 1998]



Brushes of multiple sizes

- Different styles depending on parameters

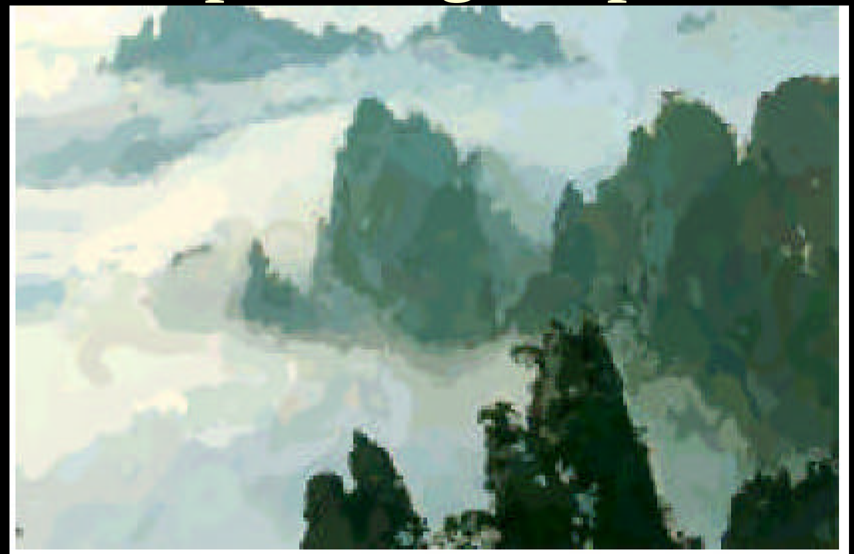
“Impressionist”

“Expressionist”

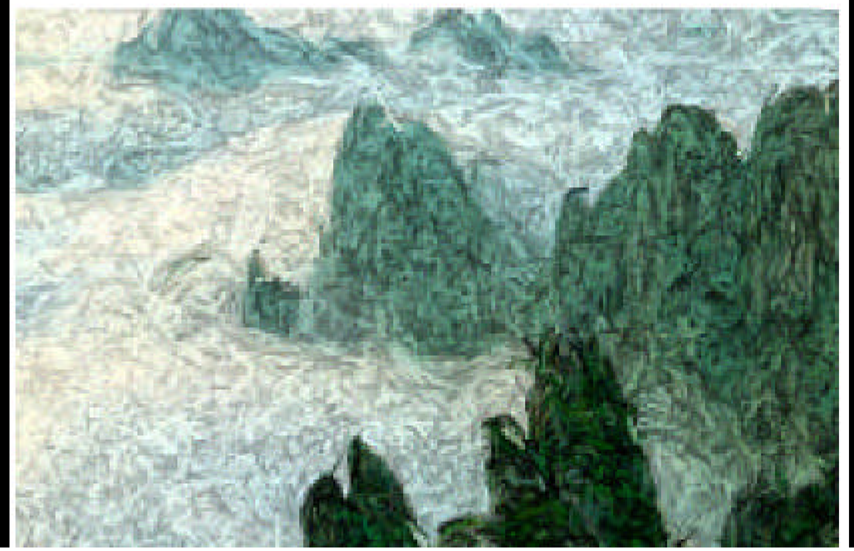
Brushes of multiple sizes

- Different styles depending on parameters

"Impressionist"



"Expressionist"

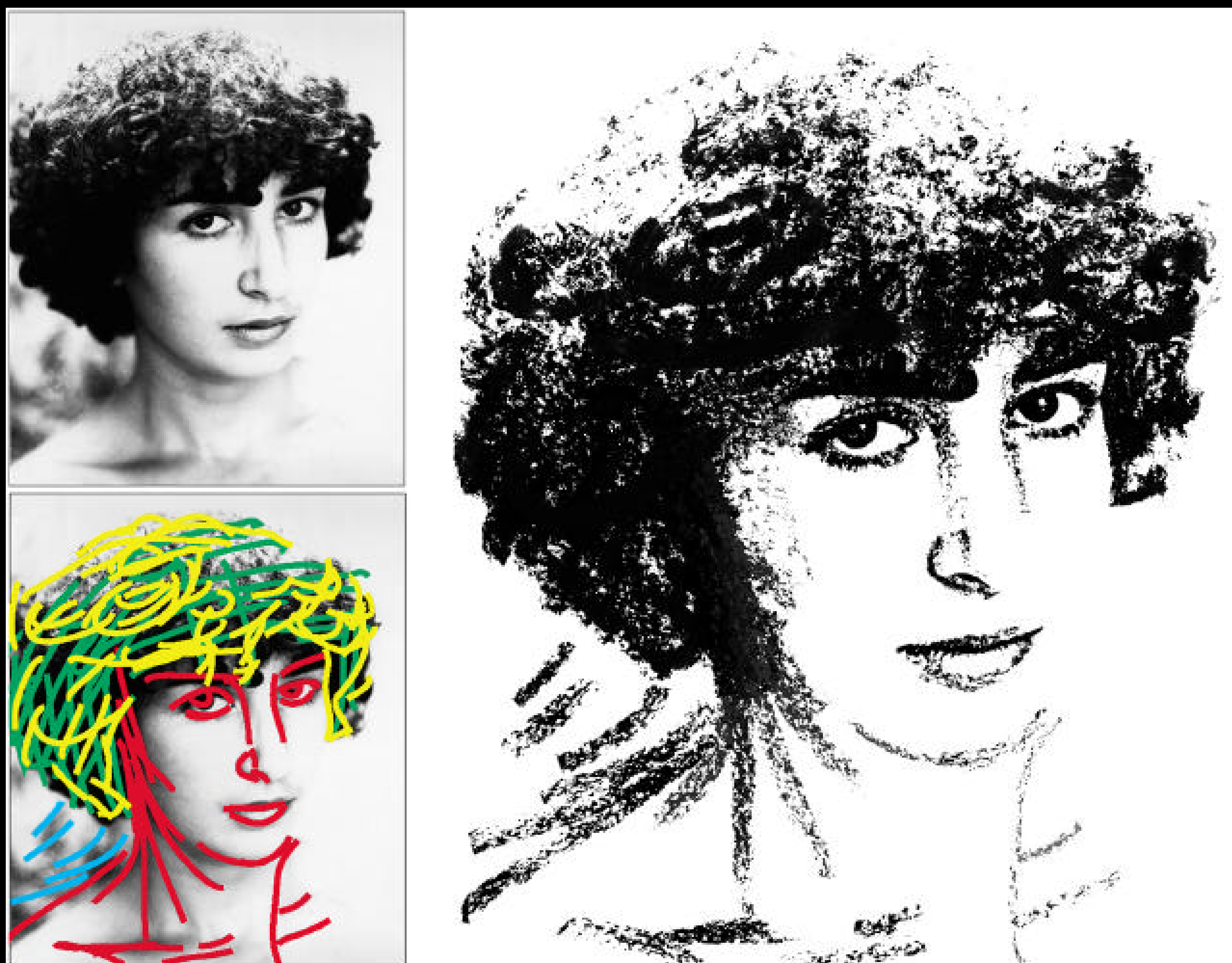


Style and soul

- Icon painting, Expressionism

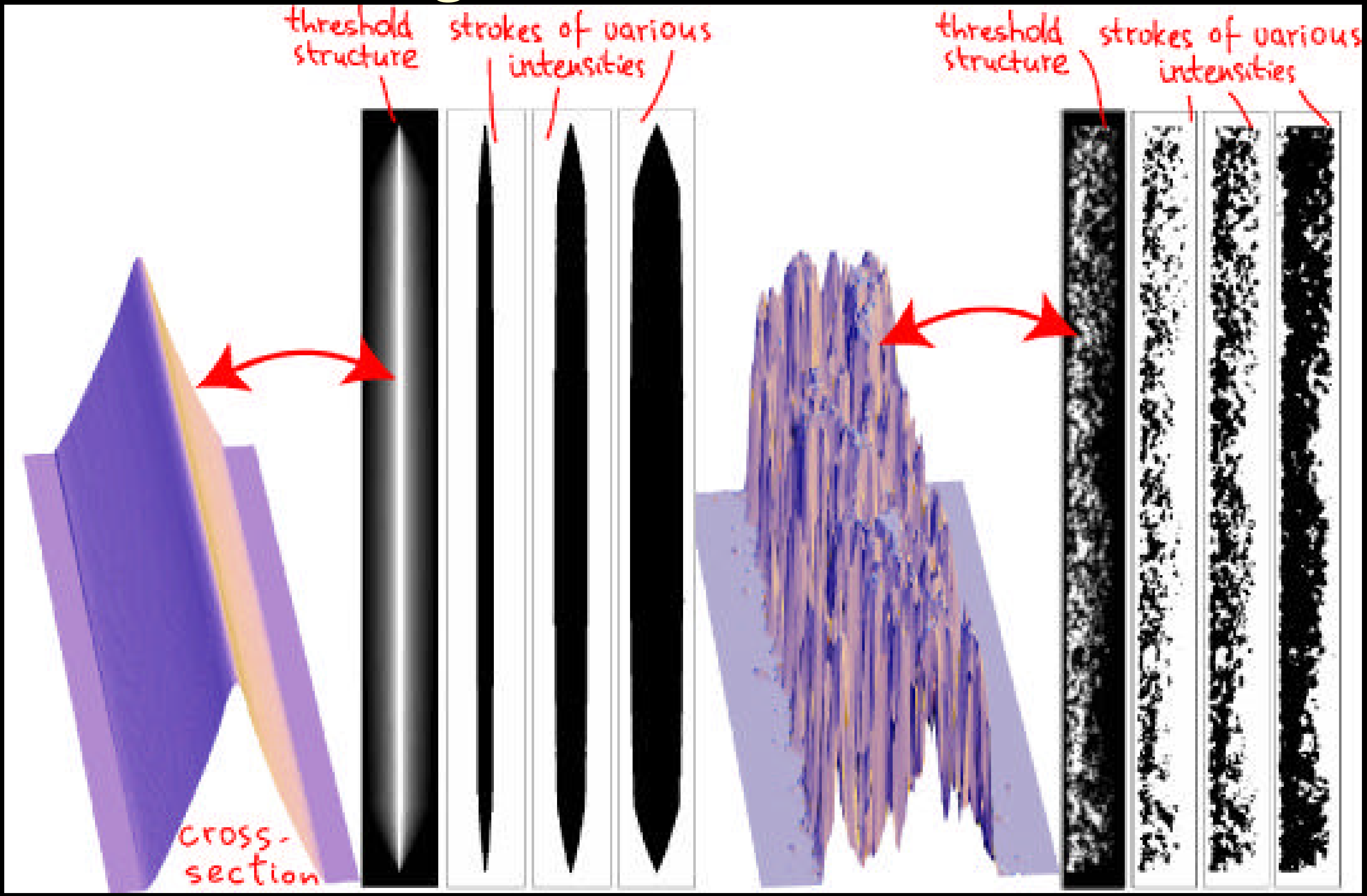
Interactive assisted drawing

- [Durand, Ostromoukhov et al.]



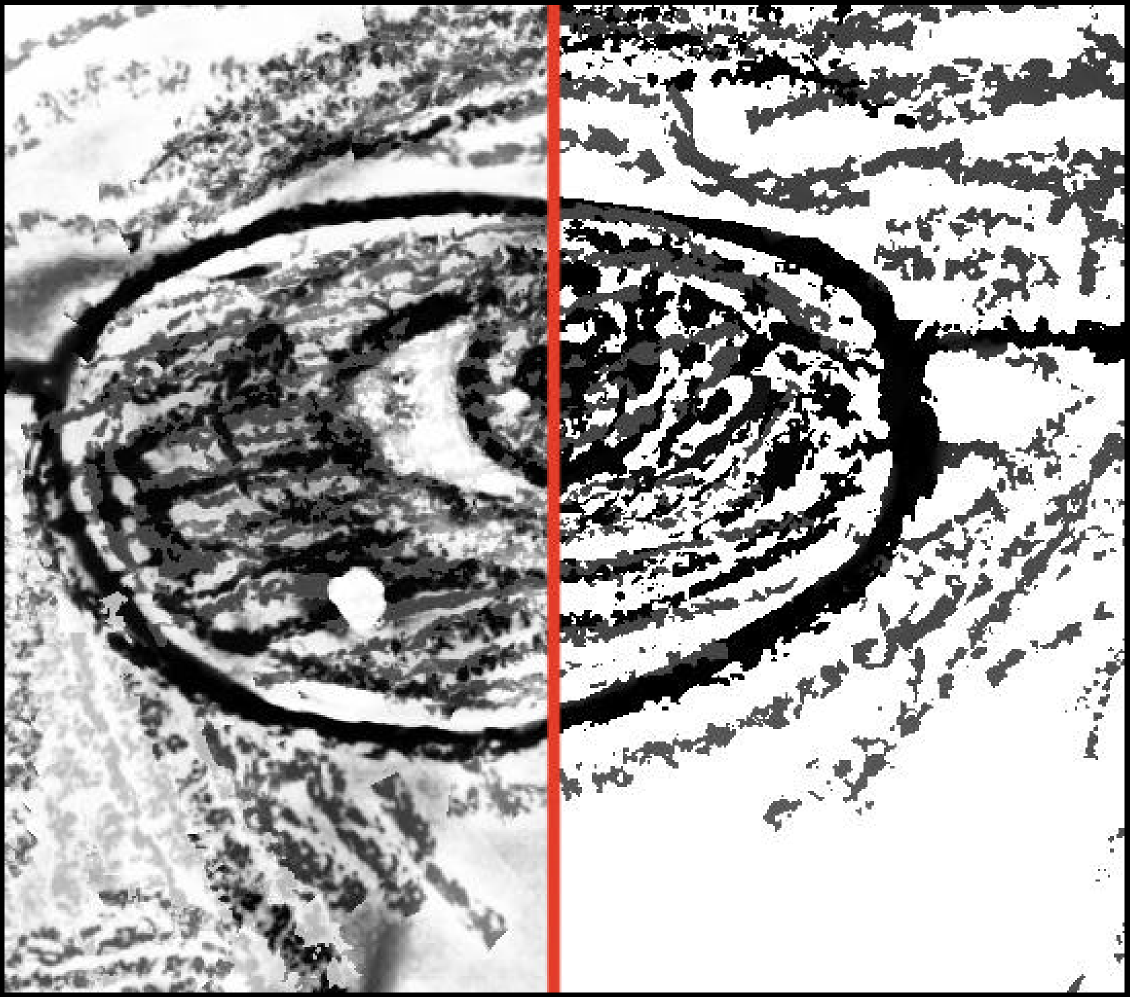
Interactive assisted drawing

- Thresholding

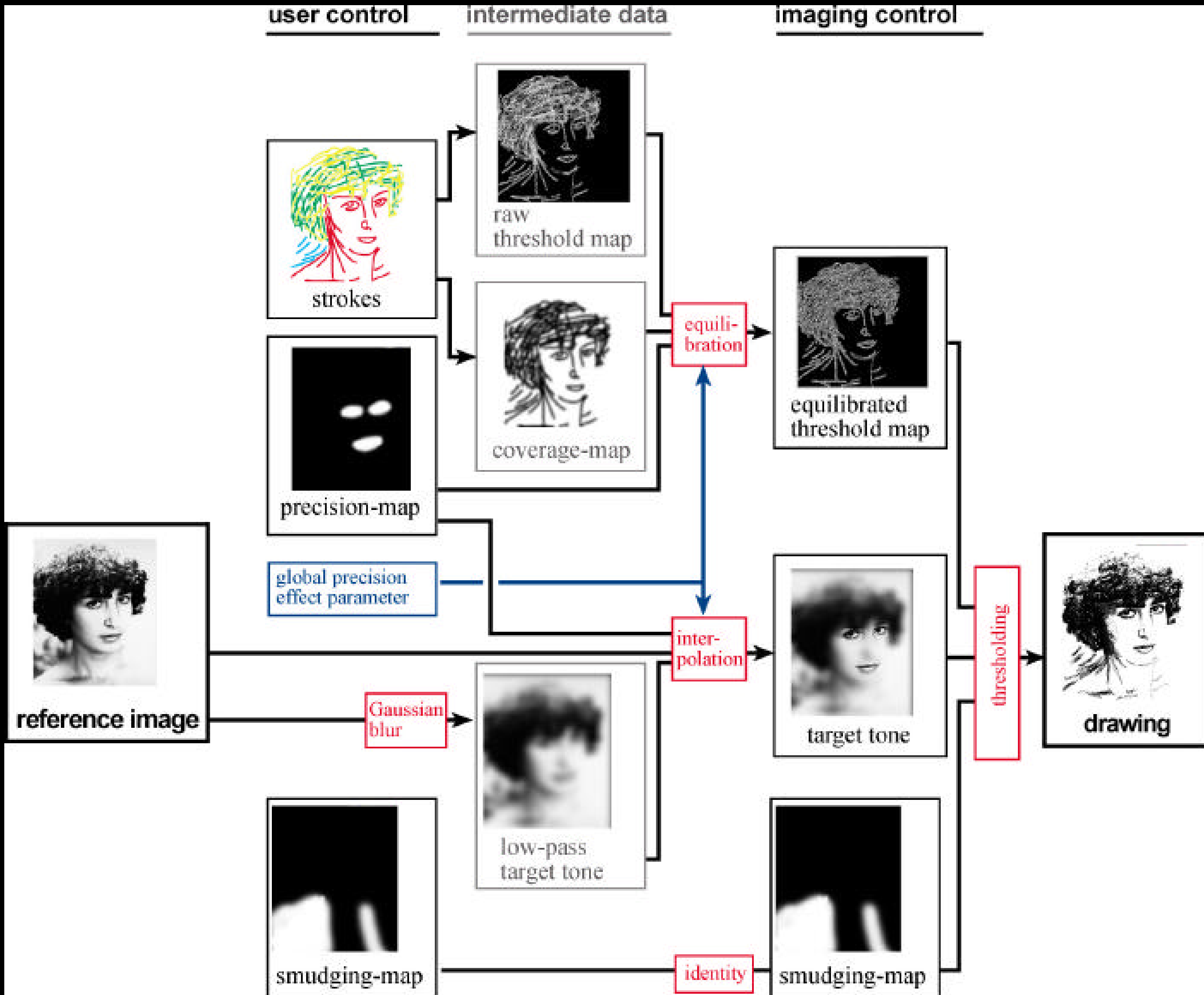


Interactive assisted drawing

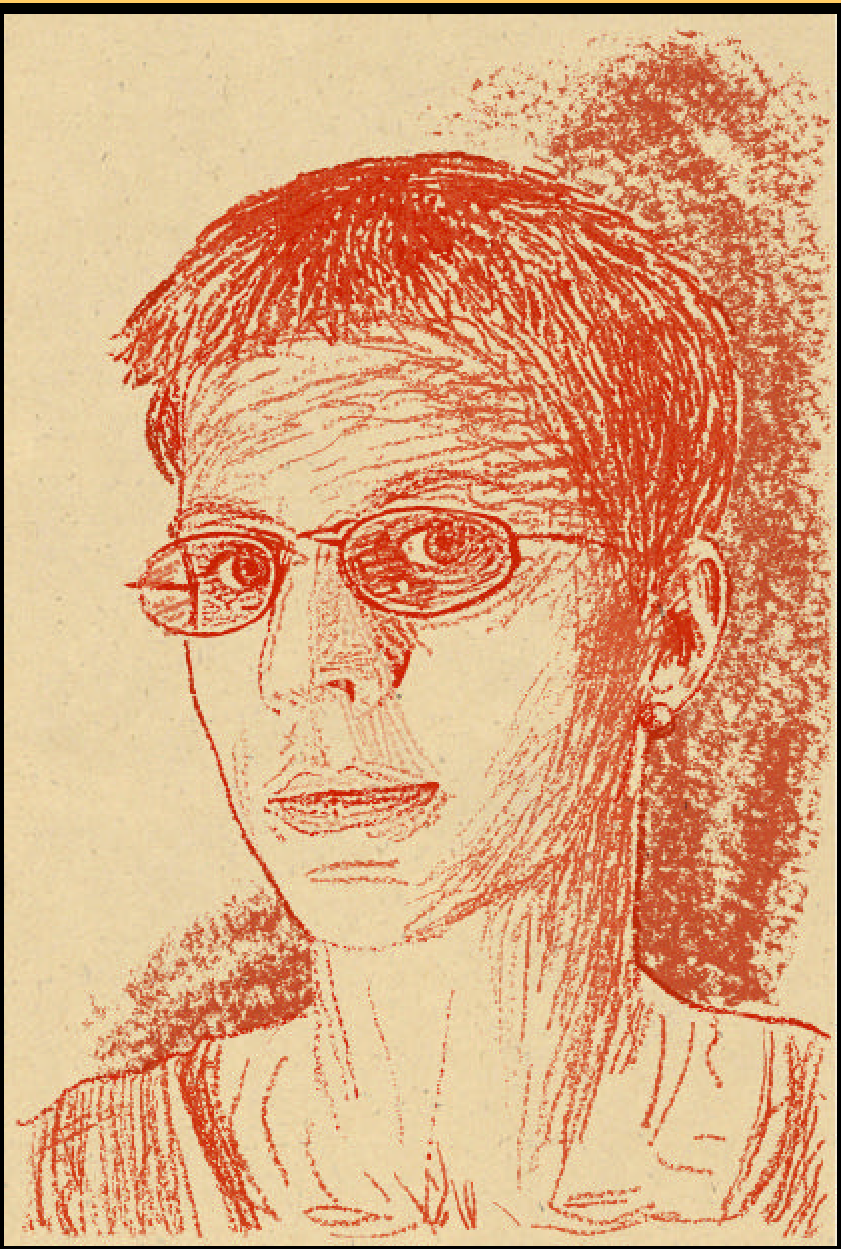
- Smudging



Interactive assisted drawing



Interactive assisted drawing



Interactive assisted drawing

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

Some issues in NPR

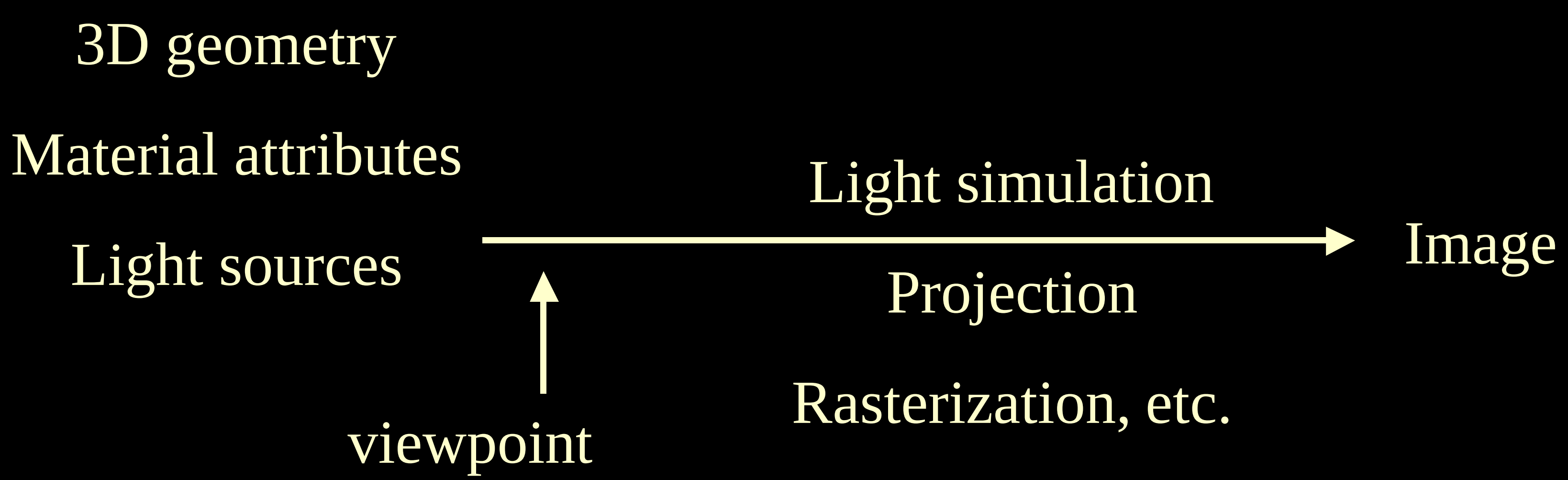
- Medium simulation
- Animation and coherence
- Line drawing, hatcing
- Shading
- Style
- Perspective
- User interface

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)



A one-way pipeline

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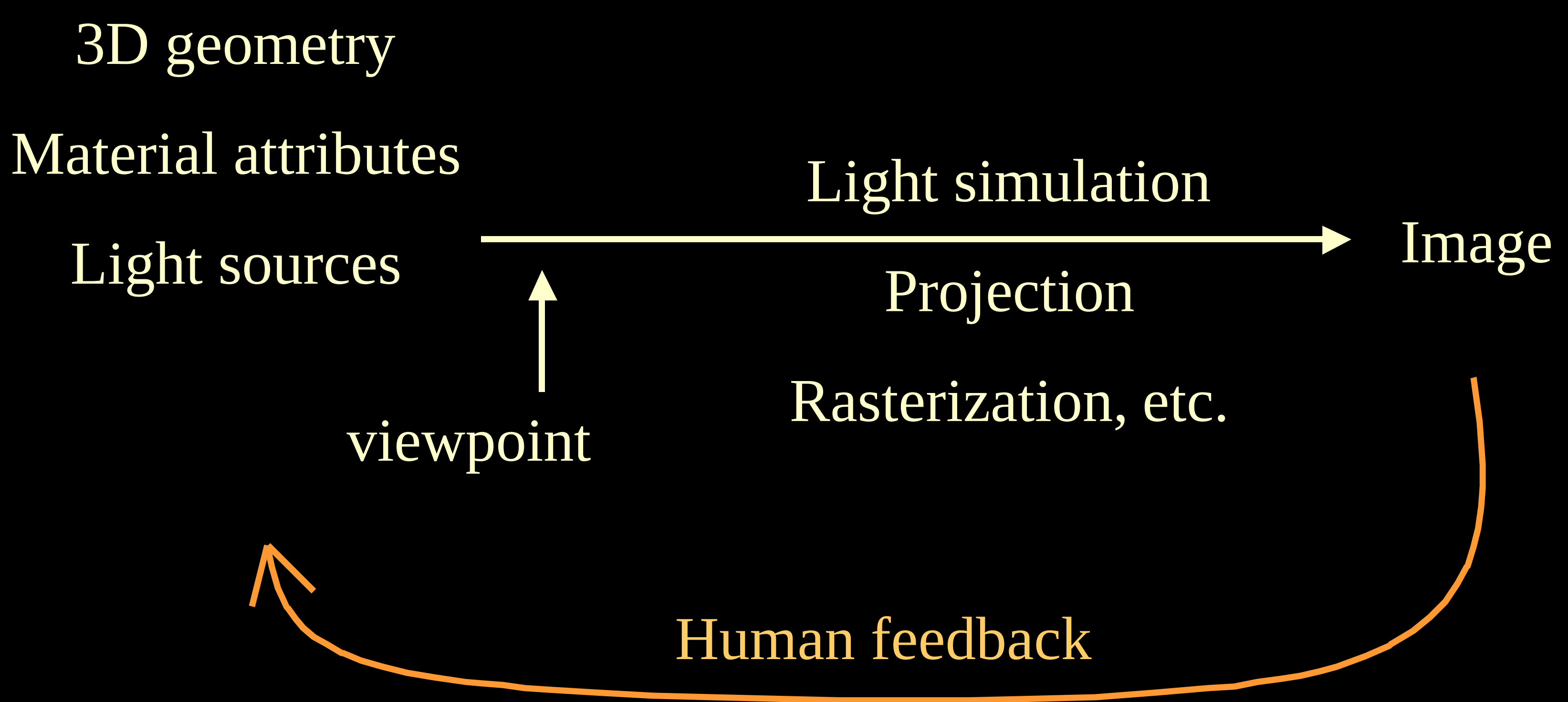
- Input is purely 3D (world space)



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