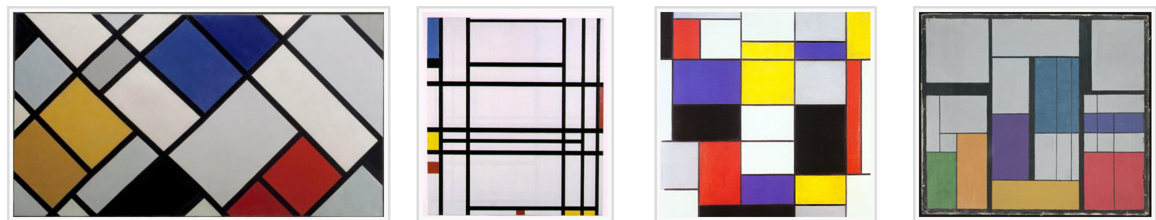
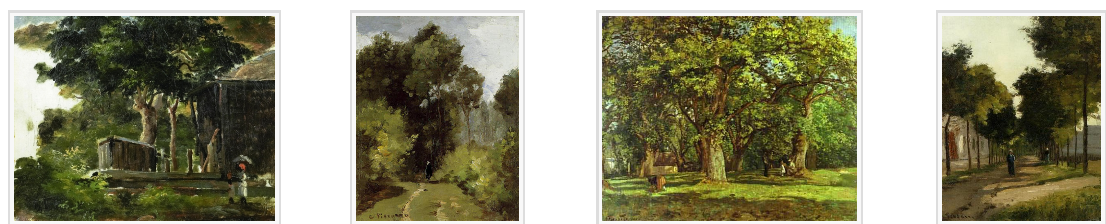
You have an Art History exam approaching, but you have been paying more attention to informatics at school than to your art classes! You will need to write a program to take the exam for you.

The exam will consist of several paintings. Each painting is an example of one of four distinctive styles, numbered 1, 2, 3 and 4.

Style 1 contains neoplastic modern art. For example:

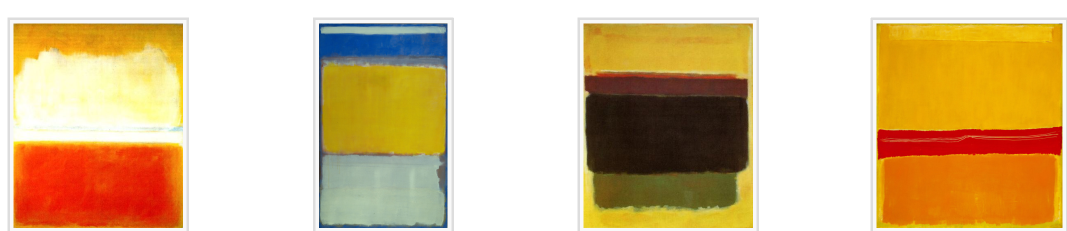


Style 2 contains impressionist landscapes. For example:



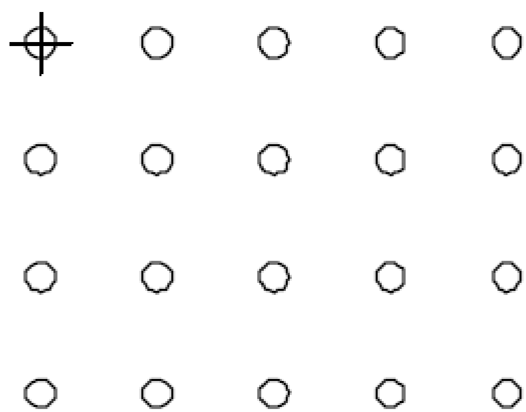
Style 3 contains expressionist action paintings. For example:

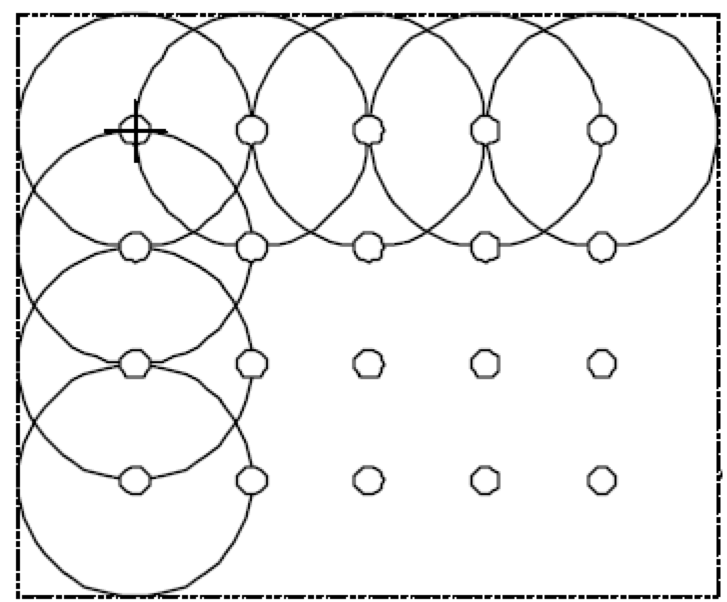
Style 4 contains colour field paintings. For example:



What is an image?

Not a little square!

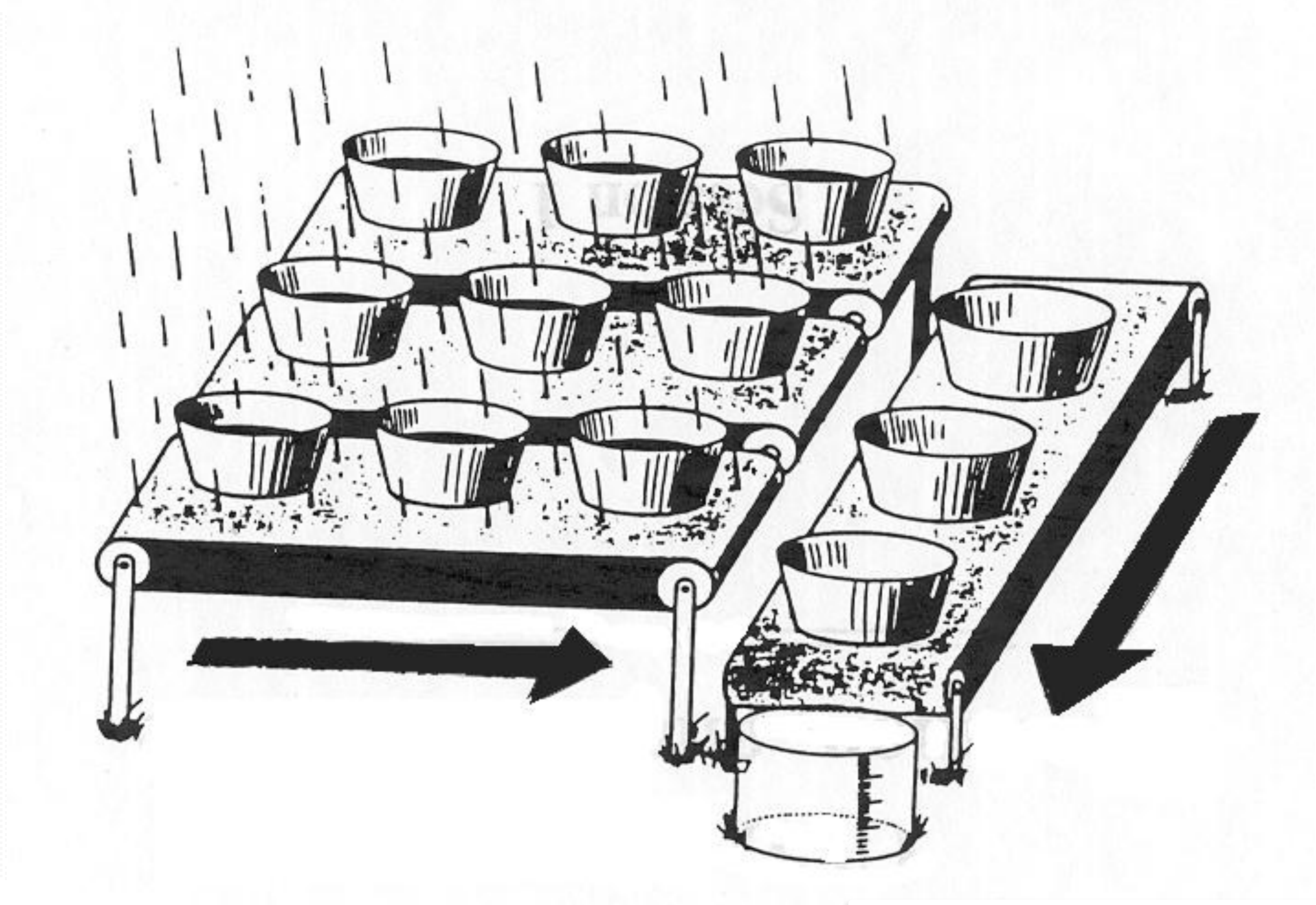




Gaussian reconstruction filter

Illustrations: Smith, MS Tech Memo 6, Jul 17, 1995

Capturing photons

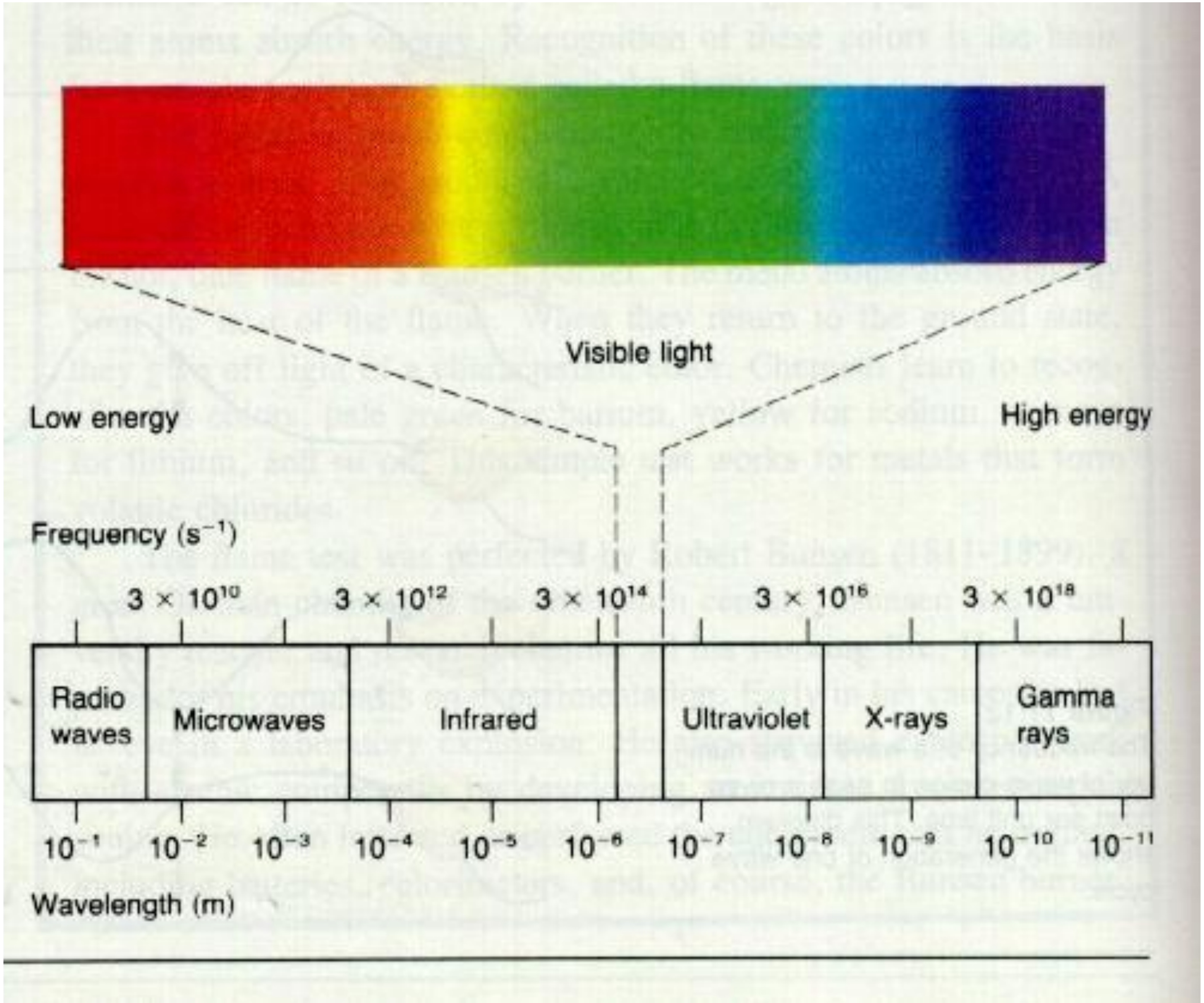


From: Lecture Notes – EAAE and/or Science "Nuggets" 2000

ETH

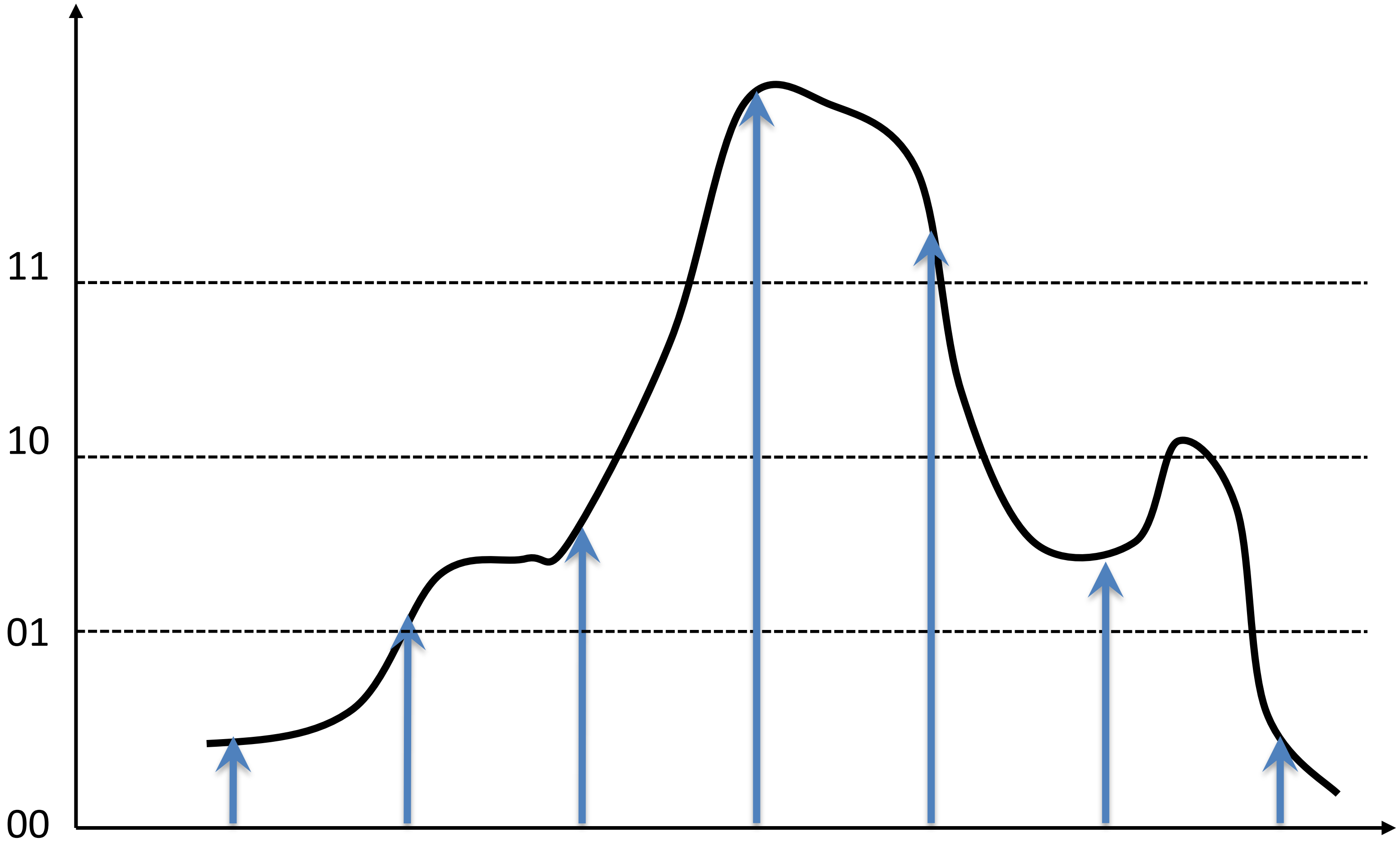
Blooming

- The buckets have finite capacity
- Photosite saturation causes blooming



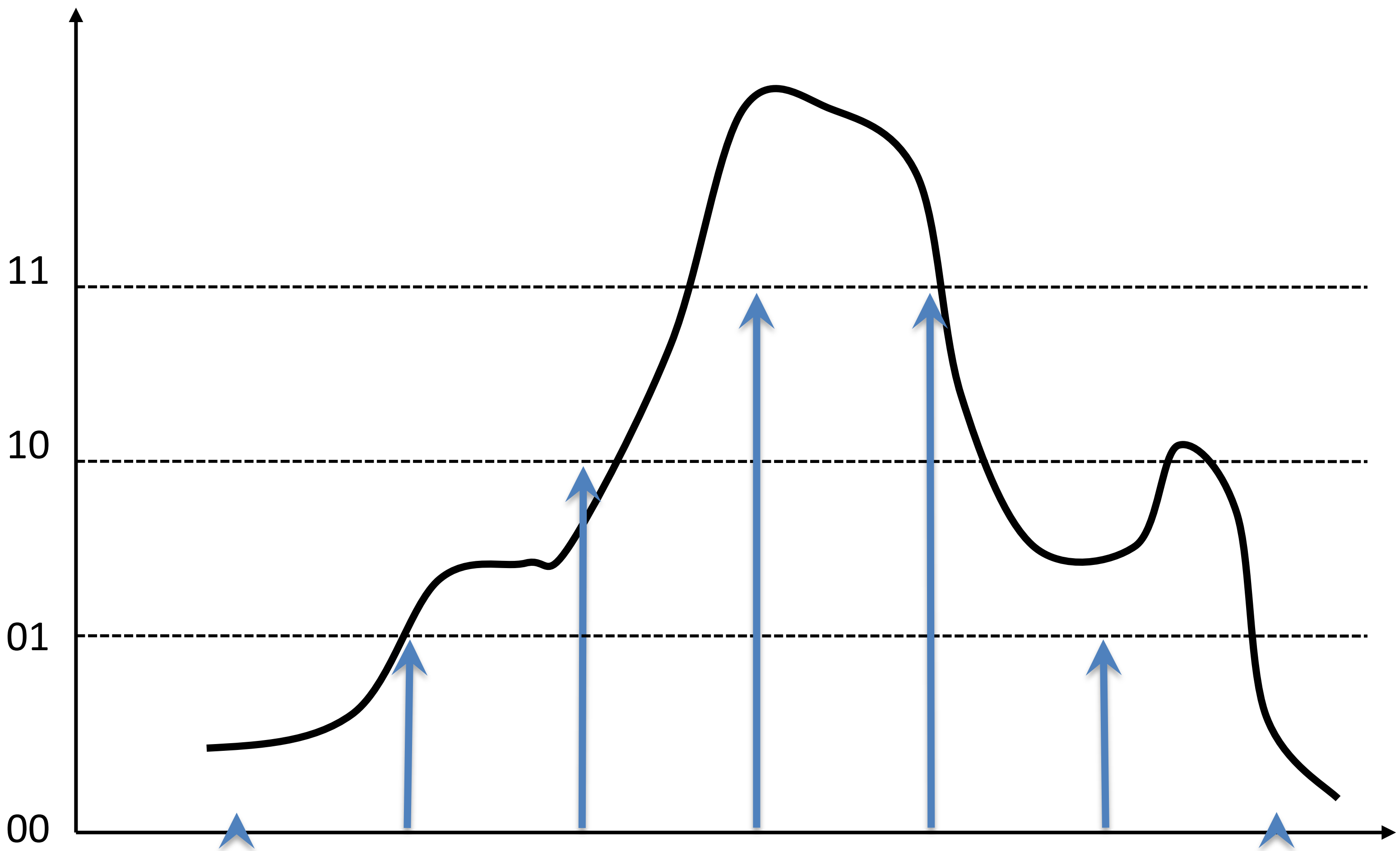
Visible light
Low energy
High energy
Frequency (s⁻¹)
3 × 10¹⁰
3 × 10¹²
3 × 10¹⁴
3 × 10¹⁶
3 × 10¹⁸
Radio waves
Microwaves
Infrared
Ultraviolet
X-rays
Gamma rays
10⁻¹
10⁻²
10⁻³
10⁻⁴
10⁻⁵
10⁻⁶
10⁻⁷
10⁻⁸
10⁻⁹
10⁻¹⁰
10⁻¹¹
Wavelength (m)

Quantization



ETH

Quantization

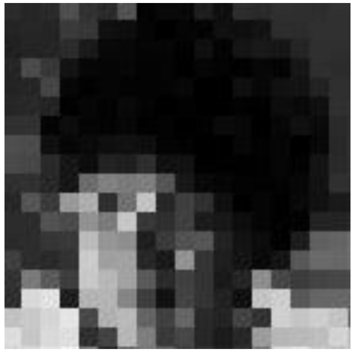


Geometric resolution

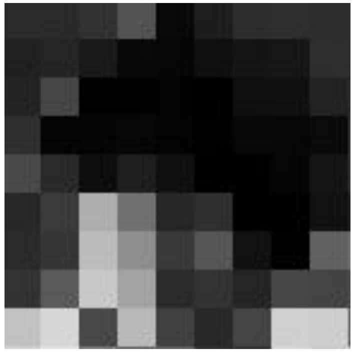
144x144

72x72

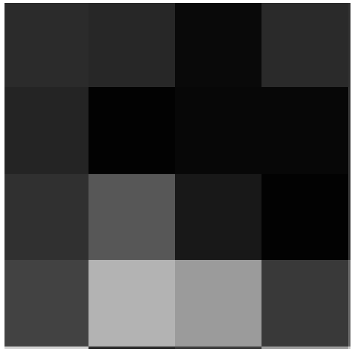
36x36



18x18



9x9



4x4

Radiometric resolution


256


128


64

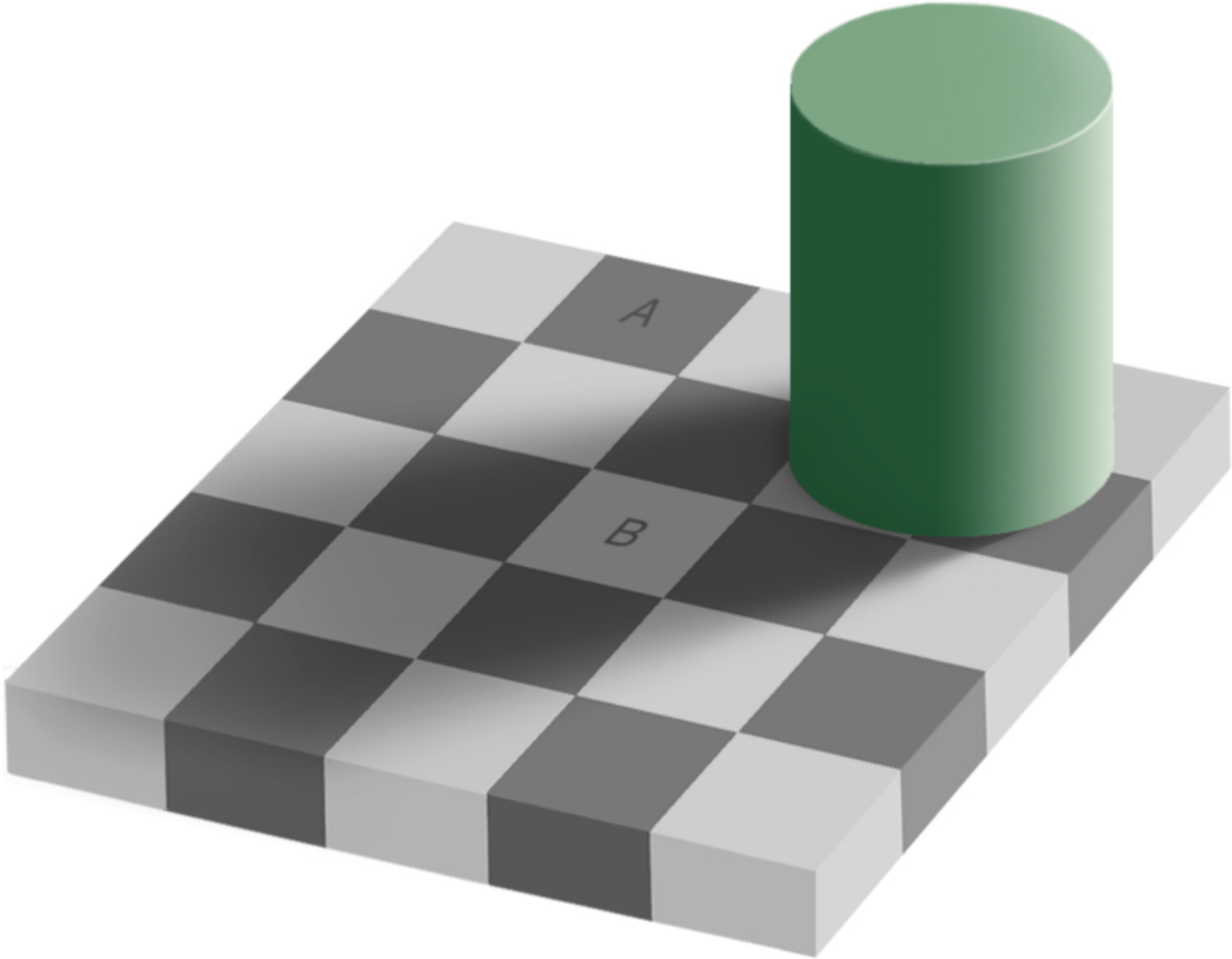

32


16

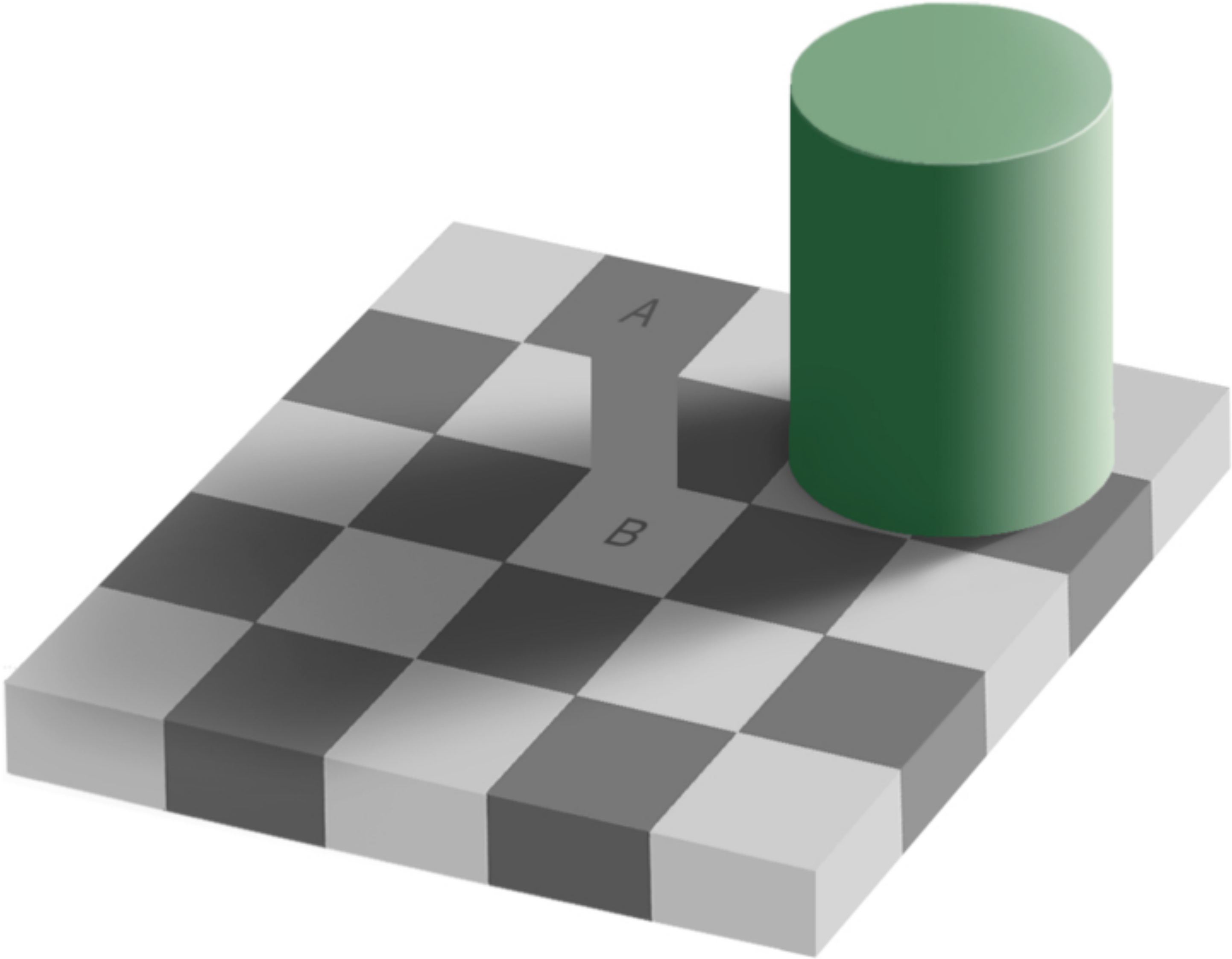

8


4


2

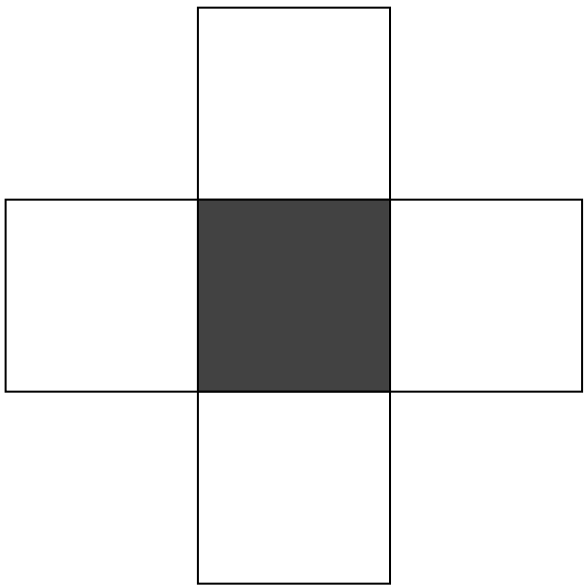


by Adrian Pingstone, based on the original created by Edward H. Adelson

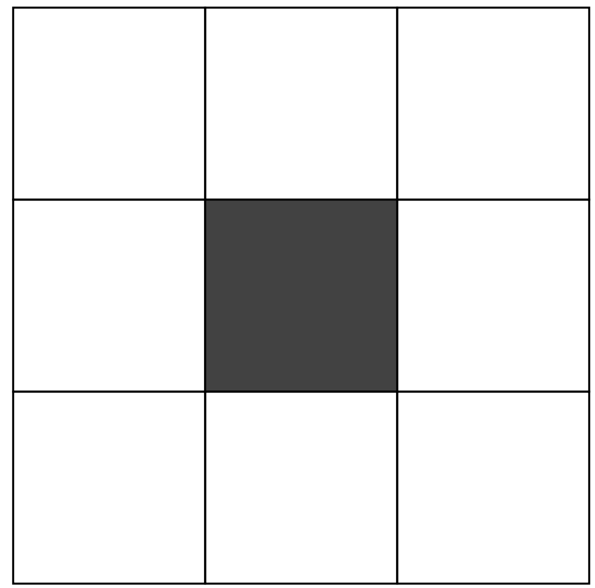


by Adrian Pingstone, based on the original created by Edward H. Adelson

Pixel Neighborhoods



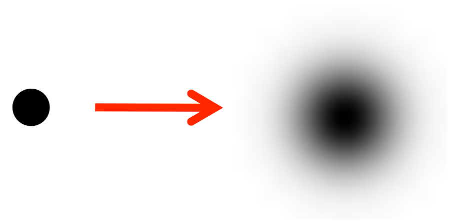
4-neighborhood



8-neighborhood

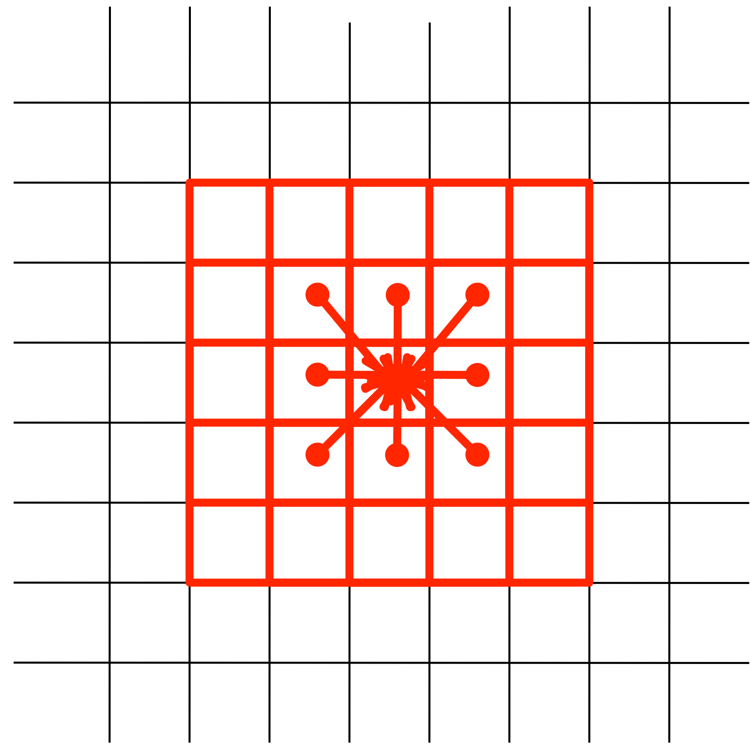
Convolution

(e.g. point spread function)



Kernel

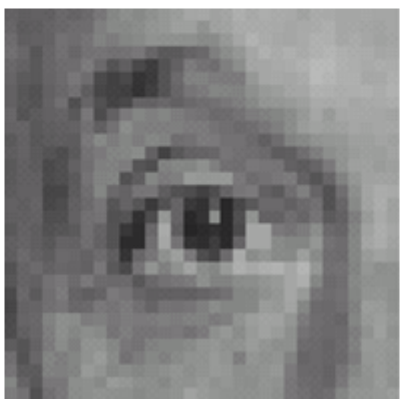
K(-1,-1)	K(0,-1)	K(1,-1)
K(-1,0)	K(0,0)	K(1,0)
K(-1,1)	K(0,1)	K(1,1)



$$
\begin{aligned}
\boxed{I'(x,y)} = {} & K(1,1)I(x-1,y-1) + K(0,1)I(x,y-1) + K(-1,1)I(x+1,y-1) \\
& + K(1,0)I(x-1,y) + K(0,0)I(x,y) + K(-1,0)I(x+1,y) \\
& + K(1,-1)I(x-1,y+1) + K(0,-1)I(x-1,y) + K(-1,-1)I(x+1,y+1)
\end{aligned}
$$

ETH

Linear Filtering (warm-up)



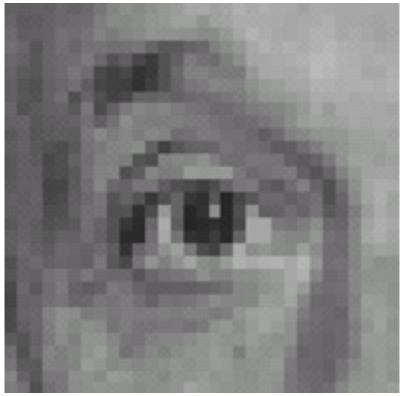
Original

0	0	0
0	1	0
0	0	0

?

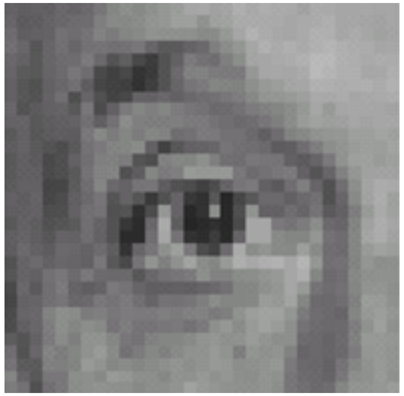
Slide credit: D.A. Forsyth

Linear Filtering (warm-up)



Original

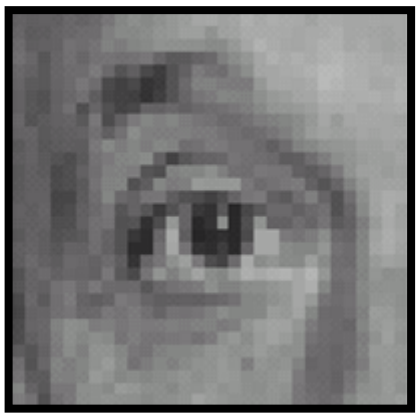
0	0	0
0	1	0
0	0	0



Filtered
(no change)

Slide credit: D.A. Forsyth

Linear Filtering



Original

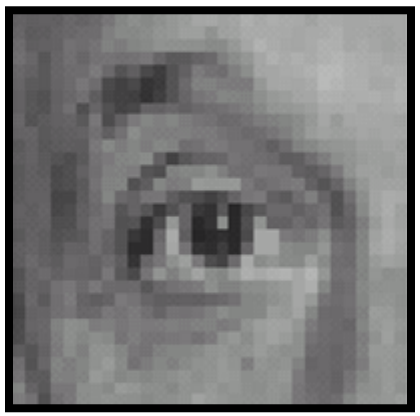
0	0	0
1	0	0
0	0	0

?

(use convolution)

Slide credit: D.A. Forsyth

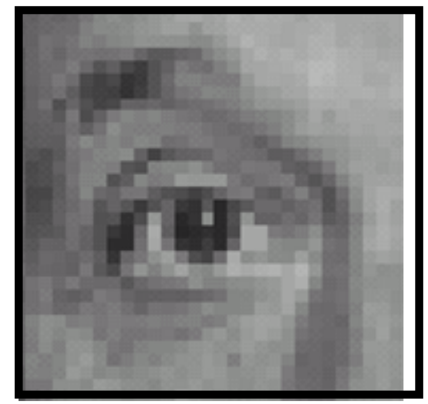
Linear Filtering



Original

0	0	0
1	0	0
0	0	0

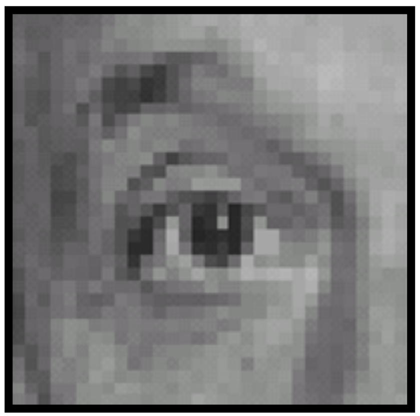
(use convolution)



Shifted left
By 1 pixel

Slide credit: D.A. Forsyth

Linear Filtering

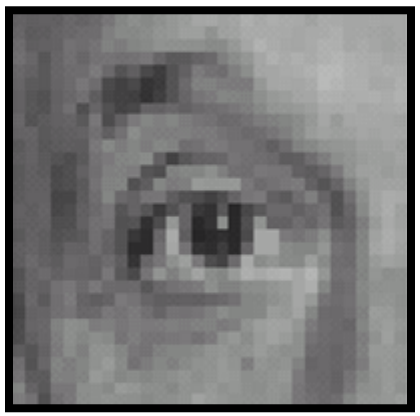


Original

1	1	1
1	1	1
1	1	1

?

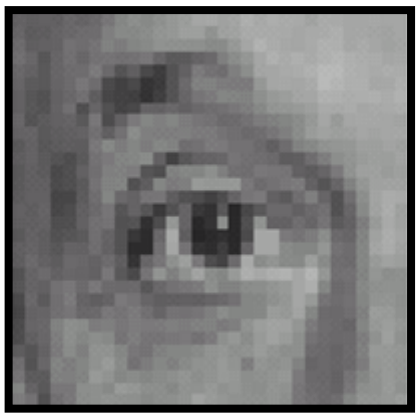
Linear Filtering



Original

1	1	1
1	1	1
1	1	1

Linear Filtering



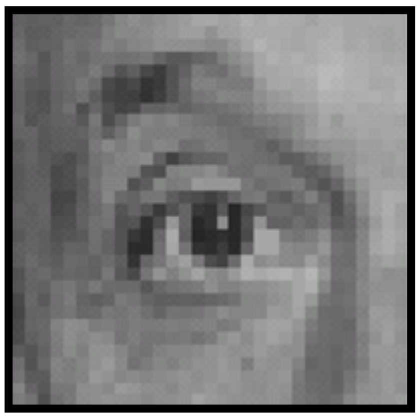
Original

$$\frac{1}{9}\begin{bmatrix}1 & 1 & 1\\ 1 & 1 & 1\\ 1 & 1 & 1\end{bmatrix}$$

?

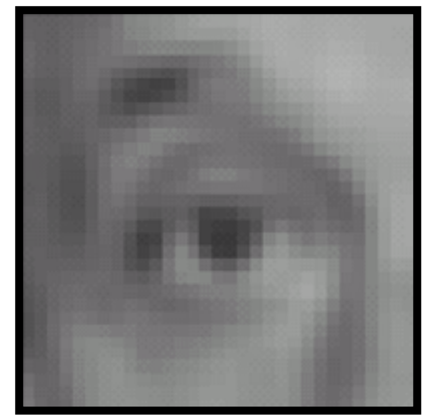
Slide credit: D.A. Forsyth

Linear Filtering



Original

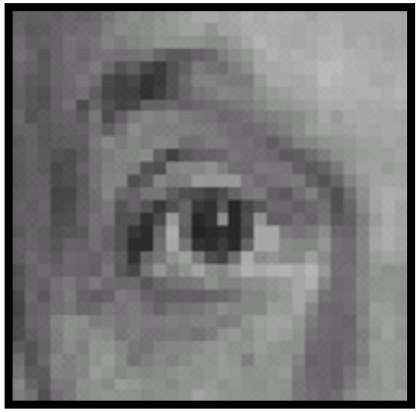
$$\frac{1}{9}\begin{bmatrix}1 & 1 & 1\\ 1 & 1 & 1\\ 1 & 1 & 1\end{bmatrix}$$



Blur (with a
box filter)

Slide credit: D.A. Forsyth

Linear Filtering



Original

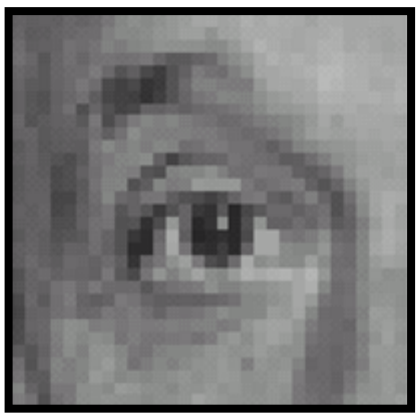
$$\begin{array}{|c|c|c|}\hline 0 & 0 & 0 \\ \hline 0 & 2 & 0 \\ \hline 0 & 0 & 0 \\ \hline \end{array} - \frac{1}{9}\begin{array}{|c|c|c|}\hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array}$$

?

(Note that filter sums to 1)

Slide credit: D.A. Forsyth

Linear Filtering



Original

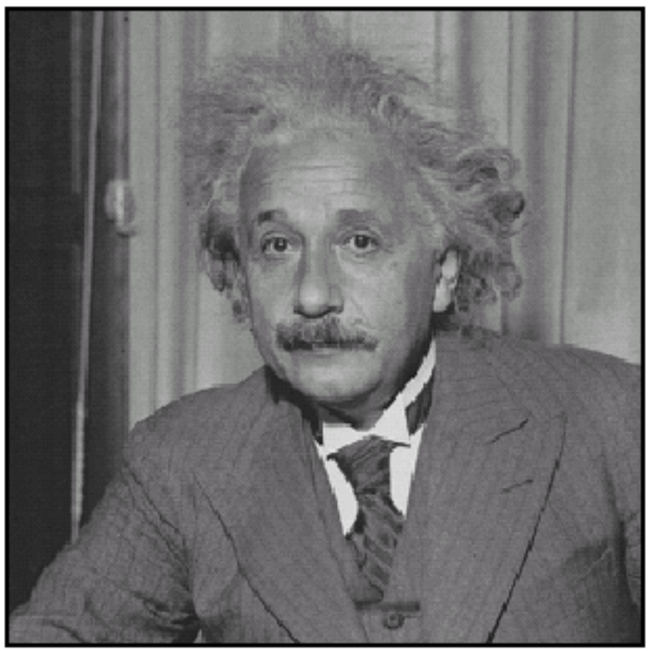
$$\begin{bmatrix}0&0&0\\0&2&0\\0&0&0\end{bmatrix} - \frac{1}{9}\begin{bmatrix}1&1&1\\1&1&1\\1&1&1\end{bmatrix}$$

Sharpening filter

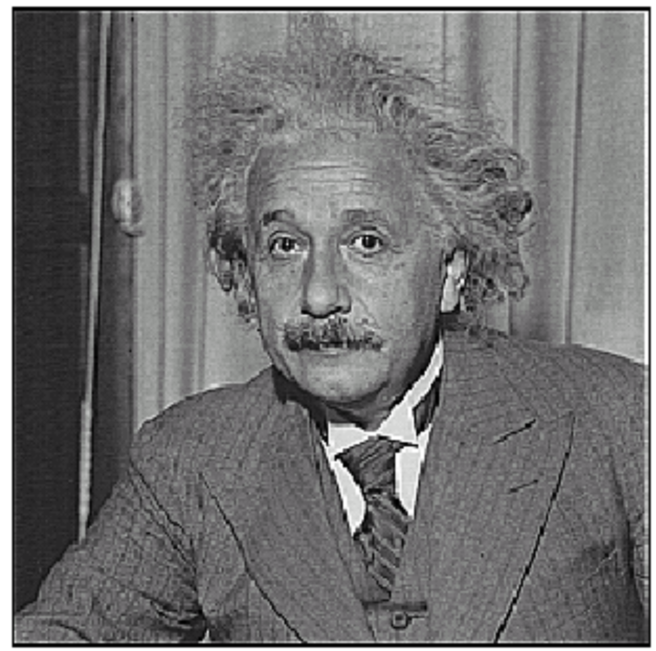
- Accentuates differences with local average

Slide credit: D.A. Forsyth

Sharpening



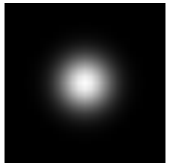
before

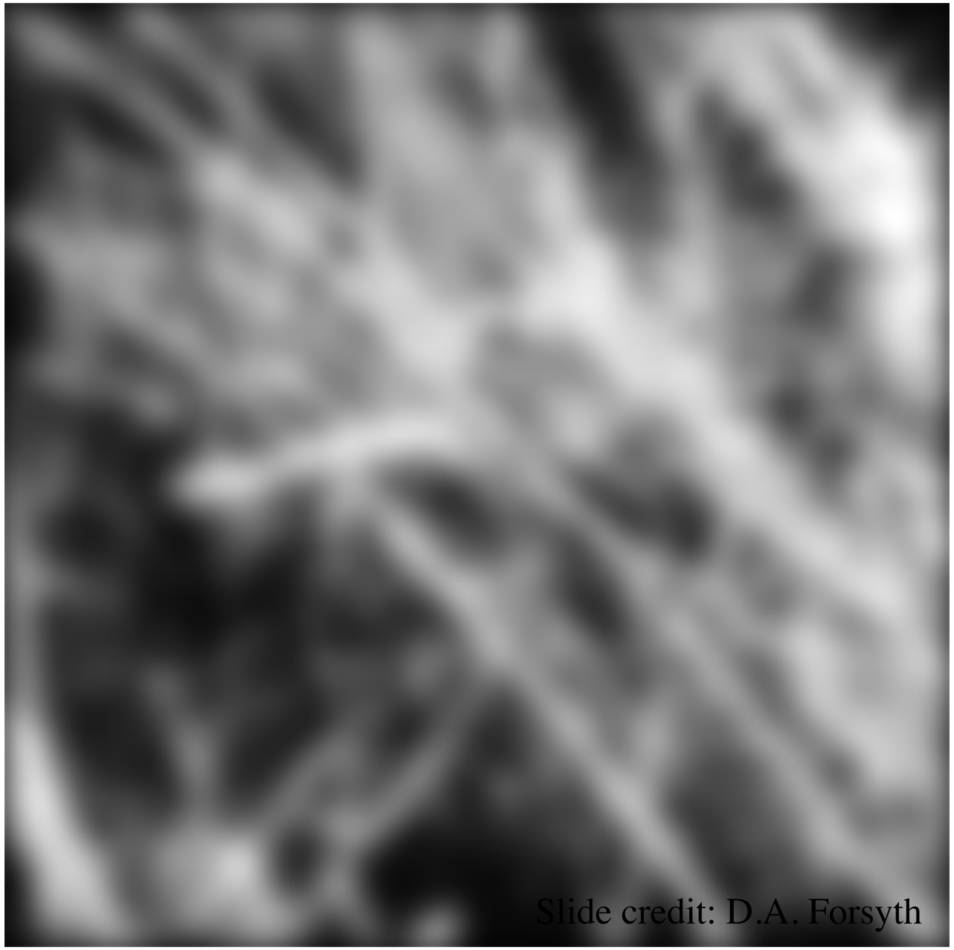


after

Slide credit: D.A. Forsyth

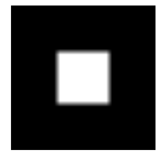
Smoothing with a Gaussian





Slide credit: D.A. Forsyth

Smoothing with a box filter



Slide credit: D.A. Forsyth

Scale Space Example

11x11; σ =3.

1

2

3

4

5

6

High-pass filters

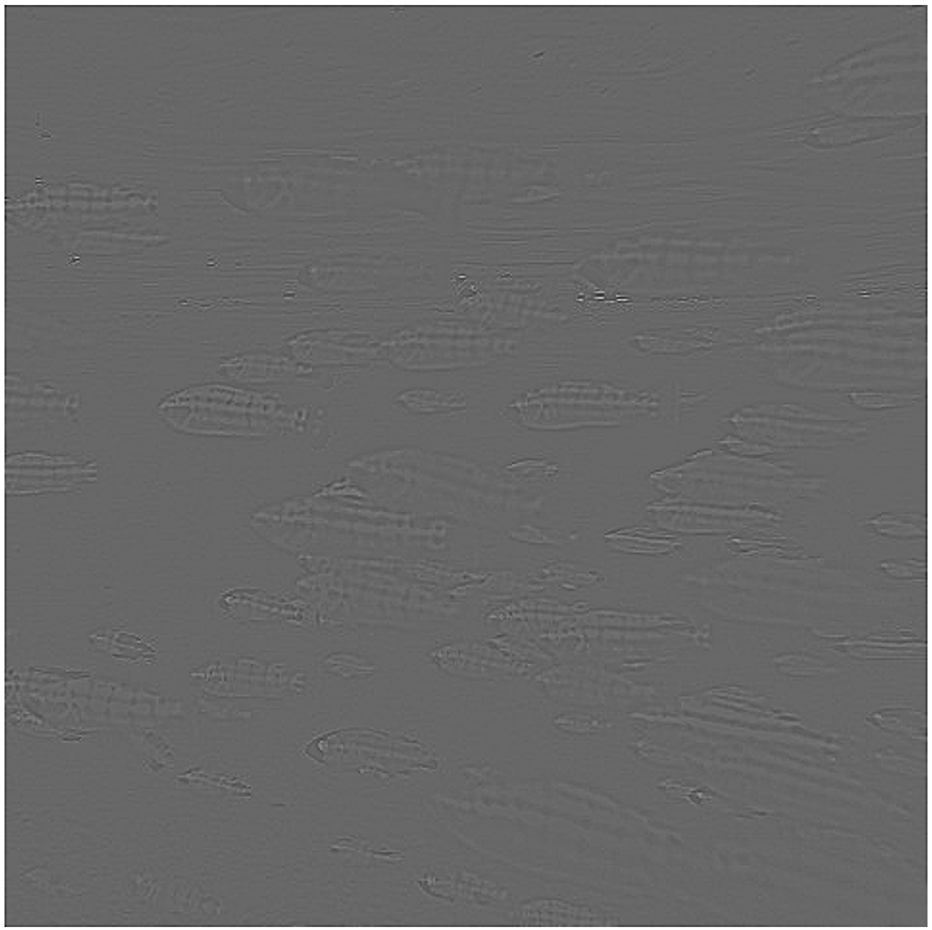
Laplacian operator:

$$\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}$$

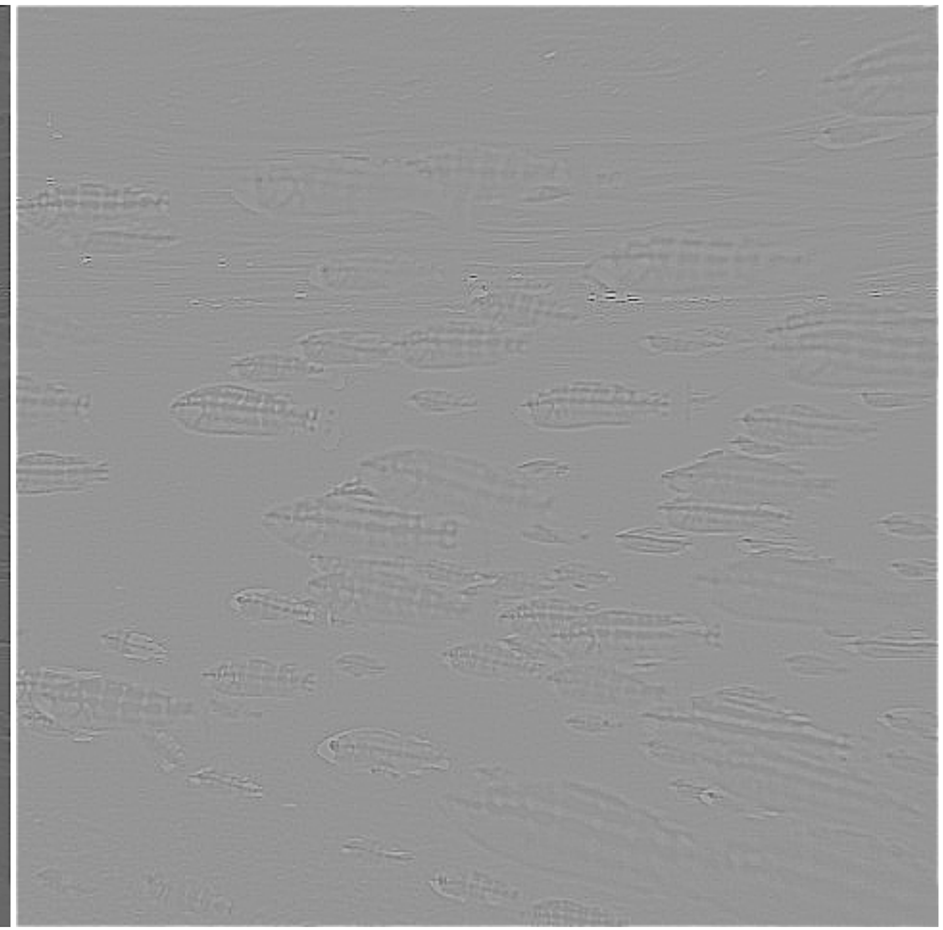
High-pass filter:

$$\begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix}$$

High-pass filters

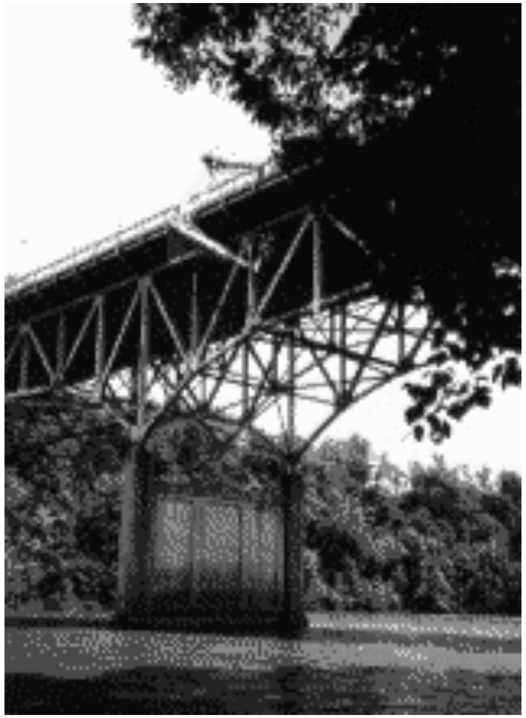


Laplacian



High pass

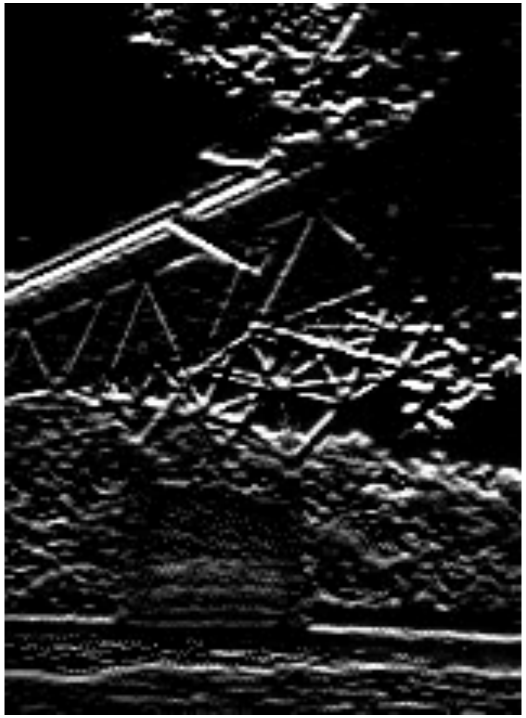
Prewitt operator example



Original *Bridge*
220x160

magnitude of image filtered with

$$\begin{pmatrix} -1 & 0 & 1 \\ -1 & [0] & 1 \\ -1 & 0 & 1 \end{pmatrix}$$



magnitude of image filtered with

$$\begin{pmatrix} -1 & -1 & -1 \\ 0 & [0] & 0 \\ 1 & 1 & 1 \end{pmatrix}$$

Prewitt operator example (cont.)

Original *Billsface*
310x241

log magnitude of image filtered with

$$\begin{pmatrix} -1 & 0 & 1 \\ -1 & [0] & 1 \\ -1 & 0 & 1 \end{pmatrix}$$

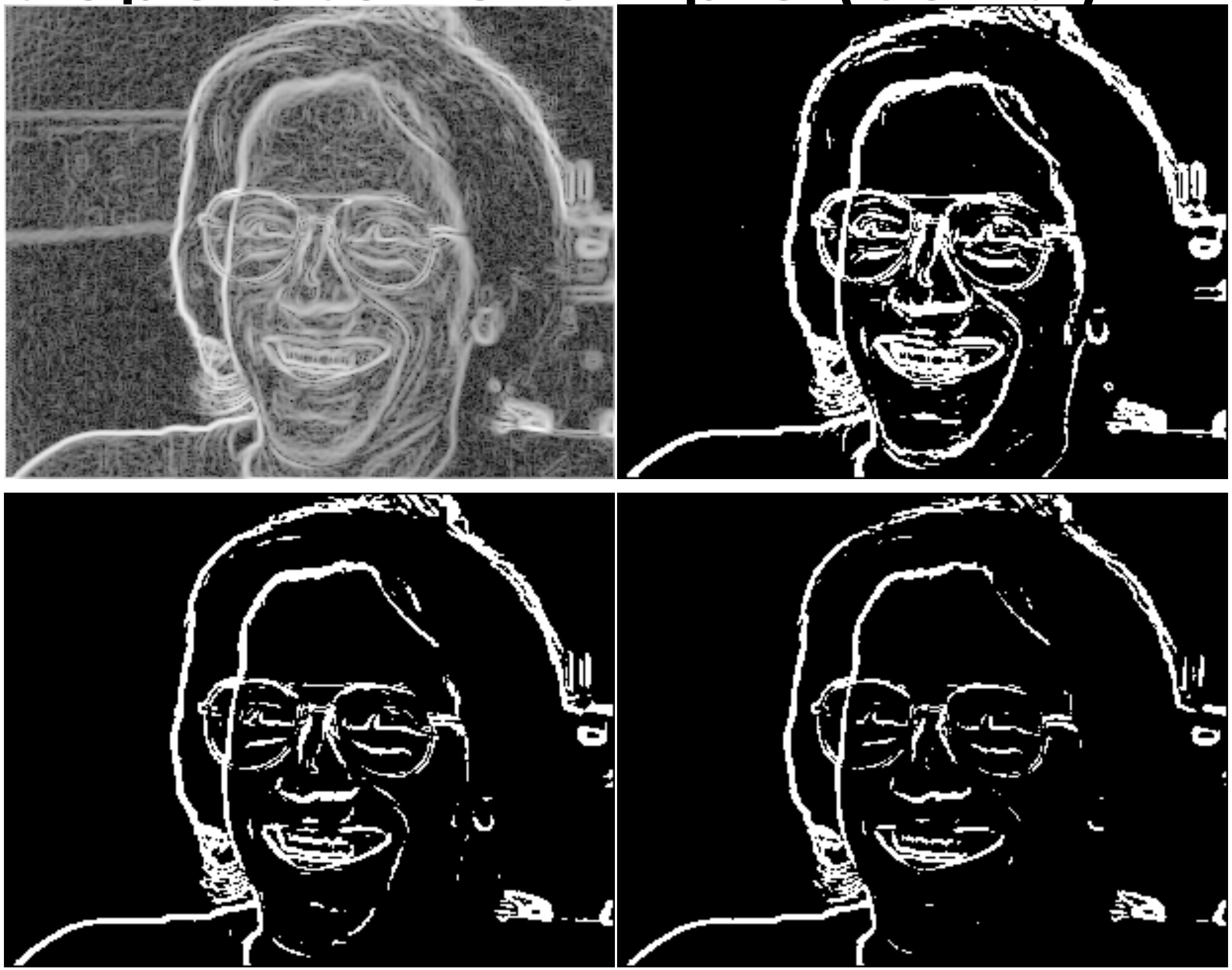
log magnitude of image filtered with

$$\begin{pmatrix} -1 & -1 & -1 \\ 0 & [0] & 0 \\ 1 & 1 & 1 \end{pmatrix}$$

Prewitt operator example (cont.)

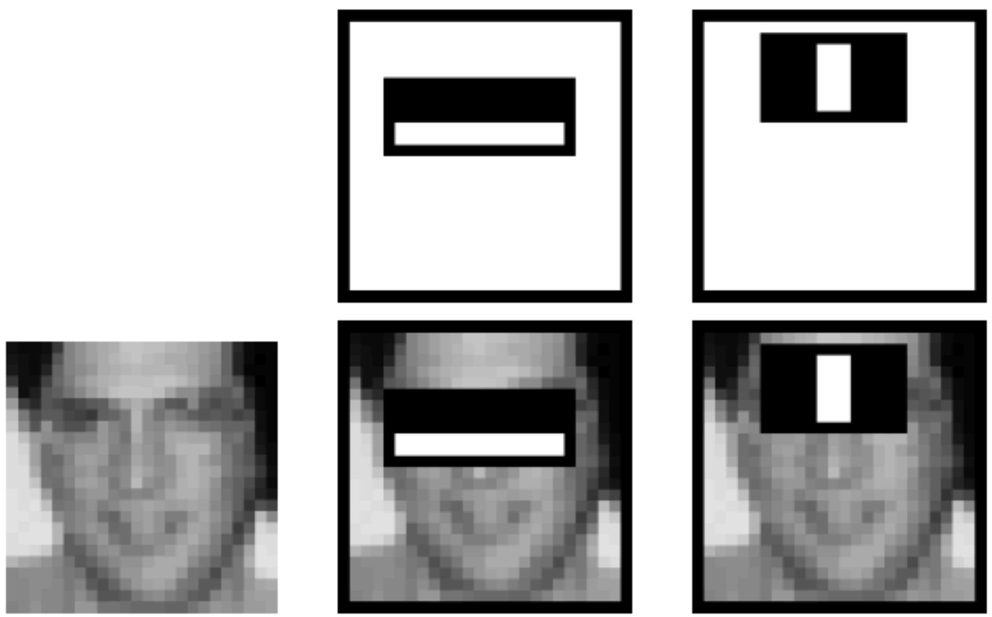
log sum of squared horizontal and vertical gradients

different thresholds



Viola-Jones cascade face detection

- Very efficient face detection using integral images



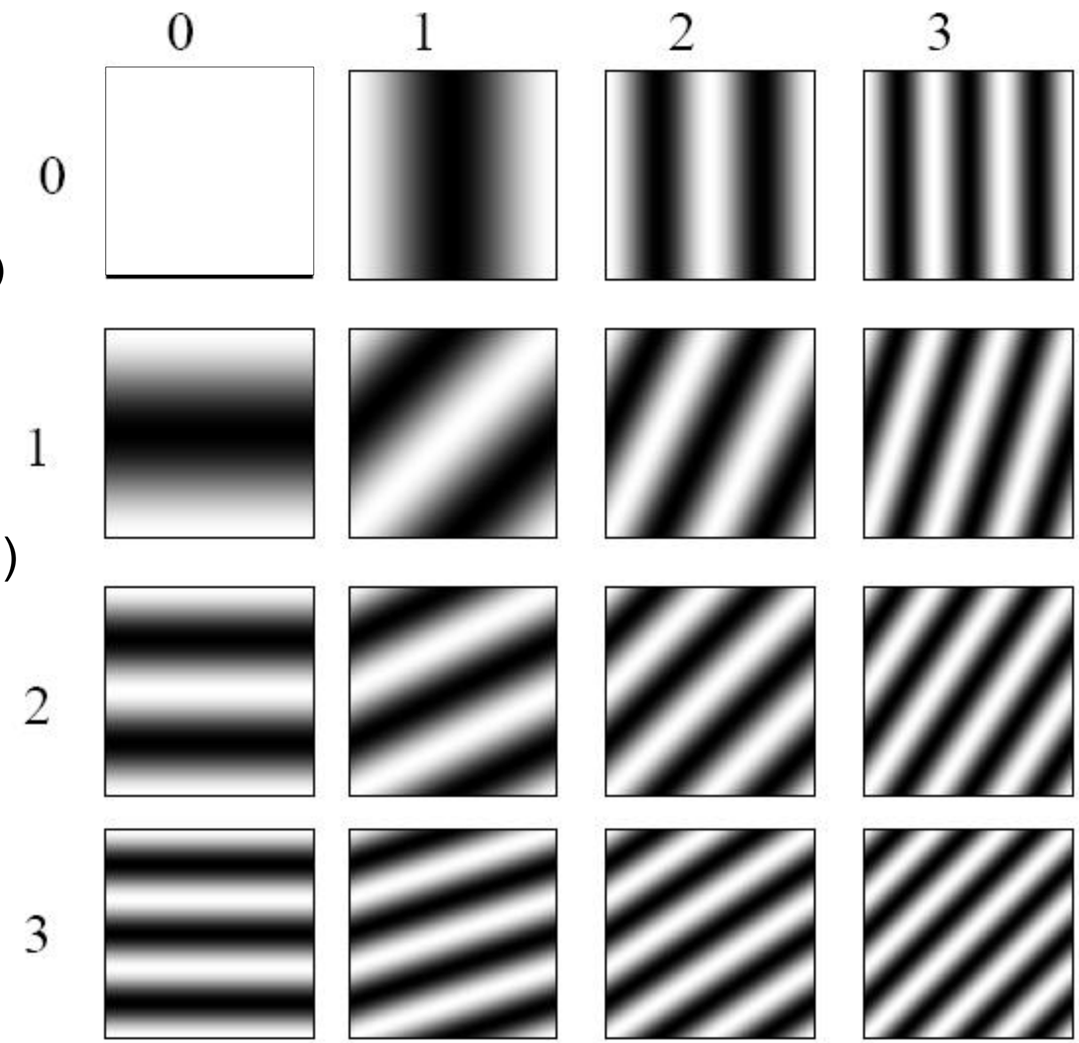
Figures from Viola and Jones 2001

Fourier basis functions

$$e^{-i2\pi(ux+vy)}$$

$$= \cos 2\pi(ux+vy) - i \sin 2\pi\,(ux+vy)$$

(note: basis functions are global)



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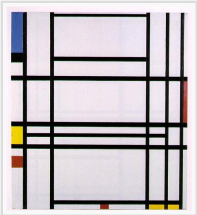
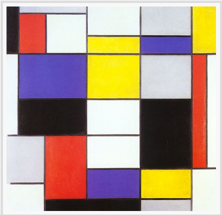
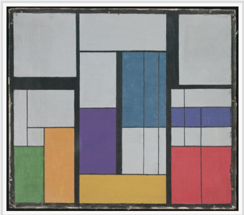




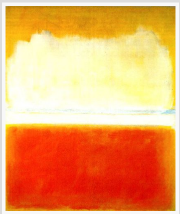
Style 2 contains impressionist landscapes. For example:

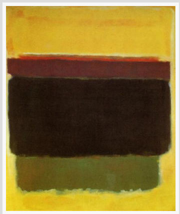



Style 3 contains expressionist action paintings. For example:




Style 4 contains colour field paintings. For example:



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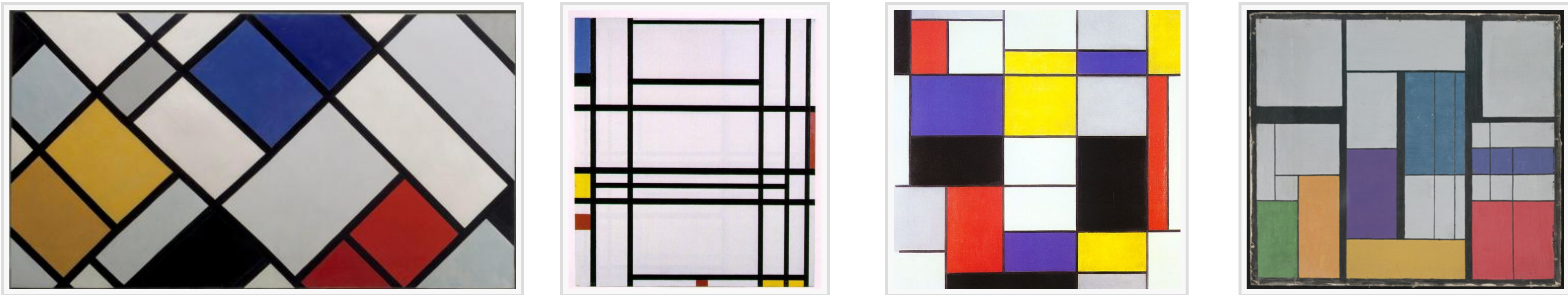
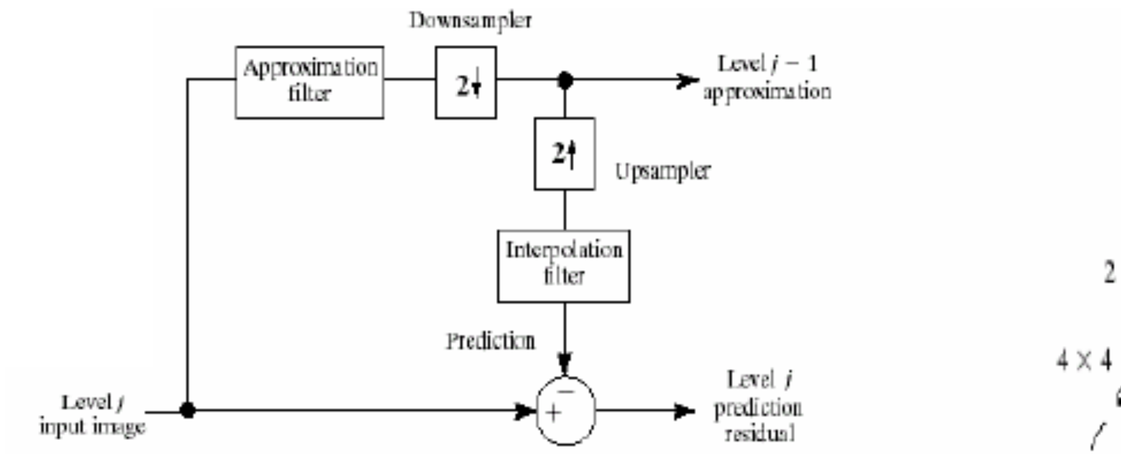
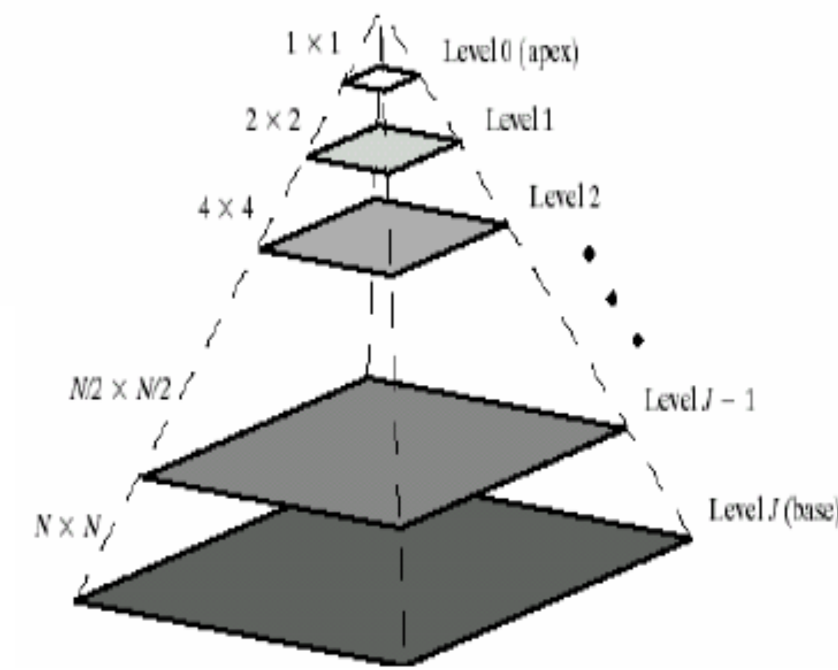


Style 2 contains impressionist landscapes. For example:

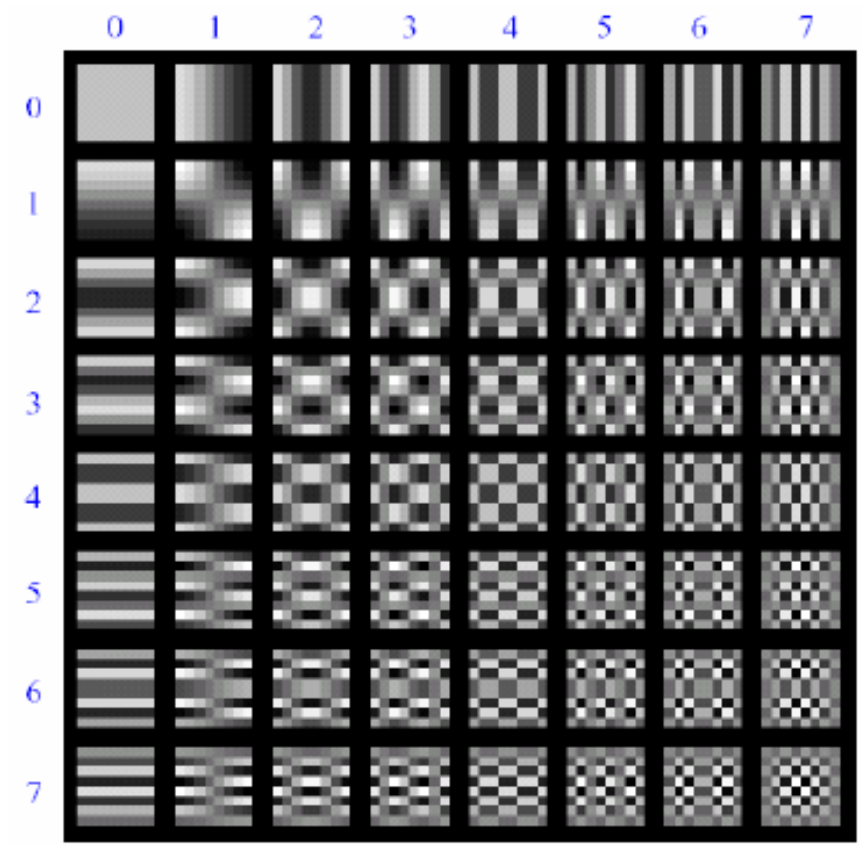
Style 3 contains expressionist action paintings. For example:

Image pyramid



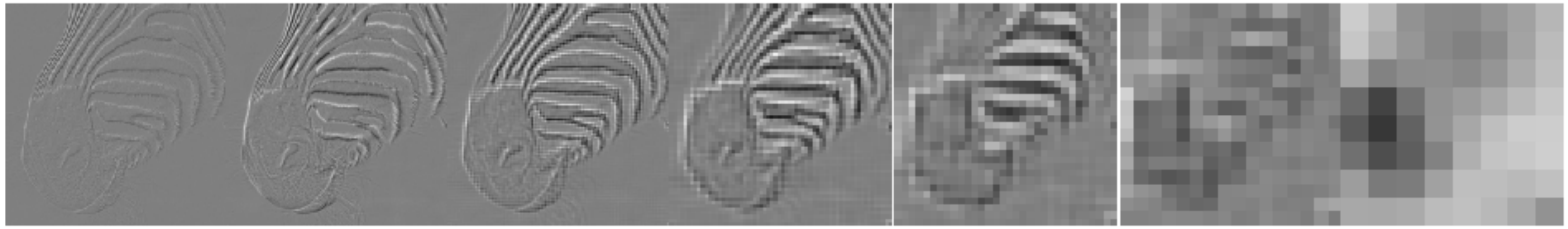


Lossy Image Compression (JPEG)

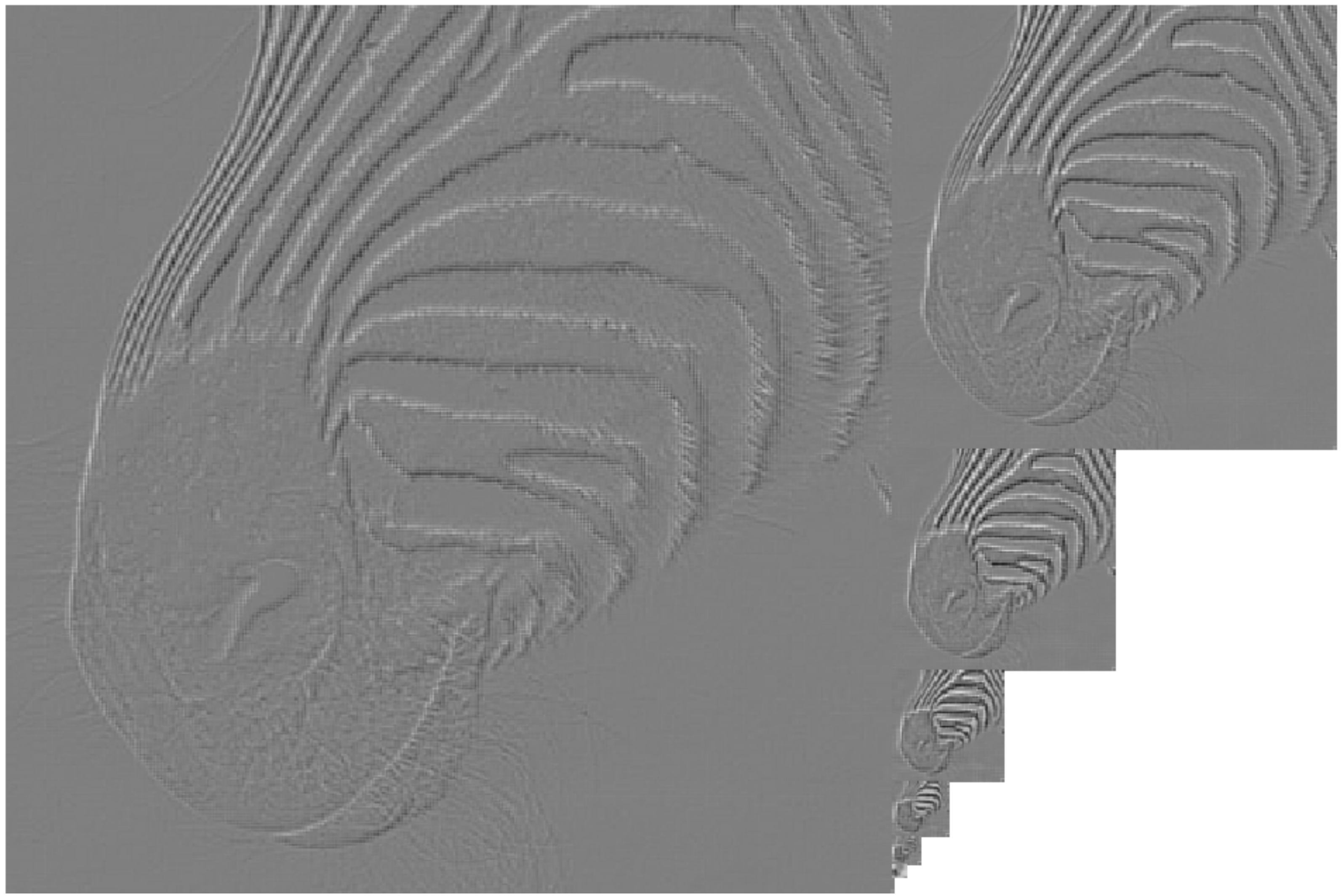


Block-based Discrete Cosine Transform (DCT)

512 256 128 64 32 16 8



512 256 128 64 32 16 8



The Walt Disney Company
Walt Disney World
Walt Disney Television Animation
Hong Kong Disneyland
Walt Disney Imagineering
Disney's Environmentality
SportsTicker
Tokyo DisneySea
Disney.com
ESPN International
Animal Kingdom
Disney Hand
ESPN
SOAP NET
abc Kids
Disney Theatrical Productions Ltd
abc Radio Division
Mighty Ducks
WTVG
Hollywood Records
Discover
Touchstone Pictures
Disney direct
Tokyo Disneyland
Disney on Ice
ESPN The Magazine
California Adventure
Buena Vista Home Entertainment
Buena Vista Music Group
abc daytime
Walt Disney Internet Group
Disney Interactive
ESPN Radio
Disney-MGM Studios
ABC Radio Networks
Disney Consumer Products
Walt Disney Studios
Radio Disney
Toon Disney
ESPN.com
Buena Vista International, Inc.
Feature Animation
abc
Disney Magazine
Disneyland Resort
DisneyToon Studios
Walt Disney Records
Walt Disney Television
ESPN Zone
abc family
Buena Vista Pictures
abc NEWS
The Muppets
Touchstone Television
Walt Disney Pictures
Adventures
ESPN HD
Disney Publishing Worldwide
X Games
Disneyland Paris
abc NEWS
Lyric Street Records
BASS
ESPN Mobile
Miramax Films
ESPN Classic
Magic Kingdom
WPVI-TV
KTRK-TV Houston
FamilyFun Magazine
ESPN 2
Hyperion
abc SPORTS
abc.com
Buena Vista Theatrical Group Ltd
Hyperion
Buena Vista Television
ESPN Regional Television
ESPN Outdoors
Jump at the Sun
WTVD
Dimension Films
Epcot
Walt Disney Parks and Resorts Online
movies.com
baby einstein
Disneyland
Disney Channel
Walt Disney International
ESPN Deportes
Jetix
bvg Buena Vista Games
ESPNEWS
Downtown Disney
Disney Cruise Line

Hao Aiqiang


Ulf Lundgren 2001


CGSociety.org
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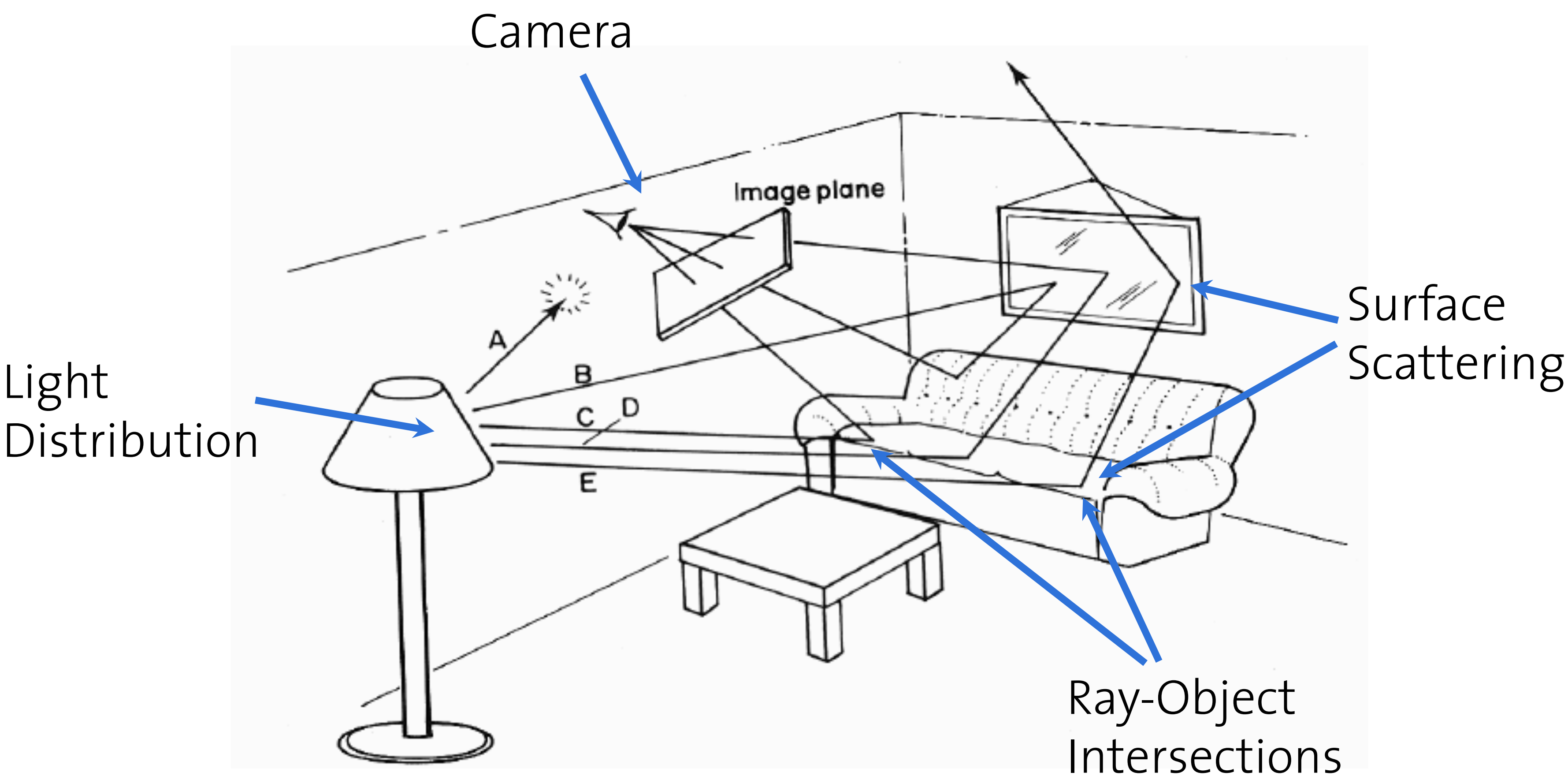
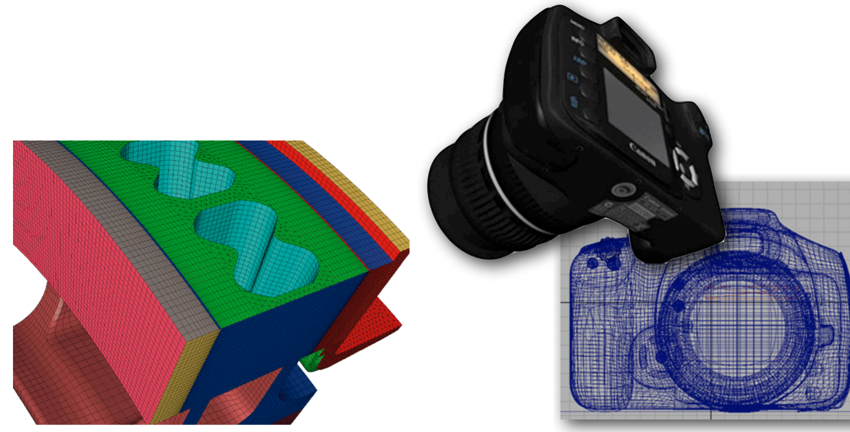
Henrik Wann Jensen

Teaser - Light Transport

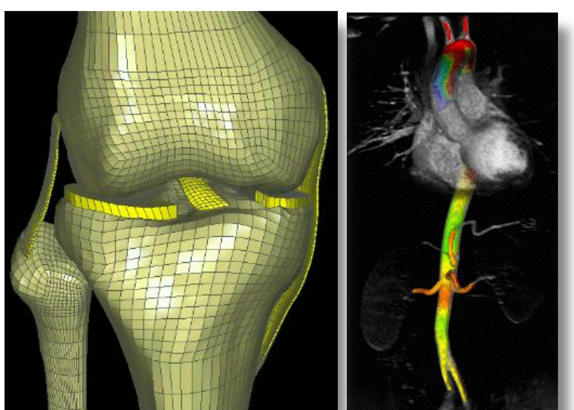


Digital shapes are pervasive

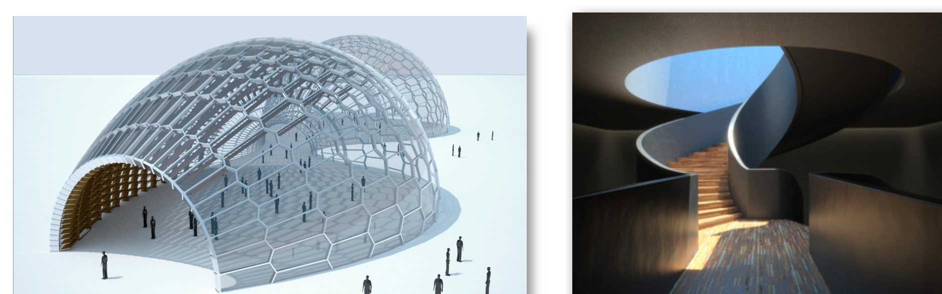
Games/Movies



Engineering/Product design



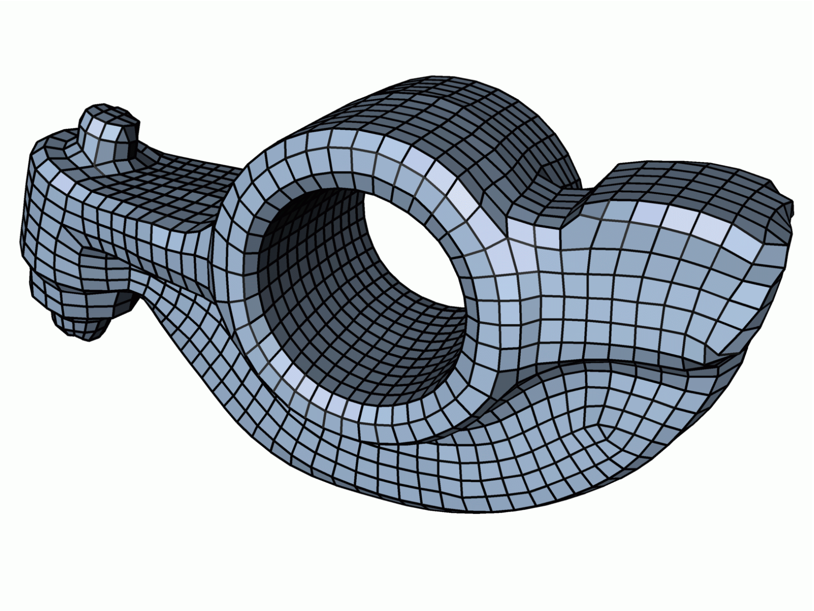
Medicine/Biology

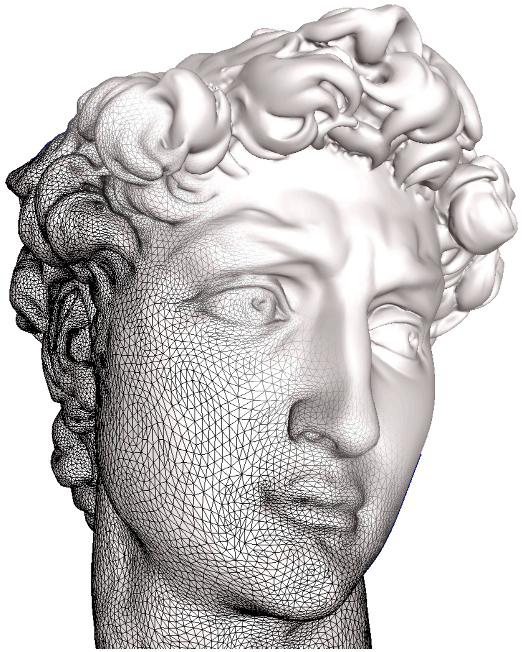


Architecture

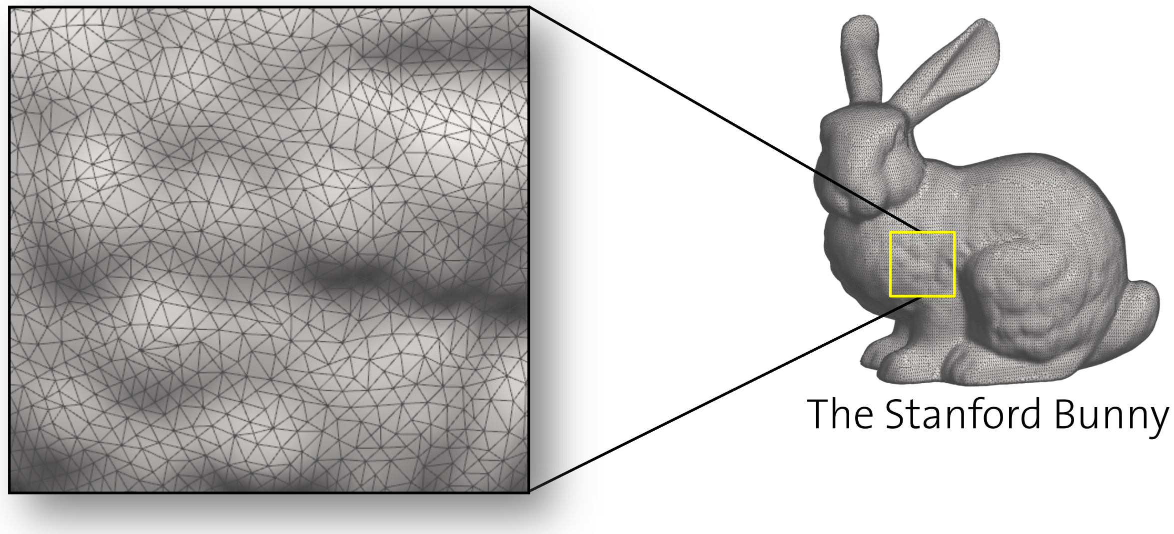
Polygonal Meshes

- Boundary representations of objects
  - Piecewise linear
  - Store: geometry and connectivity (topology)



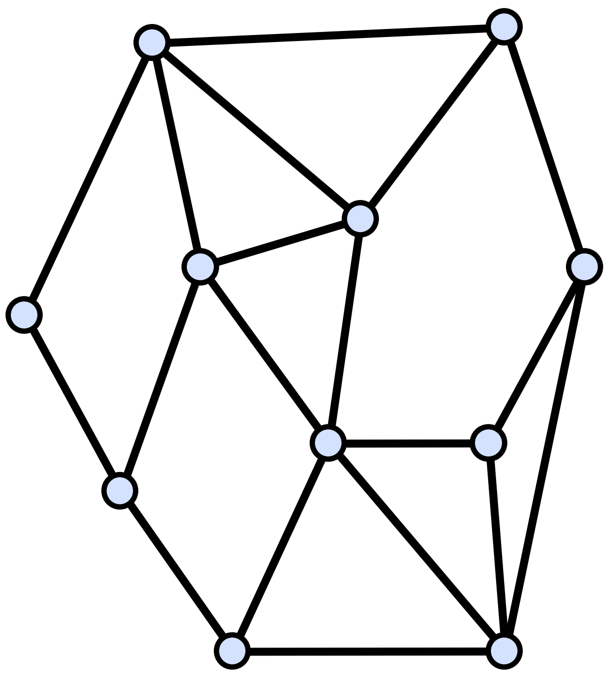


Polygonal Meshes



The Stanford Bunny

Polygonal Mesh

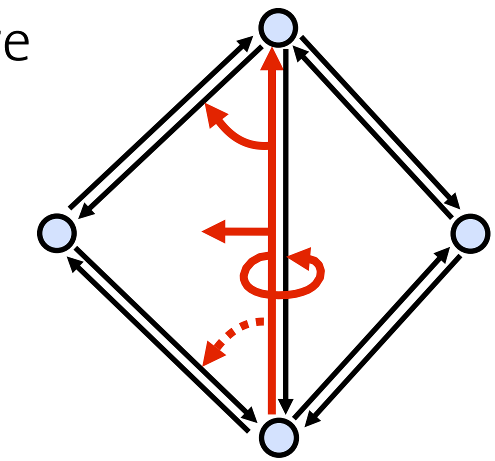


- A finite set M of closed, simple polygons Q_i is a *polygonal mesh*
  - The intersection of two polygons in M is either empty, a vertex, or an edge

$$M = \langle V, E, F \rangle$$

vertices edges faces

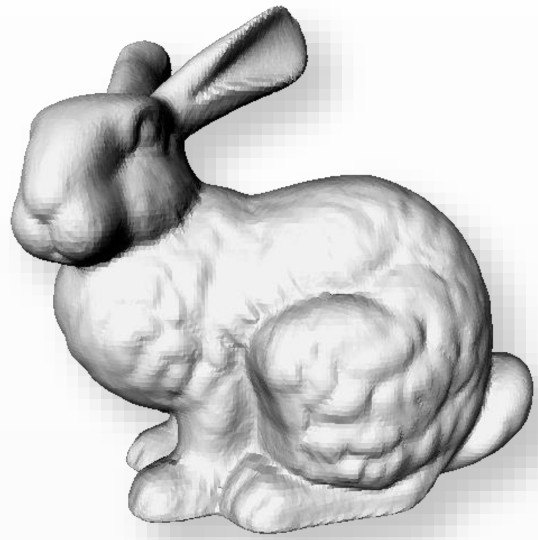
Halfedge data structure



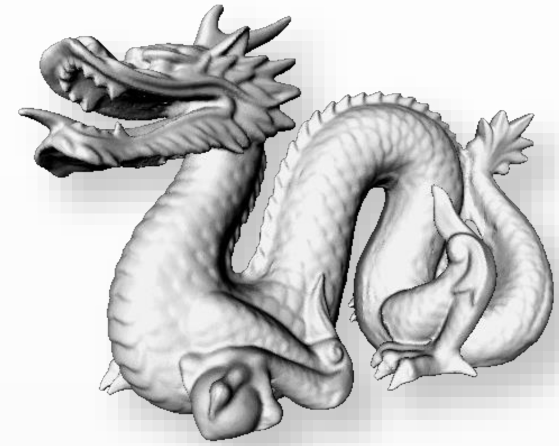
- Introduce orientation into data structure
  - Oriented edges
- Vertex
  - Position
  - 1 outgoing halfedge index
- Halfedge
  - 1 origin vertex index
  - 1 incident face index
  - 3 next, prev, twin halfedge indices
- Face
  - 1 adjacent halfedge index
- Easy traversal, full connectivity

Triangle Meshes

6 K



70 K



870 K

1 M

28 M

2 B

canning the David

480 individually aimed scans

2 billion polygons

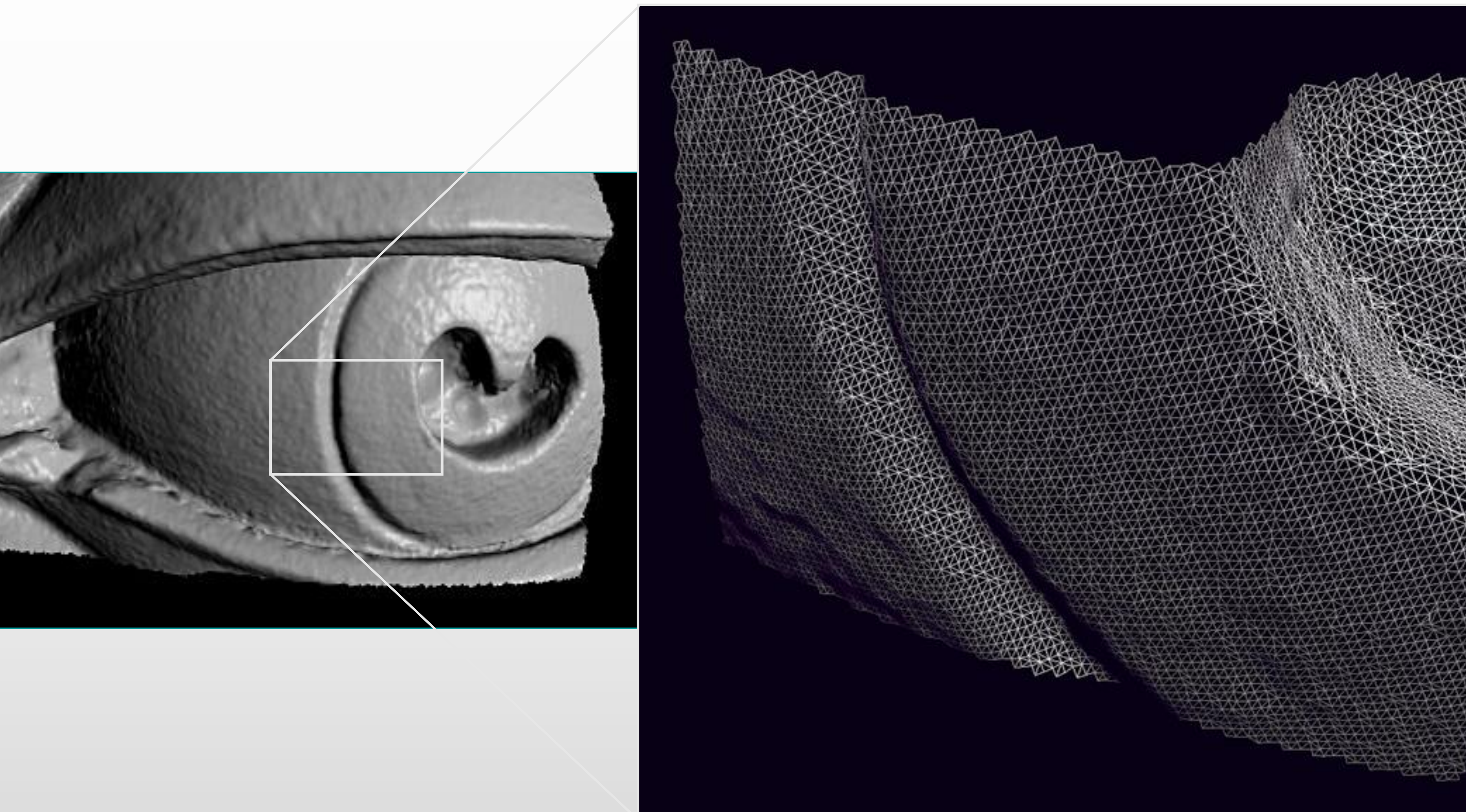
7,000 color images

32 gigabytes

30 nights of scanning

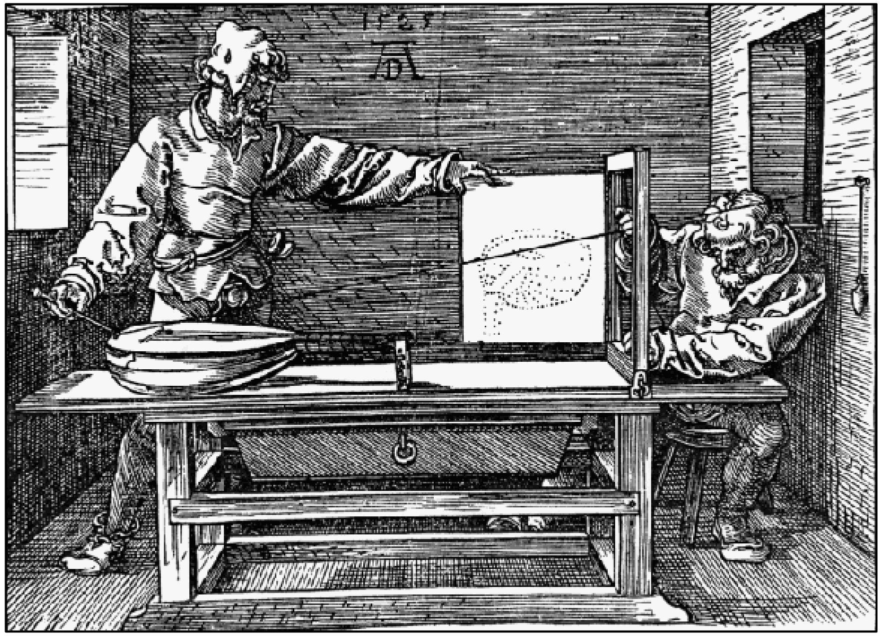
22 people

canning the David



Computer Graphics

Ray Tracing I



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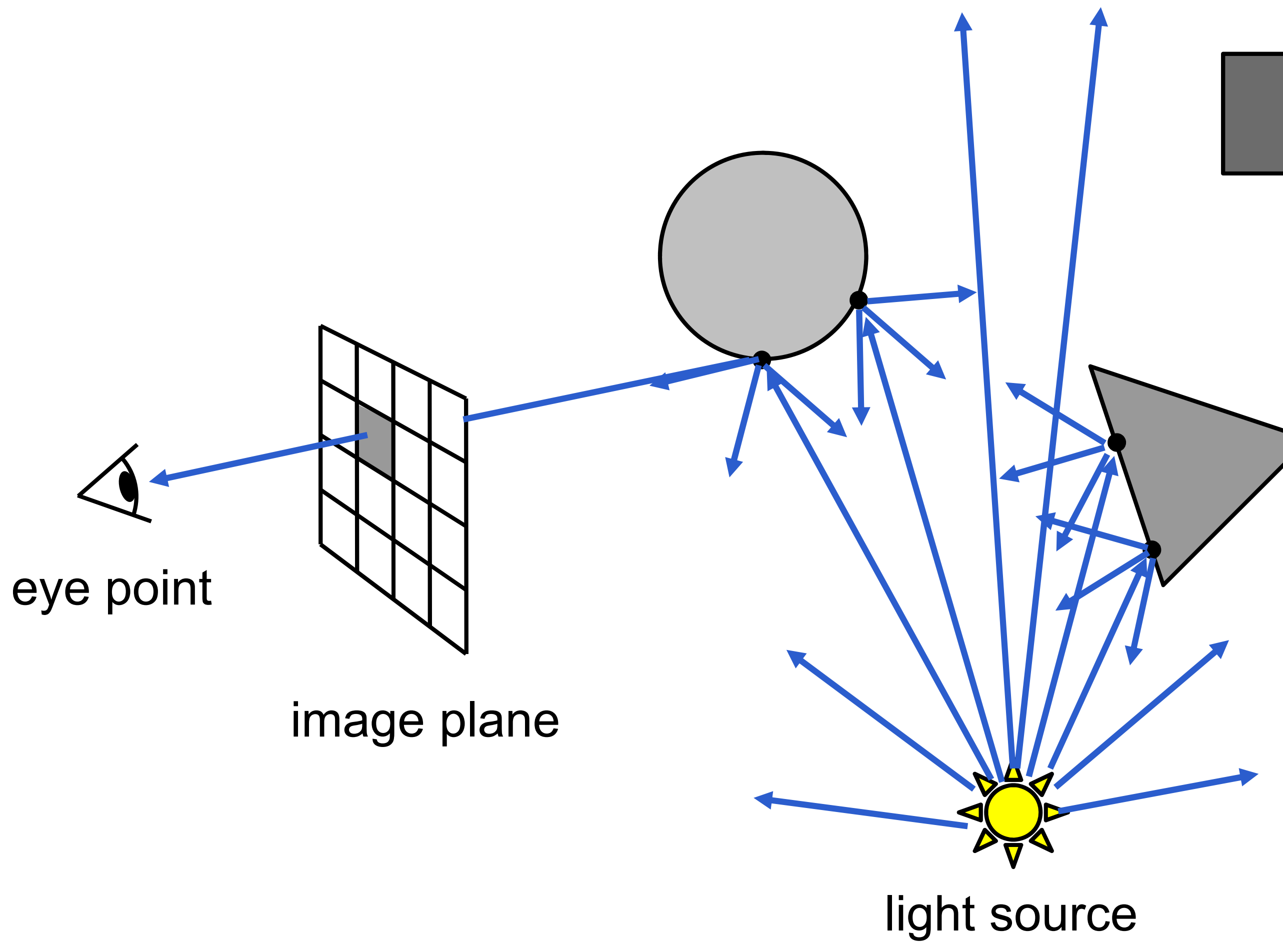
Swiss Federal Institute of Technology Zurich

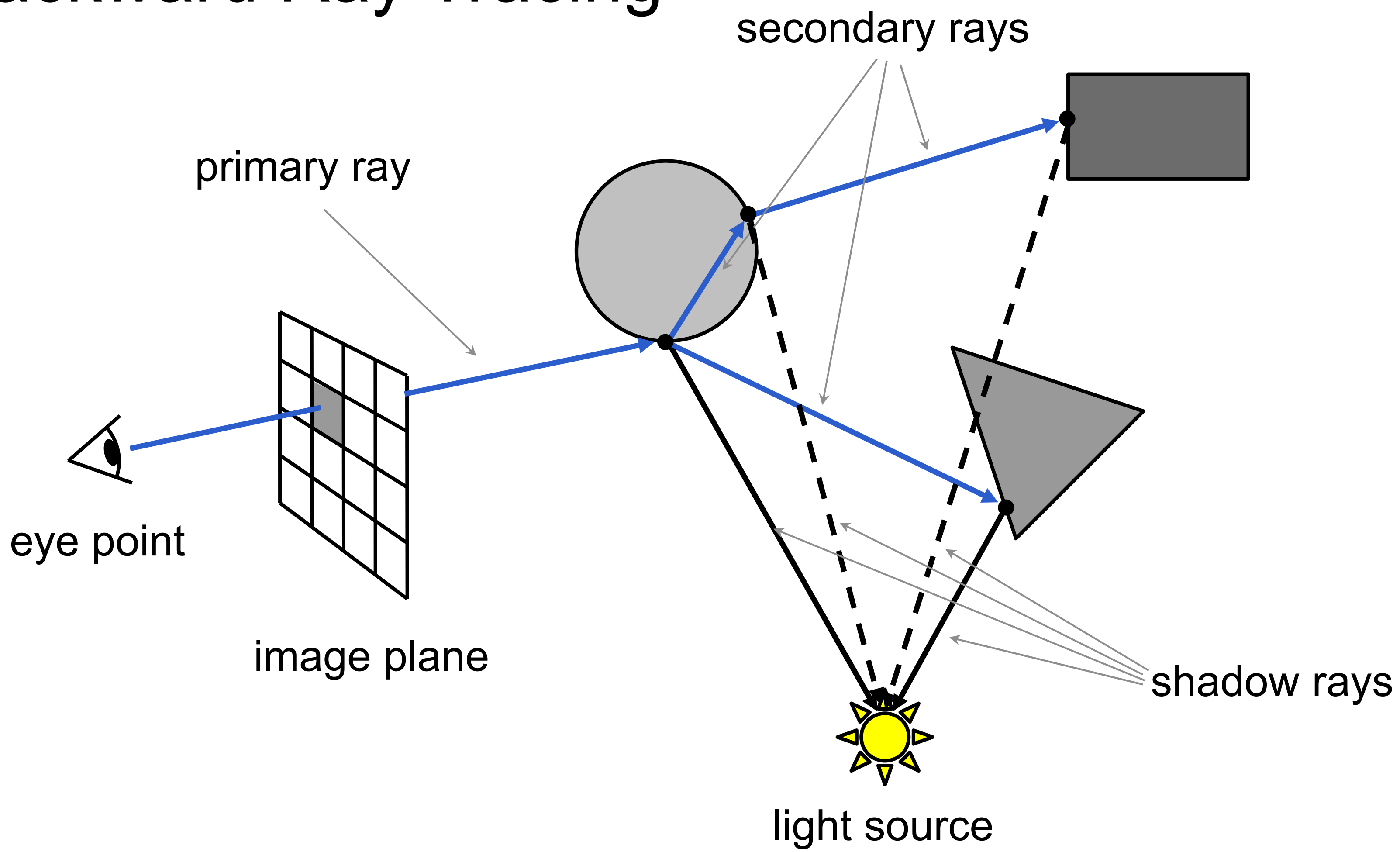
Ray Tracing - Overview

- Forward Ray Tracing



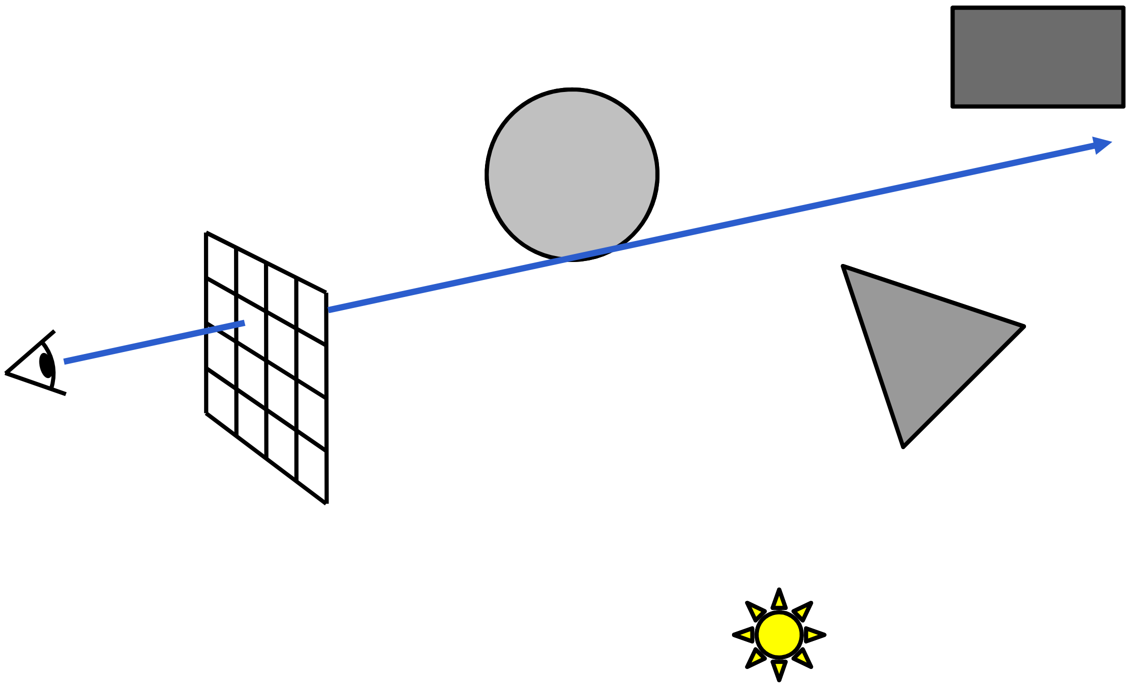
Ray Tracing - Overview

- Backward Ray Tracing



Basic Ray Tracing Pipeline

Ray Generation

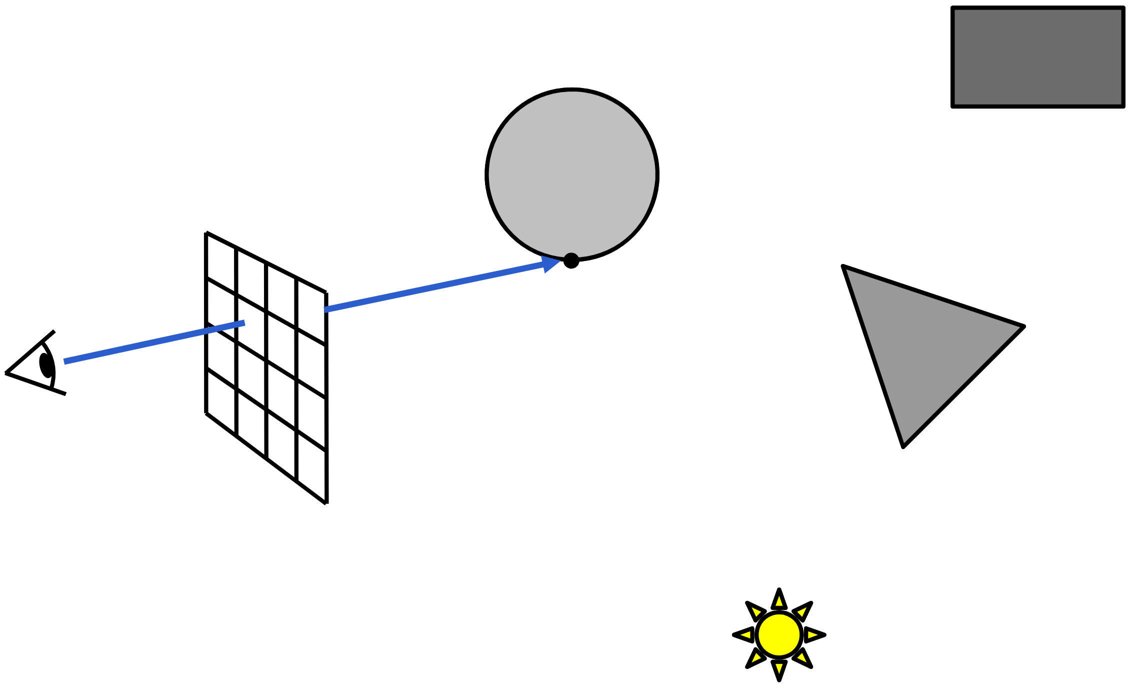


Basic Ray Tracing Pipeline

Ray Generation

↓

Intersection



Basic Ray Tracing Pipeline

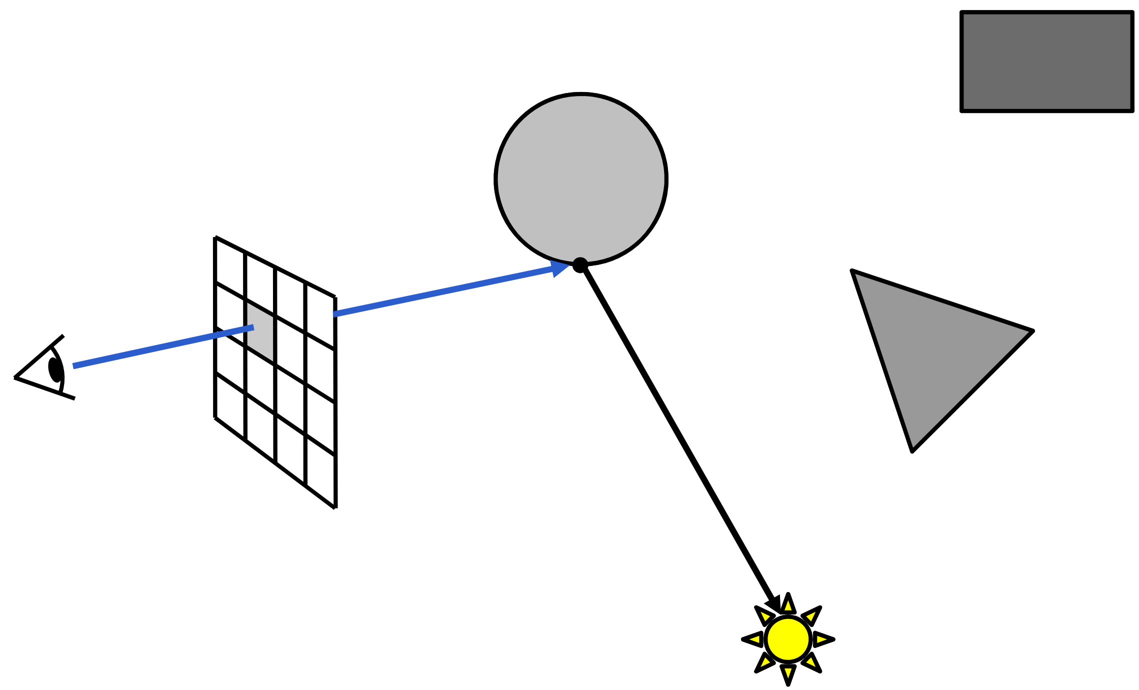
Ray Generation

↓

Intersection

↓

Shading



Basic Ray Tracing Pipeline

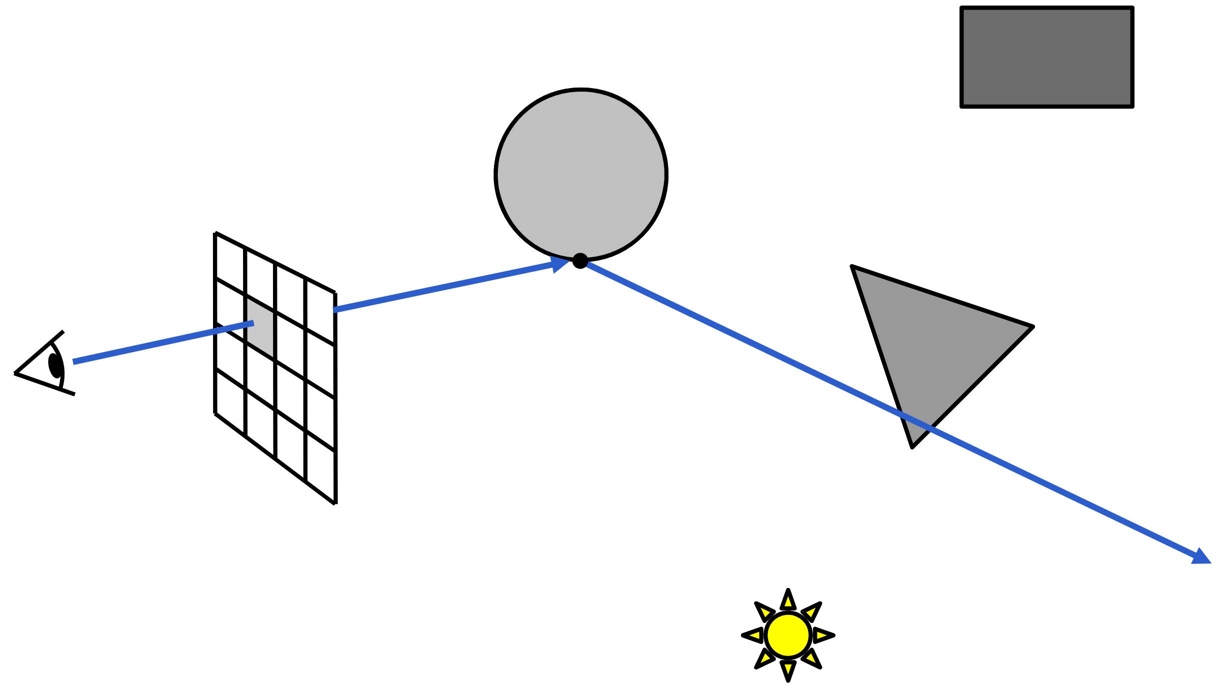
Ray Generation

↓

Intersection

↓

Shading



Basic Ray Tracing Pipeline

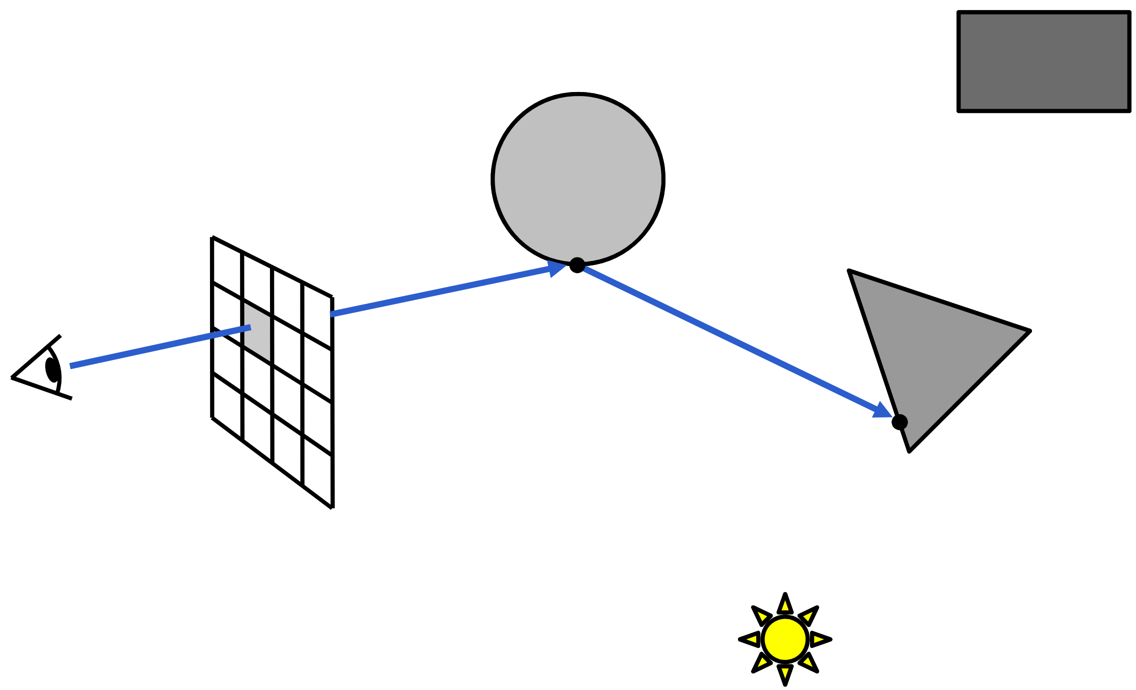
Ray Generation

↓

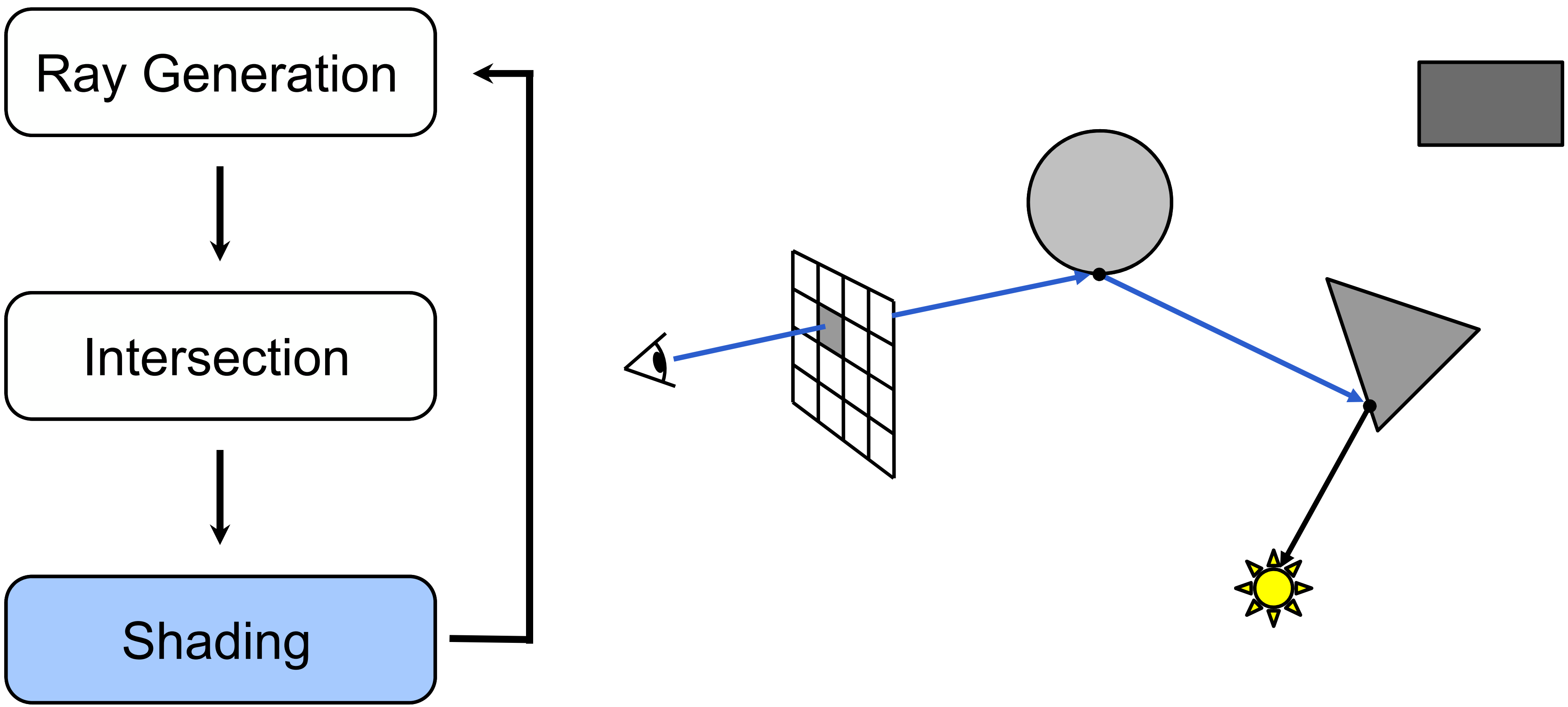
Intersection

↓

Shading



Basic Ray Tracing Pipeline



Basic Ray Tracing Pipeline

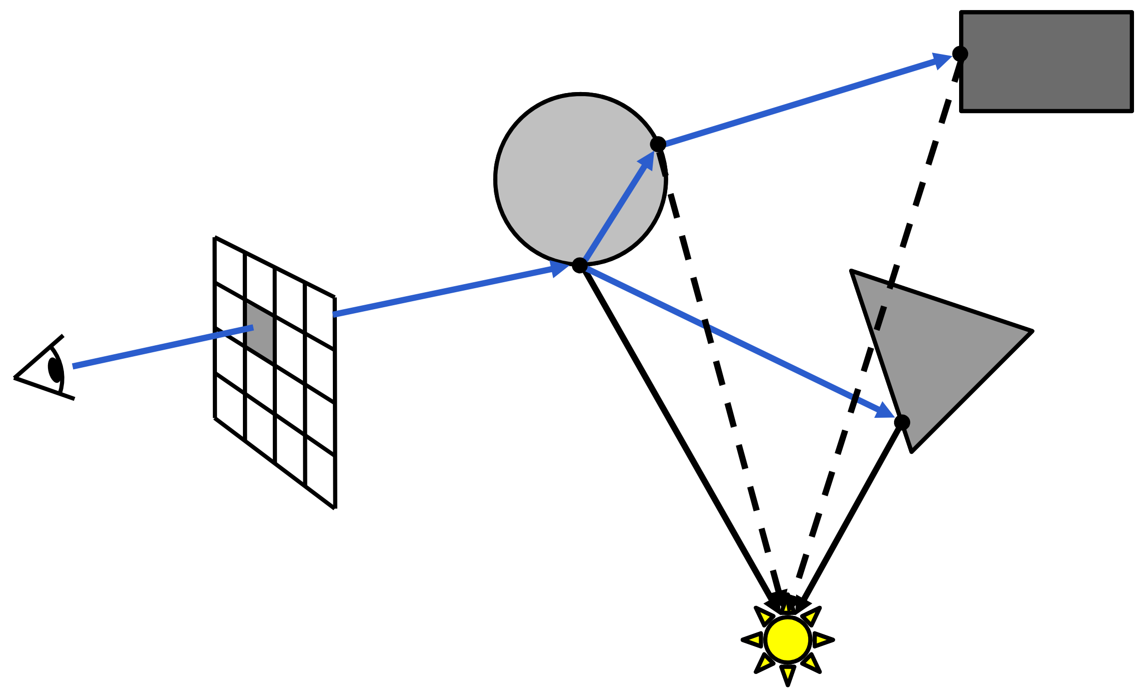
Ray Generation

↓

Intersection

↓

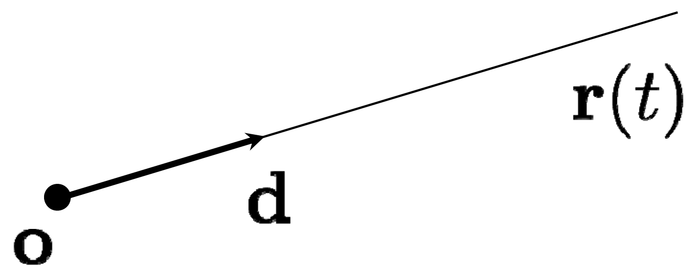
Shading



Rays

- Parametric form

$$\underset{\text{ray}}{\mathbf{r}(t)} = \underset{\text{origin}}{\mathbf{o}} + t\underset{\text{direction}}{\mathbf{d}}$$



Ray-Sphere Intersection

- Sphere equation (implicit)

$$\|\mathbf{x} - \mathbf{c}\|^2 - r^2 = 0$$

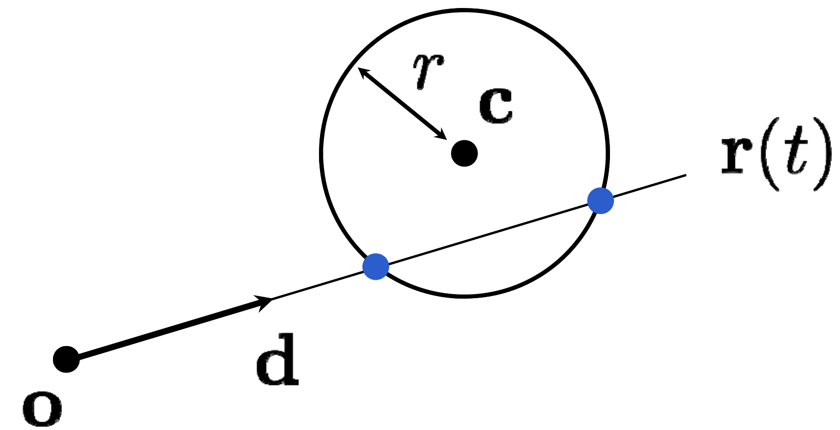
point of interest   center   radius

- Algebraic approach:
  - insert ray equation:

$$\mathbf{r}(t) = \mathbf{o} + t\mathbf{d}$$

  - and solve for t

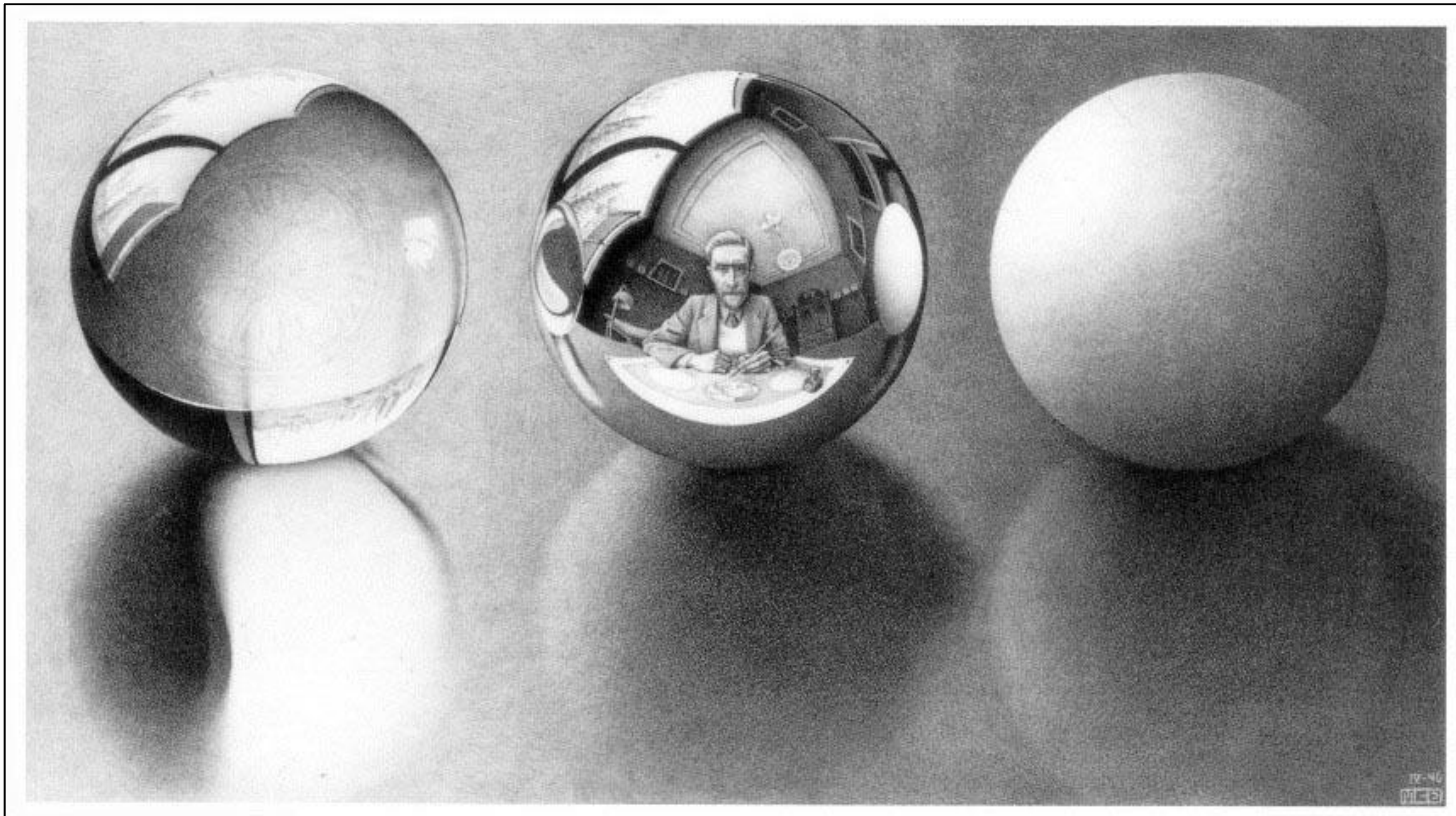
$$\|\mathbf{o} + t\mathbf{d} - \mathbf{c}\|^2 - r^2 = 0$$



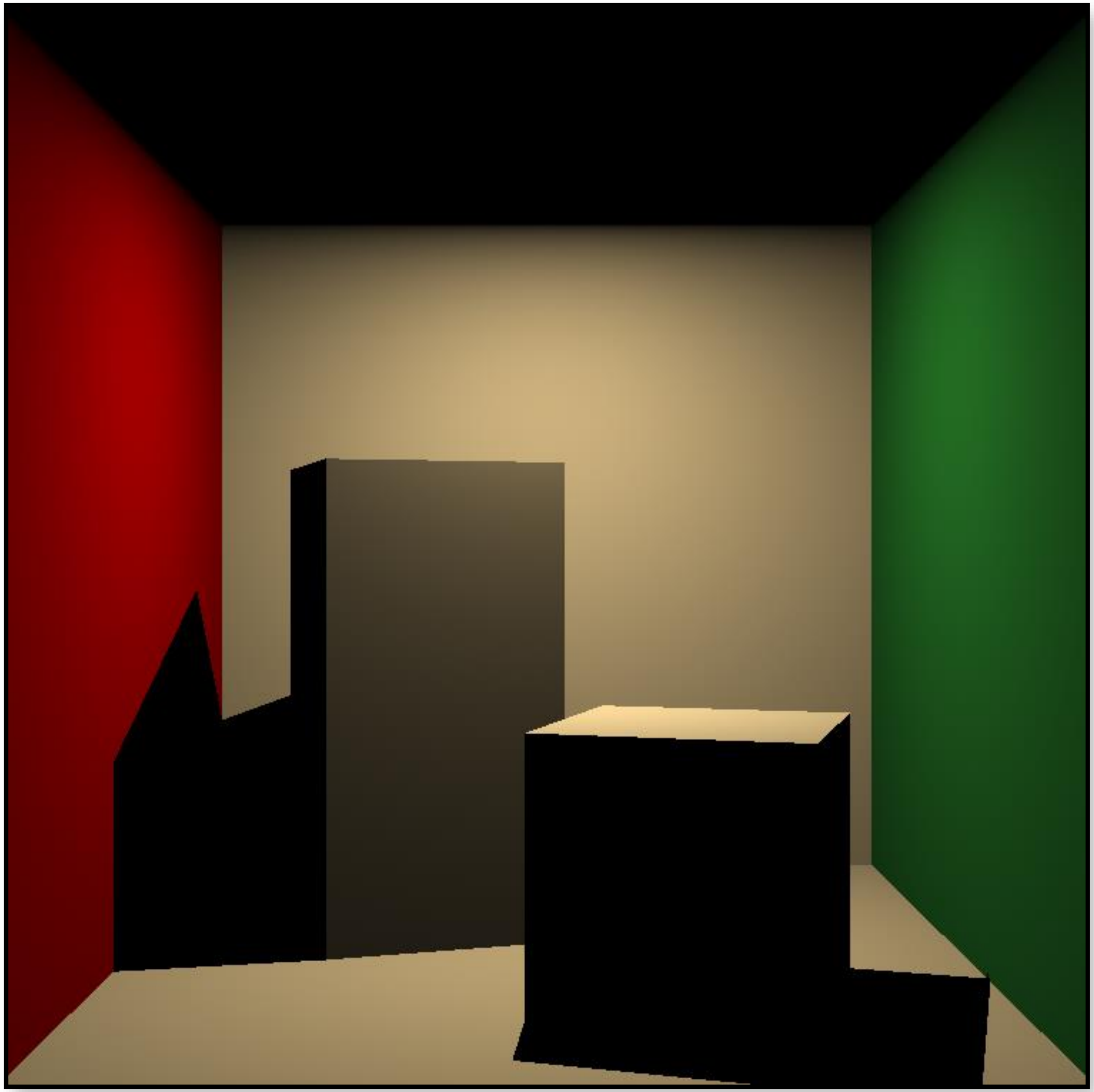
Visual Break

Computer Graphics

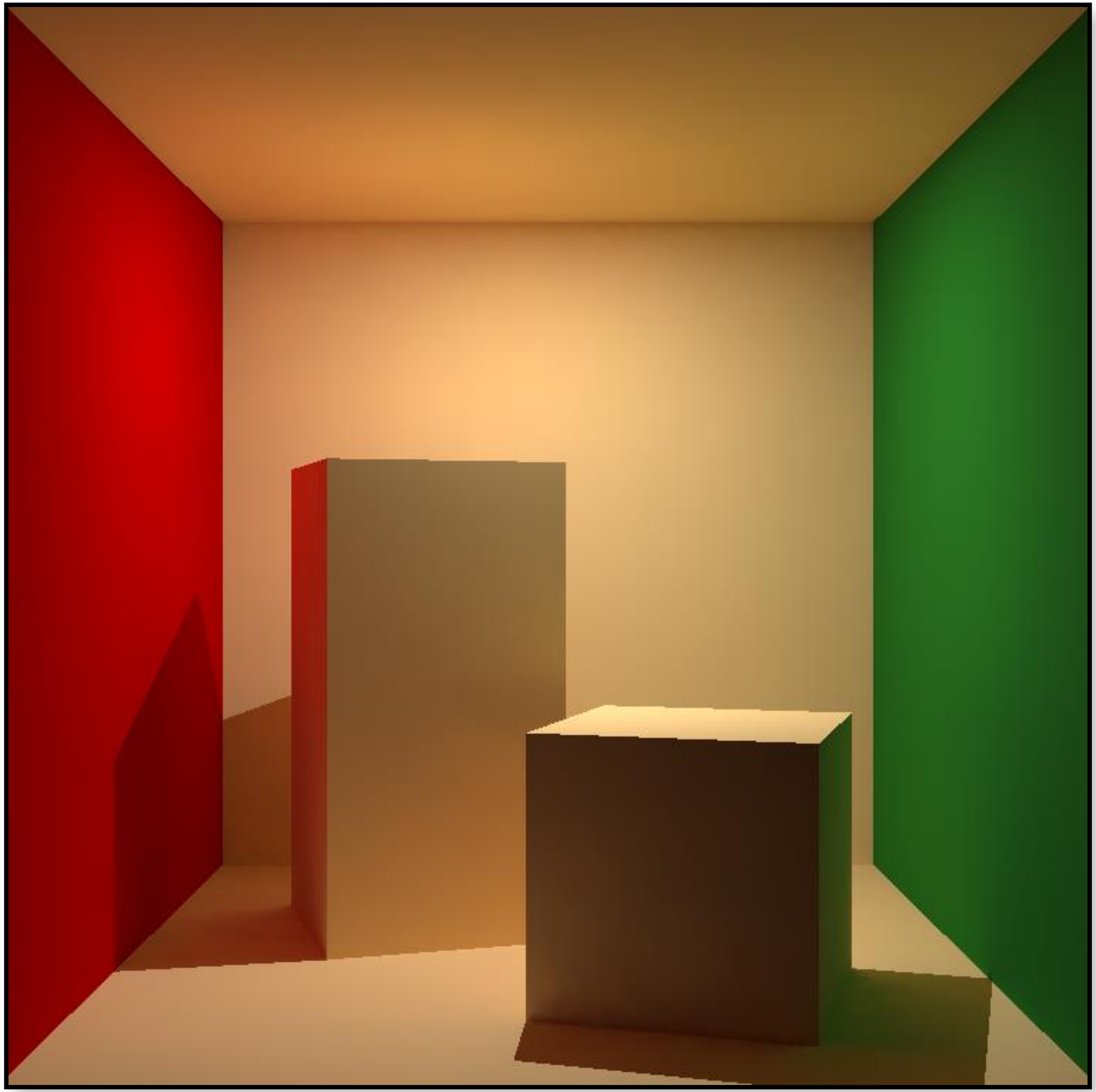
Shading



Direct Illumination

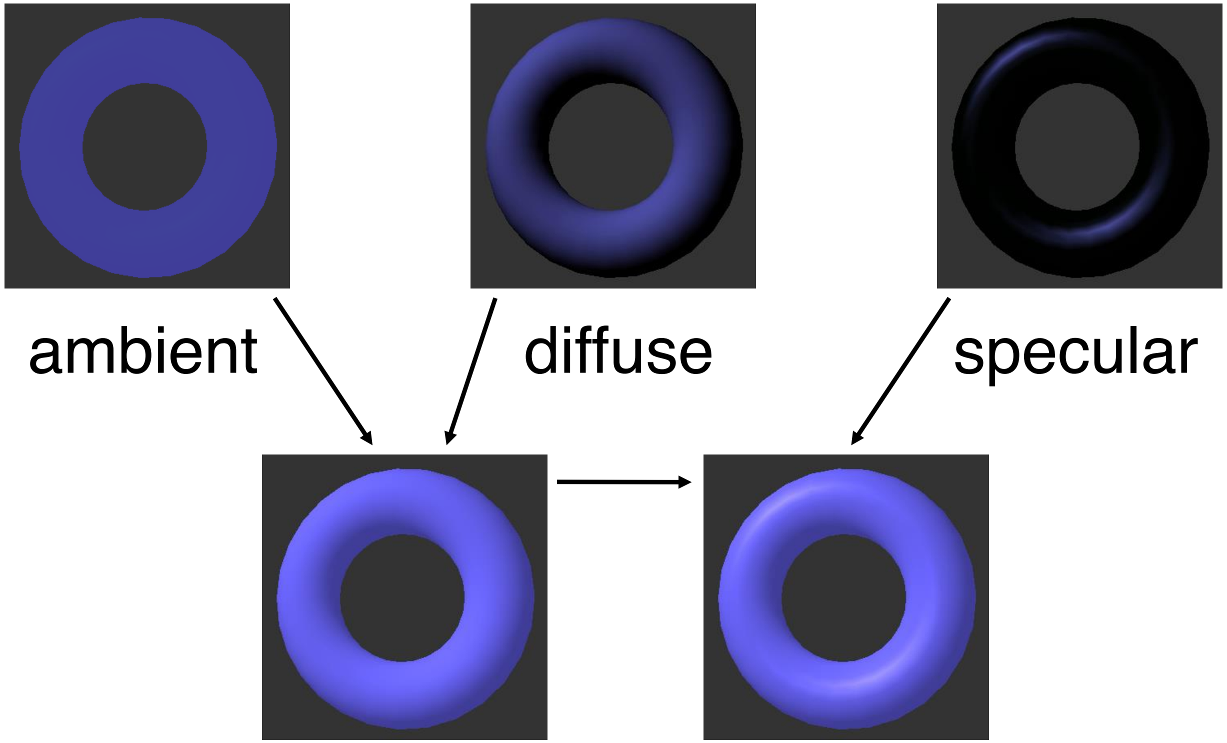


Direct + Indirect Illumination



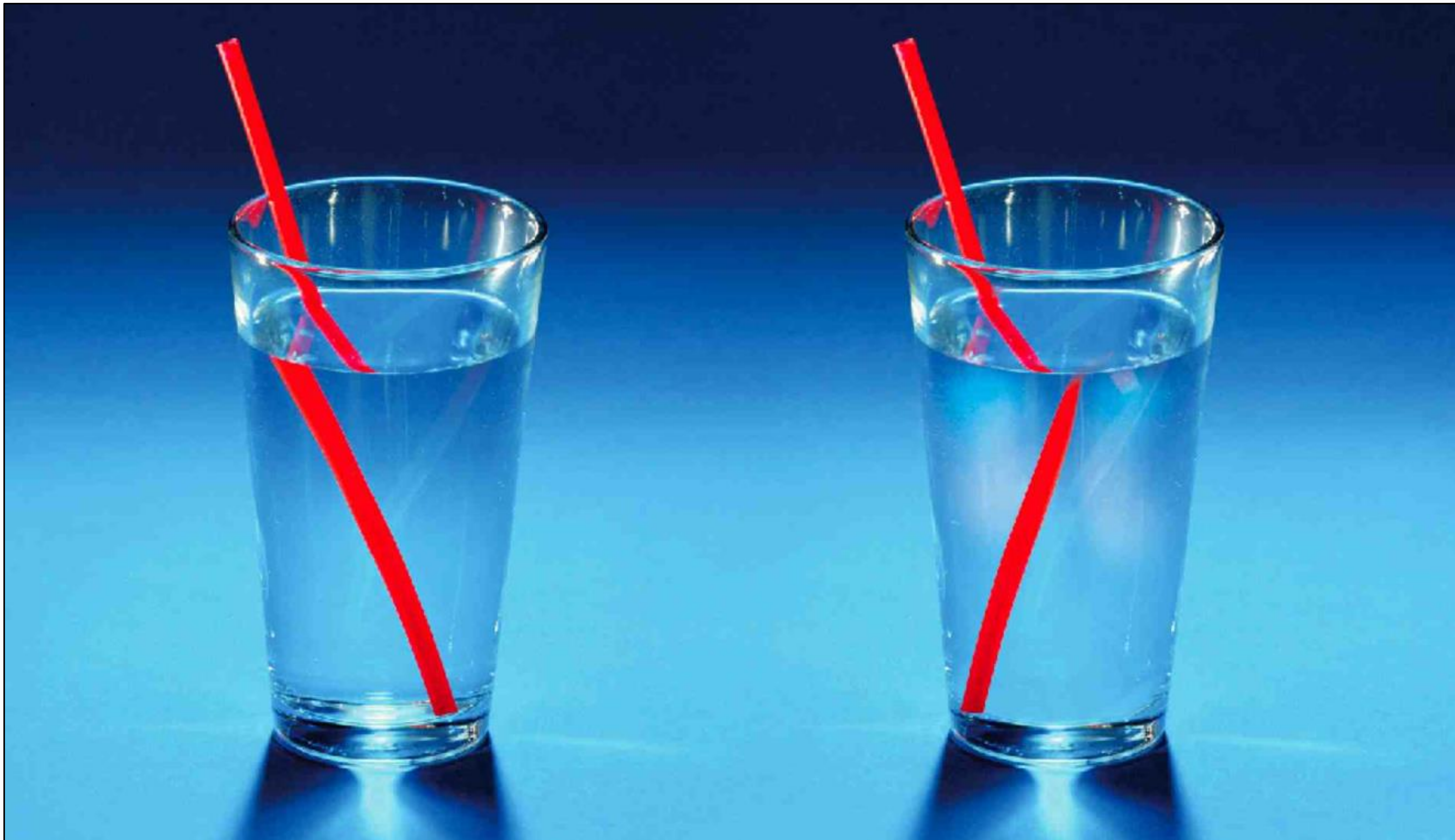
Shading

- Simple shading model



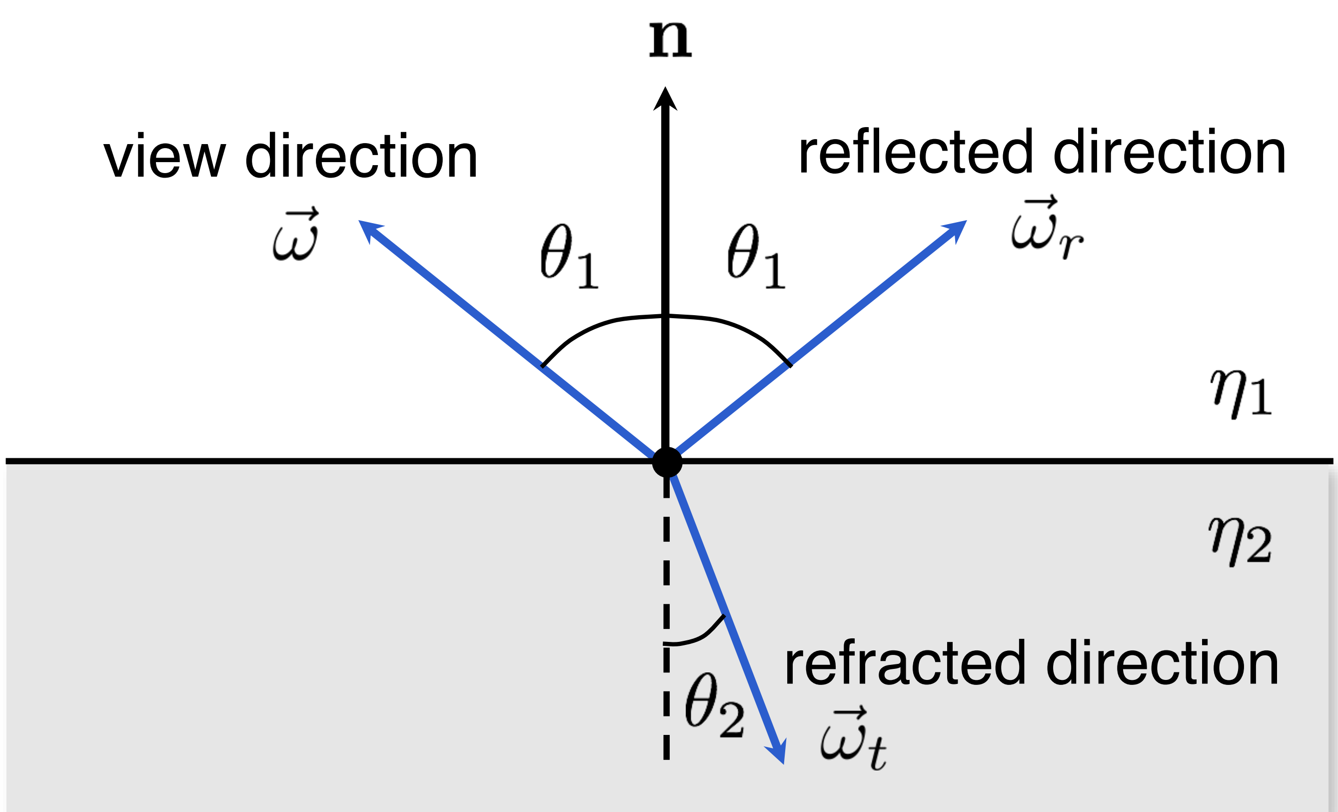
Diffuse Shading

Specular Refraction



Specular Refraction

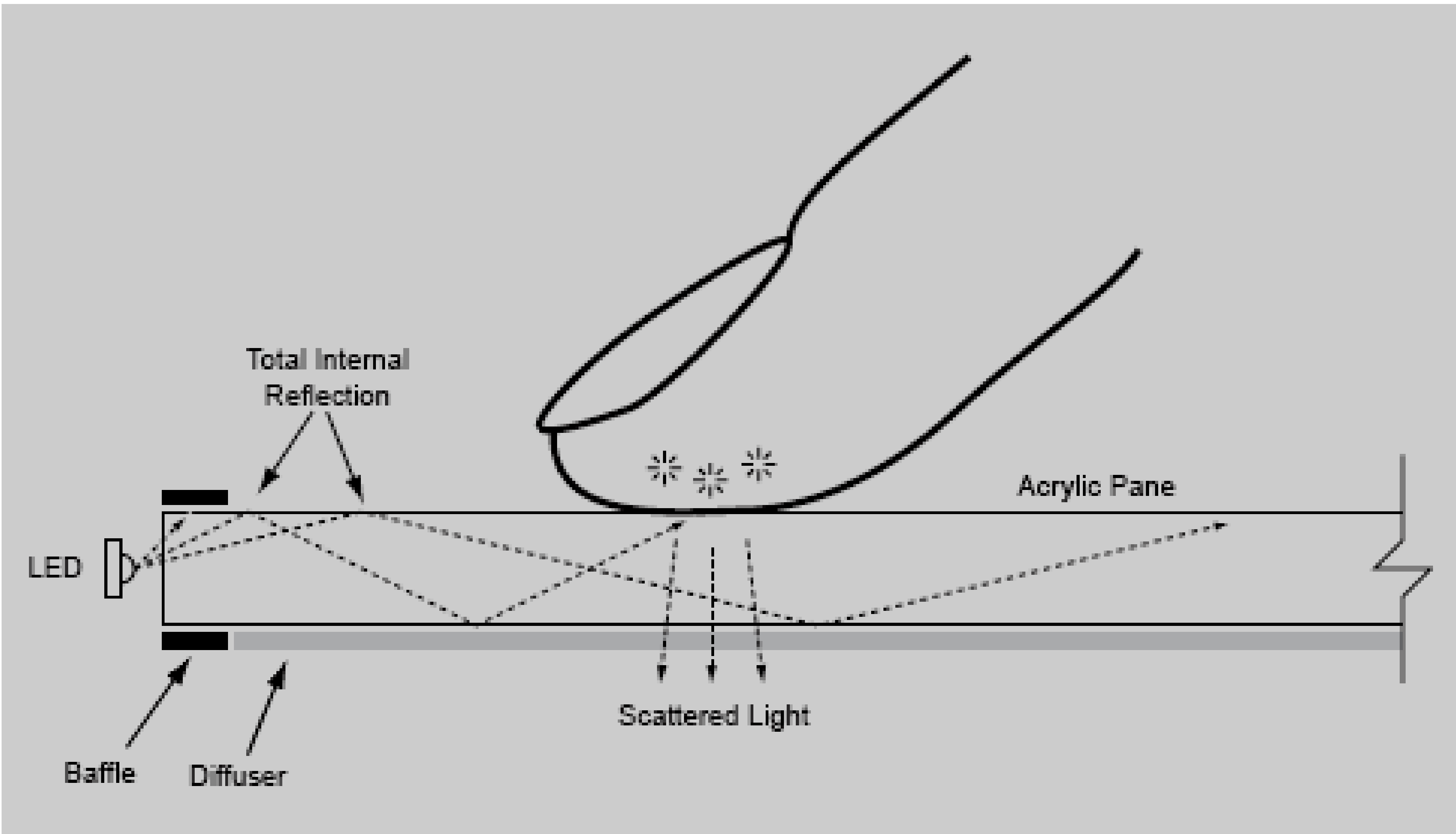
- Snell's law



$$\eta_1 \sin\theta_1 = \eta_2 \sin\theta_2$$

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

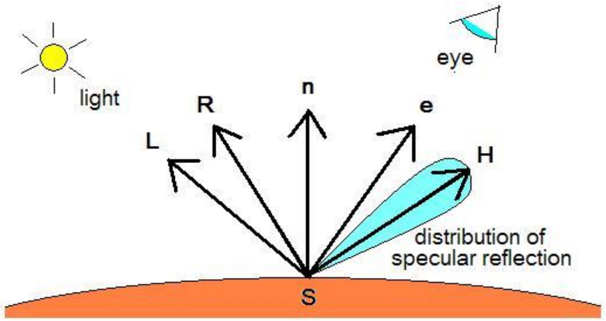
Total Internal Reflection



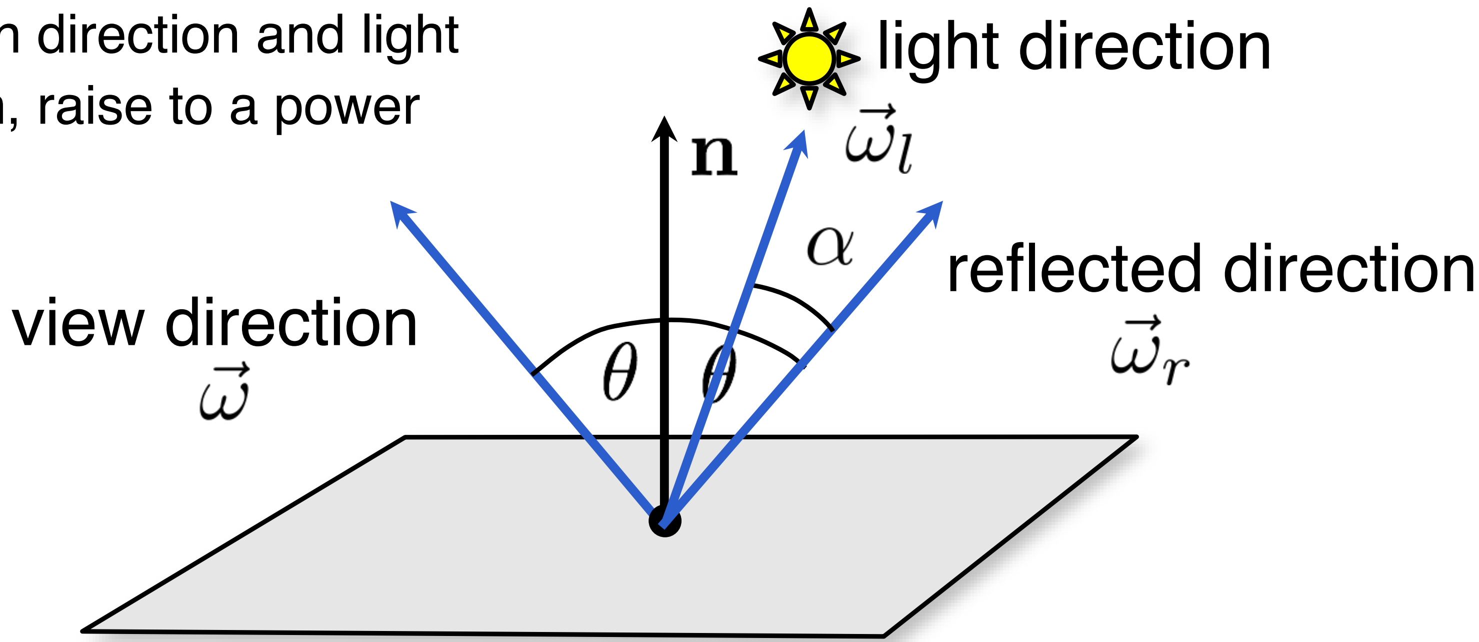
Tomatoes

Simulating Highlights

- Problem: Point light sources
- Solution: Blurry reflection of light source



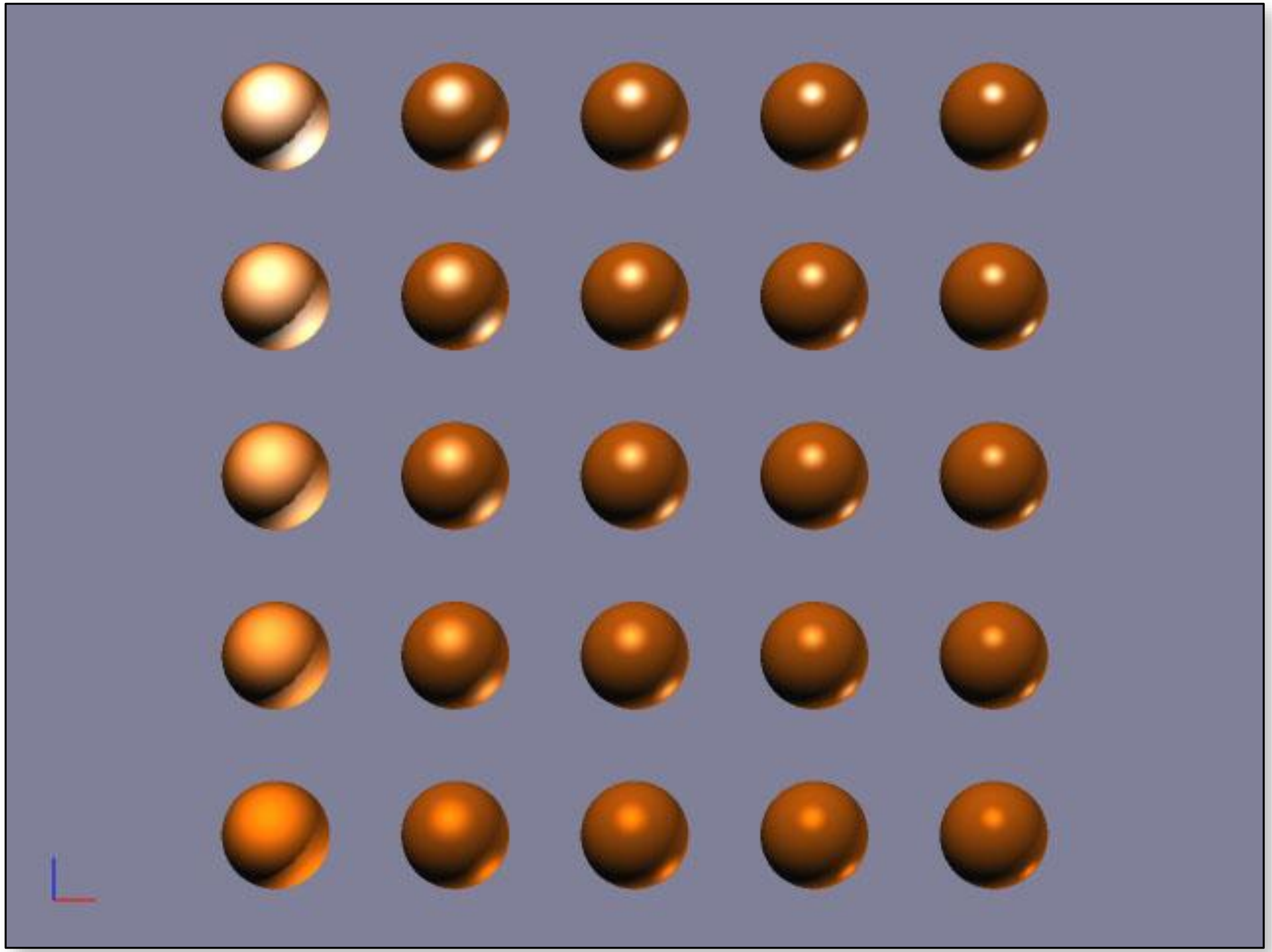
- Phong model
  - compute cosine of angle between reflection direction and light direction, raise to a power



$$L_s(\mathbf{x}, \vec{\omega}) {+}{=}\; k_s \frac{\cos^n \alpha}{\vec{\mathbf{n}} \cdot \vec{\omega}_l} E = k_s \frac{(\vec{\omega}_r \cdot \vec{\omega}_l)^n}{\vec{\mathbf{n}} \cdot \vec{\omega}_l} E$$

Specular Highlights

- Phong model
  - “shininess” parameter



Computer Graphics

Ray Tracing II

Acceleration Structures

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Some images borrowed from Pharr and Humphreys

Physically Based Rendering 2010

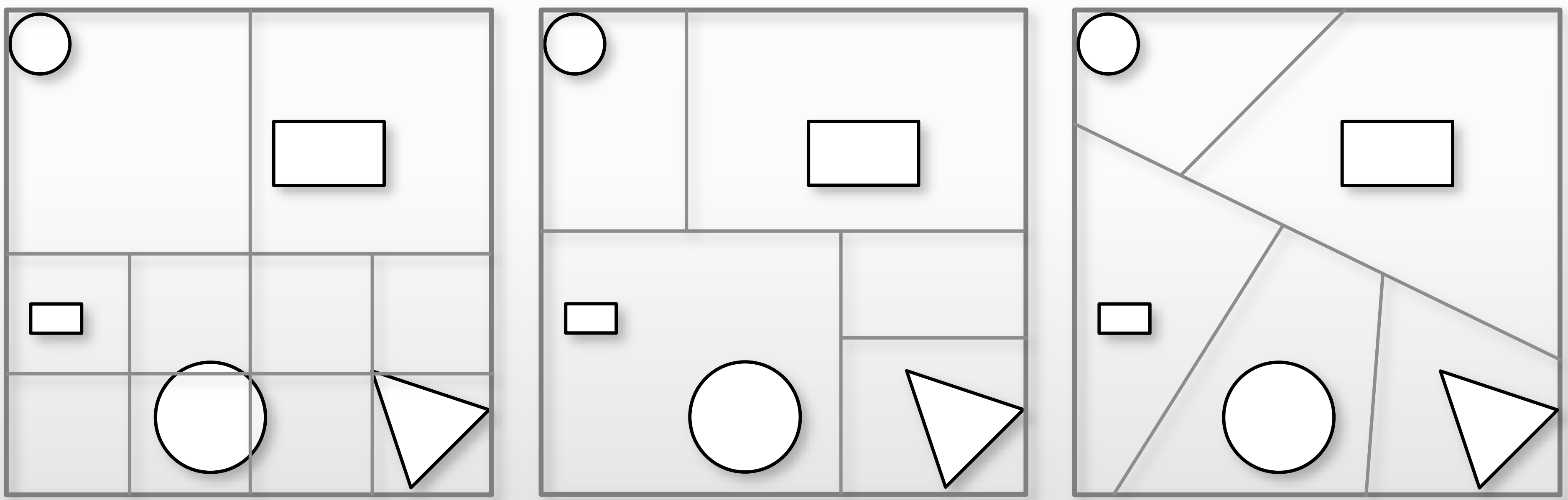
ETH

Eidgenössische Technische Hochschule Zürich

Swiss Federal Institute of Technology Zurich

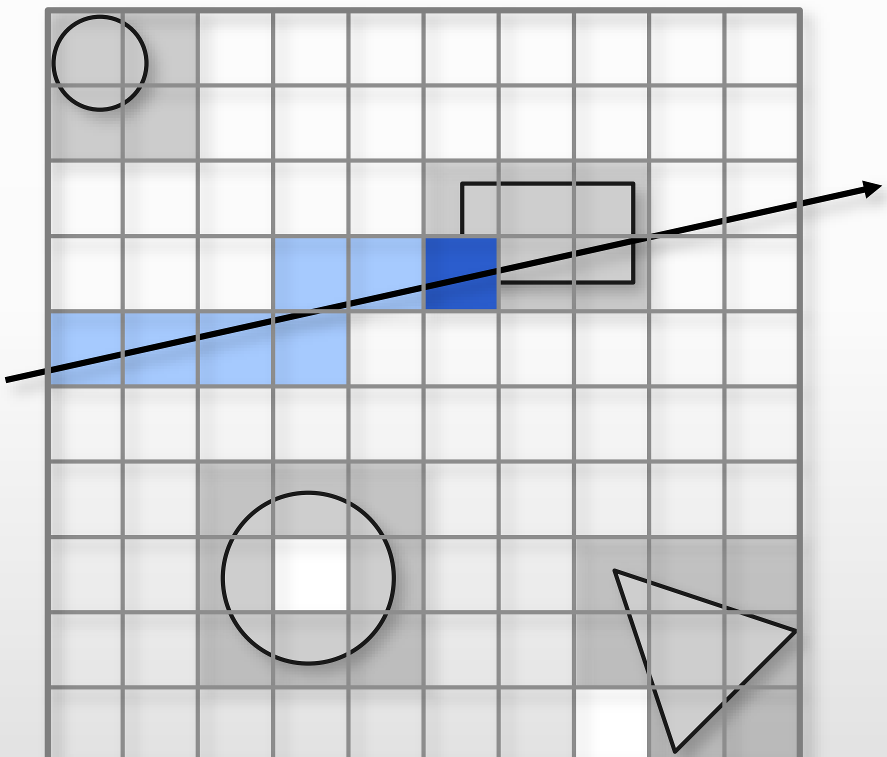
Spatial Hierarchies

- Classical divide-and-conquer approach
- Several variations

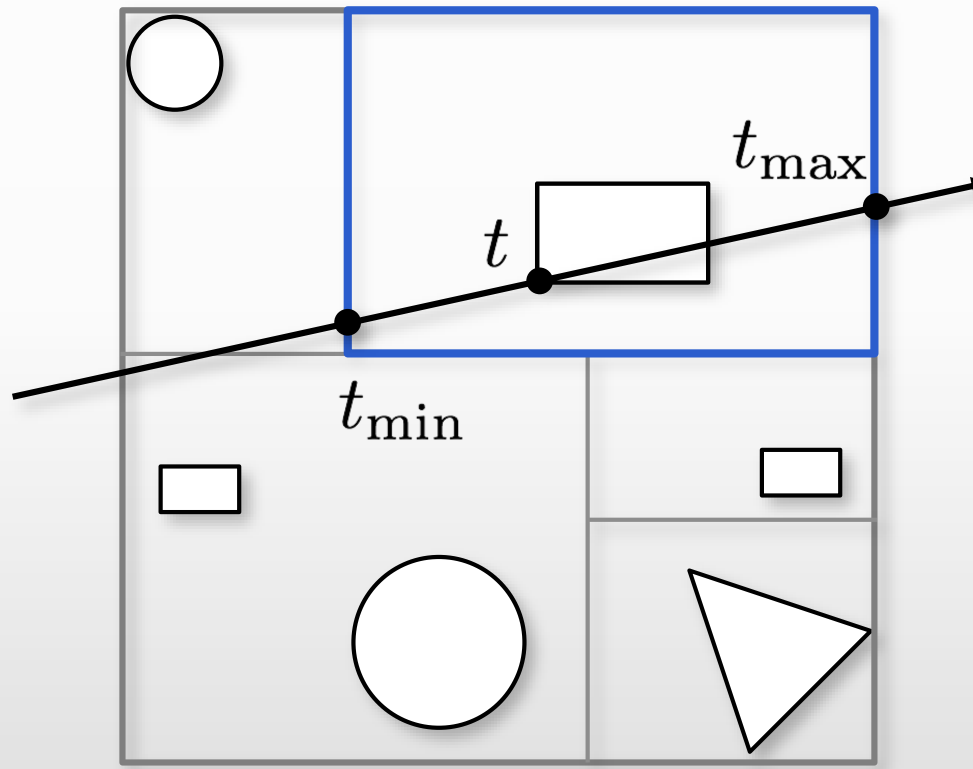


octree kd-tree bsp-tree

Comparison

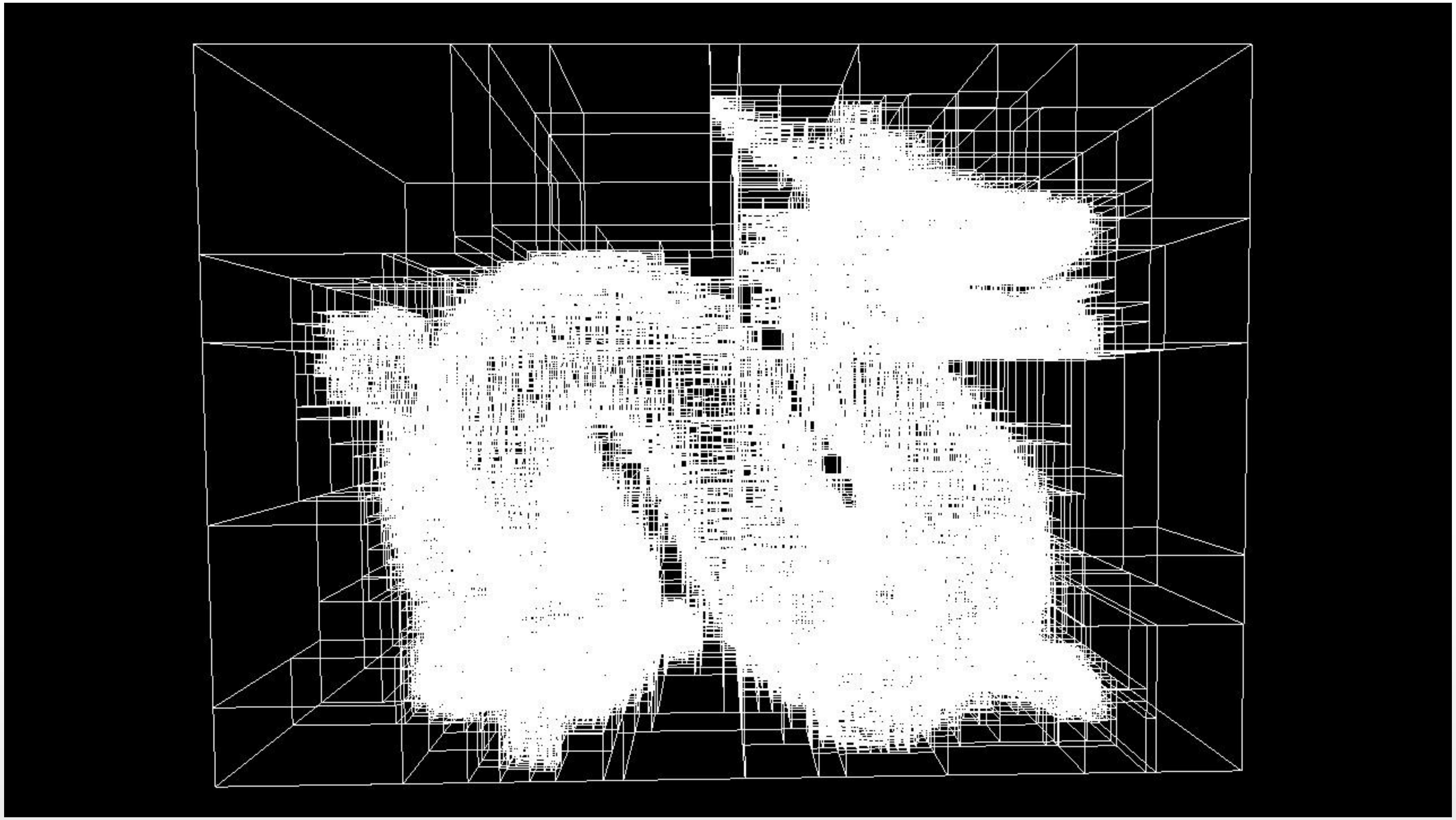


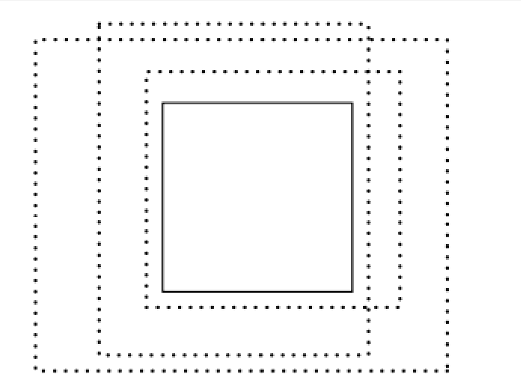
uniform grid



kd-tree

KD-Tree

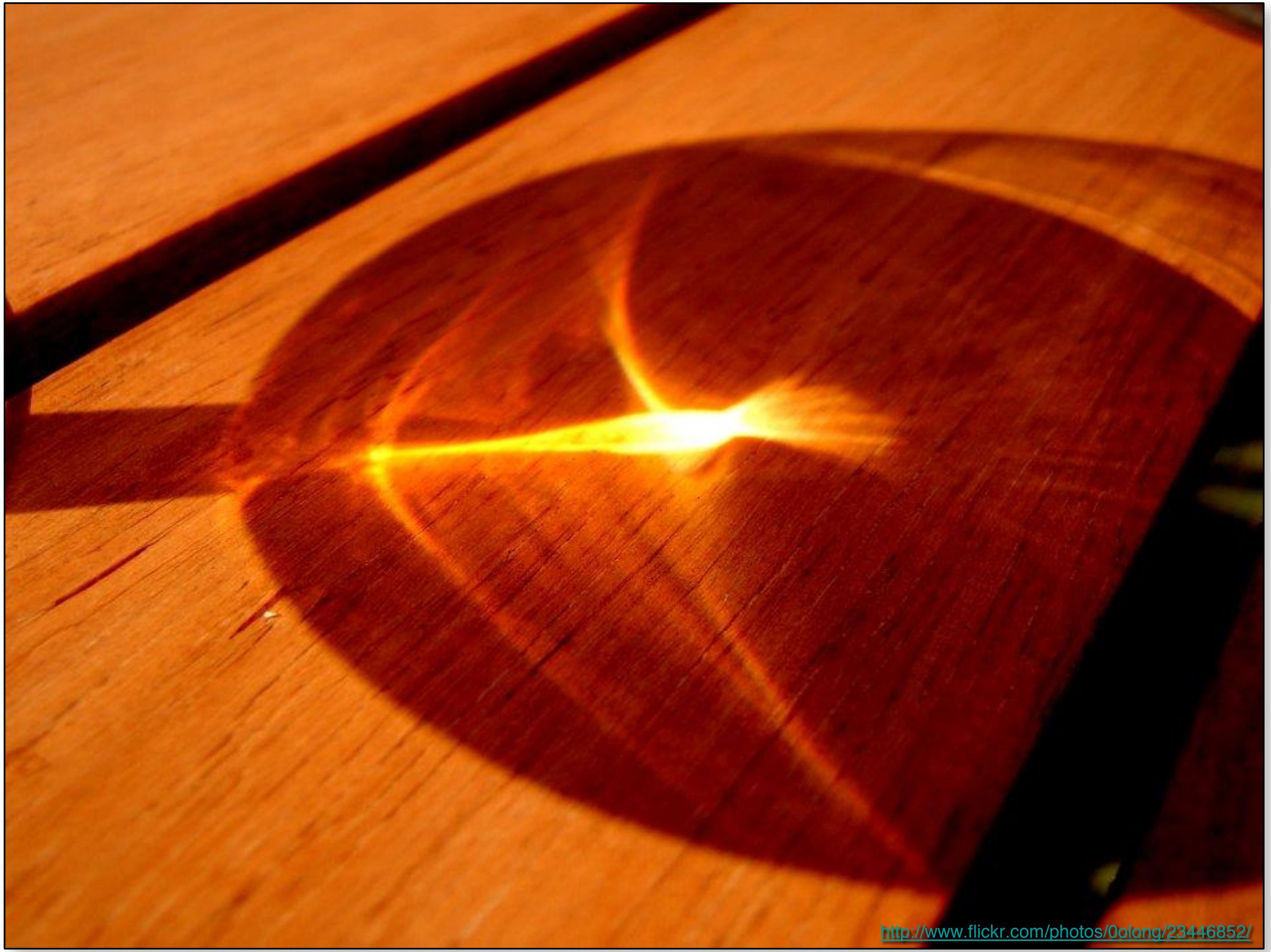




- Worst case scenario?

Participating Media (Fog)

Caustics Are Pretty



http://www.flickr.com/photos/33351978@N00/271590472/

Advanced Effects

- Subsurface Scattering

Henrik Jensen

UC San Diego