6.A44 Computational Photography

Frédo Durand

Light, exposure and dynamic range

- **Exposure: how bright is the scene overall**
- **Dynamic range: contrast in the scene**

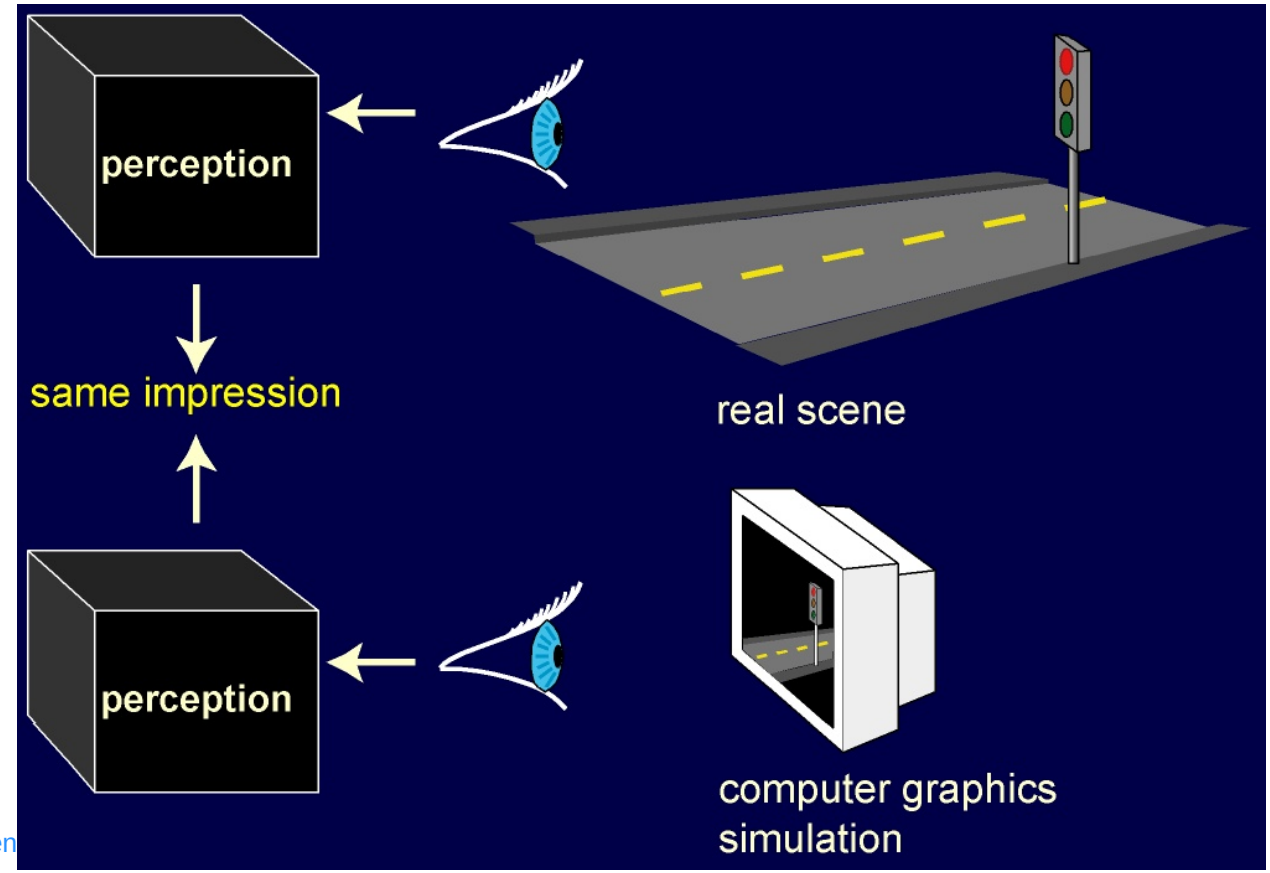
- **Bottomline problem: illumination level and contrast are not the same for a photo and for the real scene.**

Example:

- Photo with a Canon G3
- Jovan is too dark
- Sky is too bright

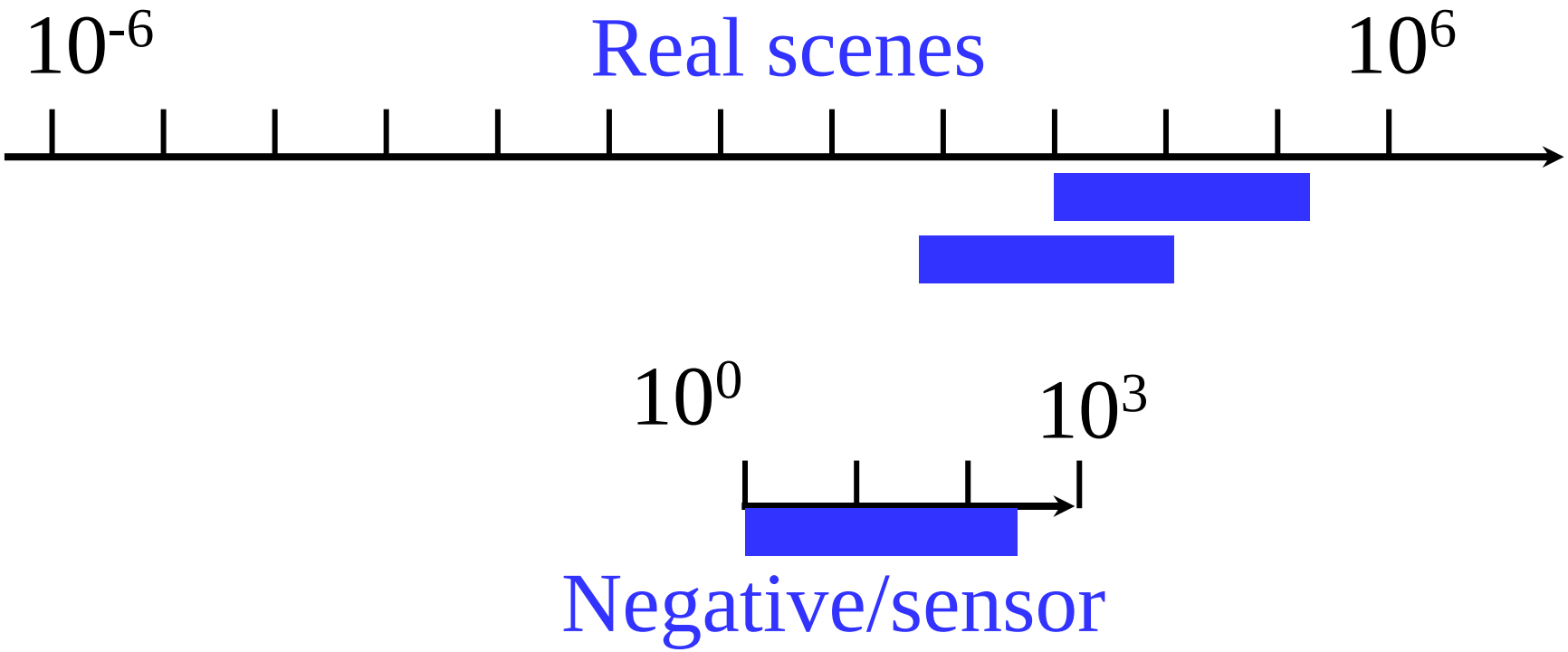
Tone mapping

- **Bottomline problem: illumination level and contrast are not the same for a photo and for the real scene.**
- **Goal: Reproduce a faithful impression**



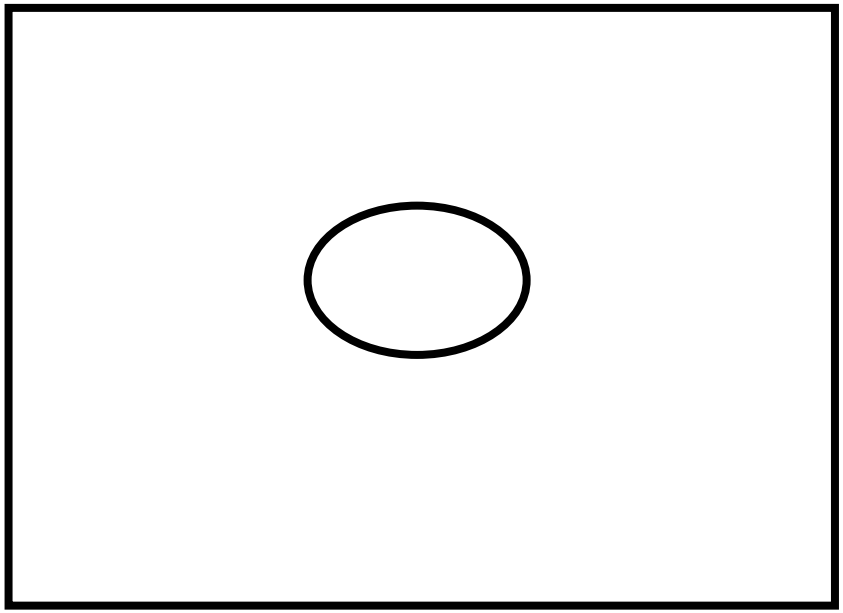
Problem 1

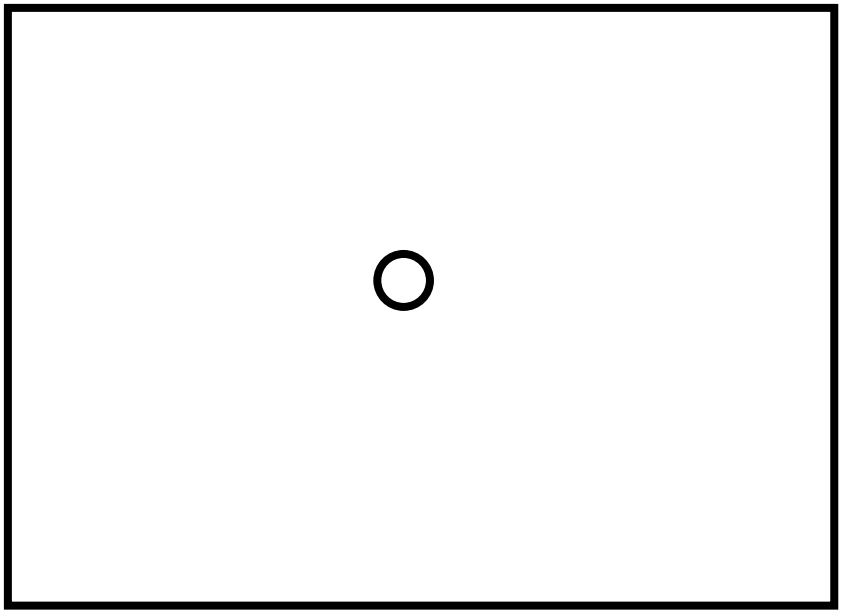
- **The range of illumination levels that we encounter is 10 to 12 orders of magnitudes**
- **Negatives/sensors can record 2 to three orders of magnitude**
- **How do we center this window? Exposure problem.**



Metering: measuring scene brightness

- **Centered average**
- **Spot**
- **Incident**
  - Measure incoming light





Nikon 3D Color Matrix

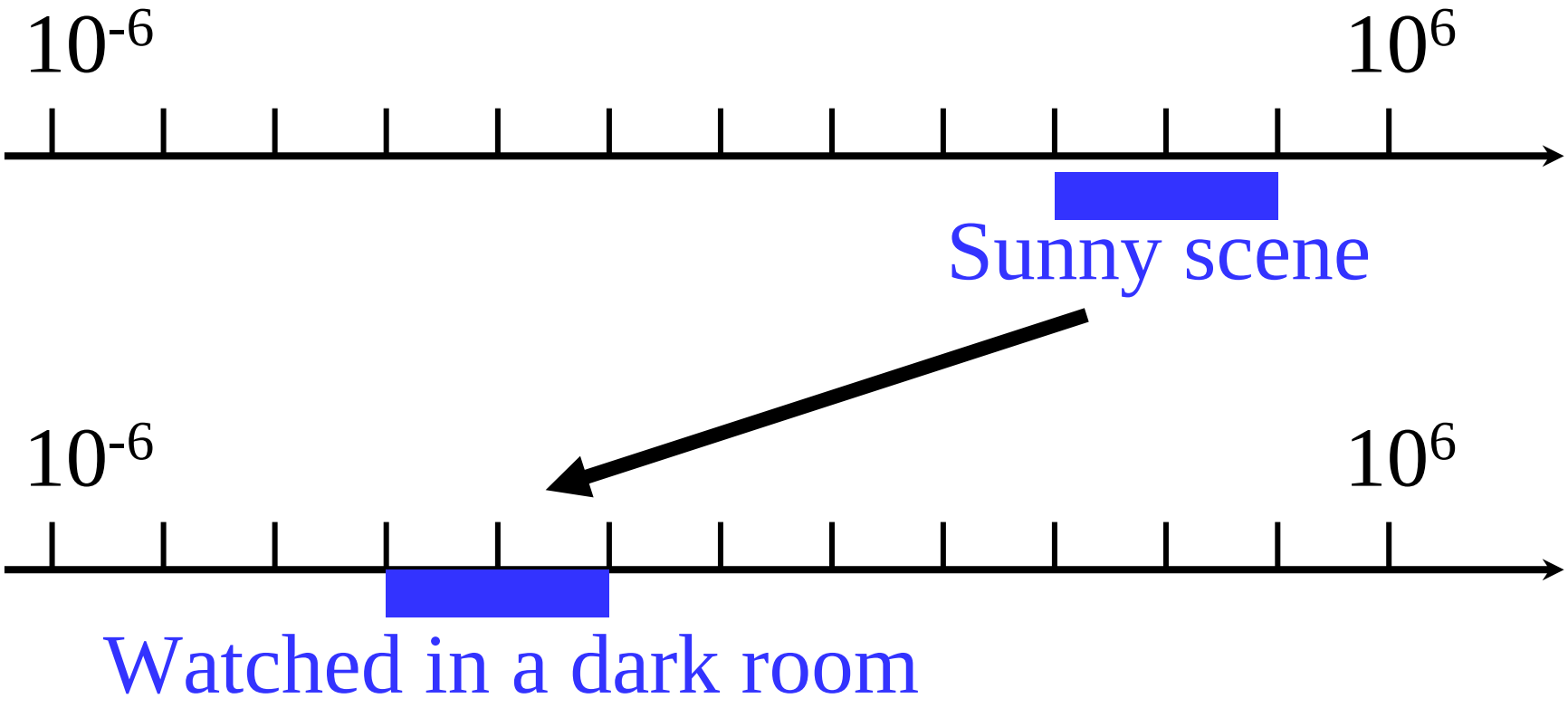
- **Database of 30,000 photos**
- **Multiple captors (segments)**
- **Exposure depends on**
  - Brightness from each segments
  - Color
  - Contrast
  - Distance
  - Focus (where is the subject)

Bracketing

- **Takes 2 or three pictures around the automatic exposure**

Problem 2

- **The image intensity does not match the real conditions**



Hunt and Stevens effect

- **Stevens effect**
  - Contrast increases with luminance

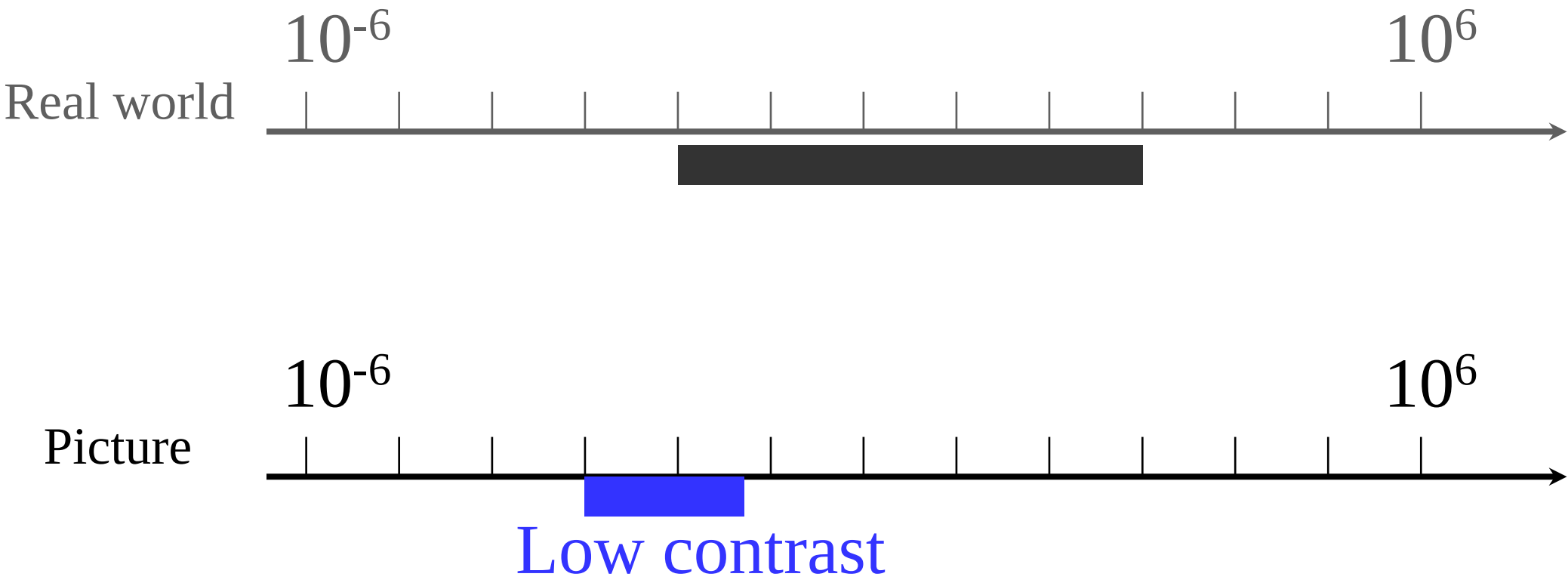
Hunt and Stevens effect

- **Stevens effect**
  - Contrast increases with luminance
- **Bartleson-Breneman effect**
  - Image contrast changes with surround
  - A dark surround decreases contrast
    (make the black of the image look less deep)
- **Hunt effect**
  - Colorfulness increases with luminance

- **Hence (one of) the need for gamma correction**

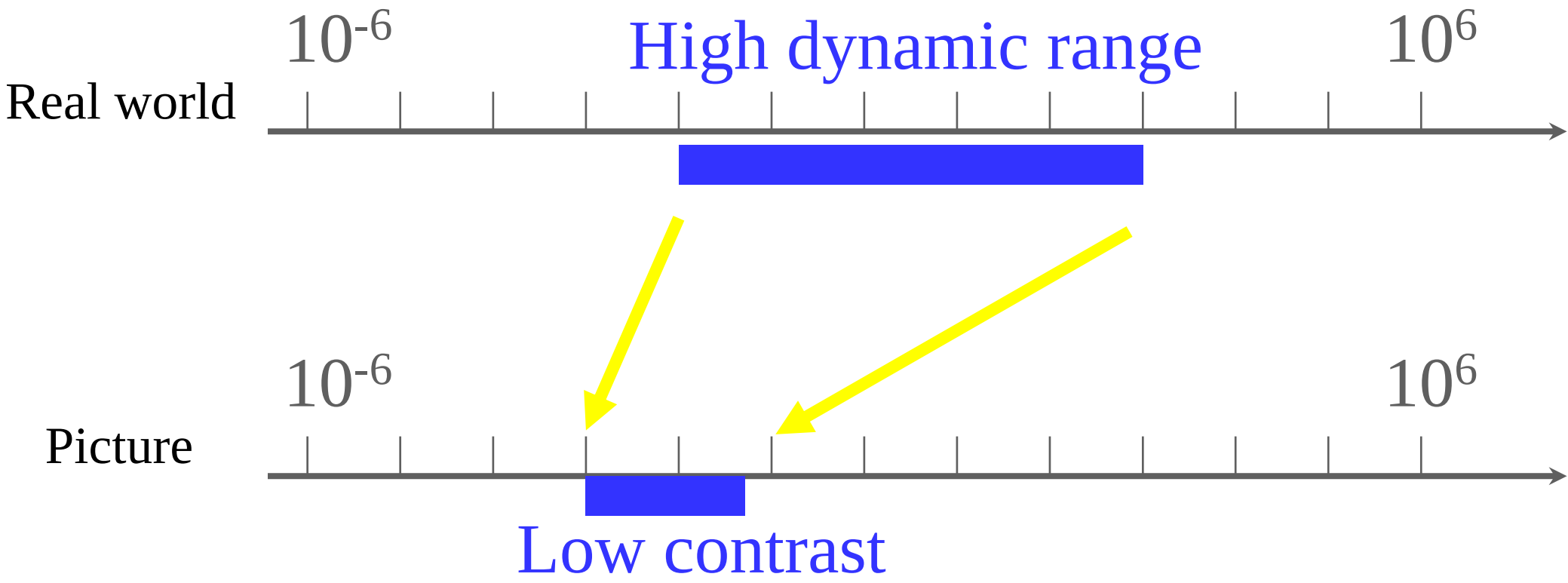
Problem 3: Picture dynamic range

- **Typically 1: 20 or 1:50**
  - Black  is ~ 50x darker than white 
- **Max 1:500**



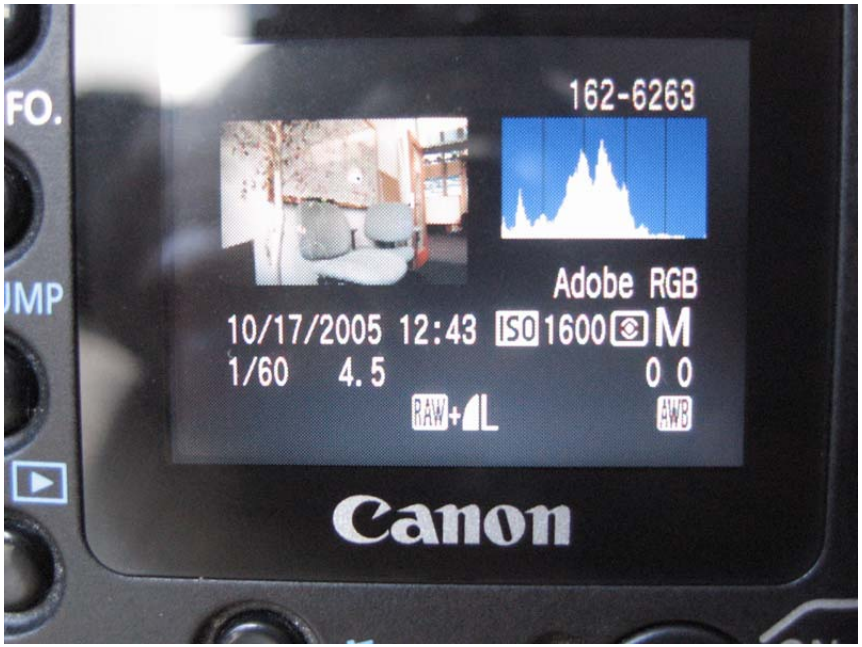
Contrast reduction

- **Match limited contrast of the medium**
- **Preserve details**



Histogram

- See http://www.luminous-landscape.com/tutorials/understanding-series/understanding-histograms.shtml
- http://www.luminous-landscape.com/tutorials/expose-right.shtml
- Horizontal axis is pixel value
- Vertical axis is number of pixels



Highlights

- **Clipped pixels (value >255)**
- **Pro and semi-pro digital cameras allow you to make them blink.**

The infamous 8 bits

- **Digital photography**
- **8 bits means 1 to 255 contrast**
- **Enough for display**
- **Not enough for**
  - Editing
  - Tone reproduction
  - Dodging & burning
  - Etc.

The limit of illusion

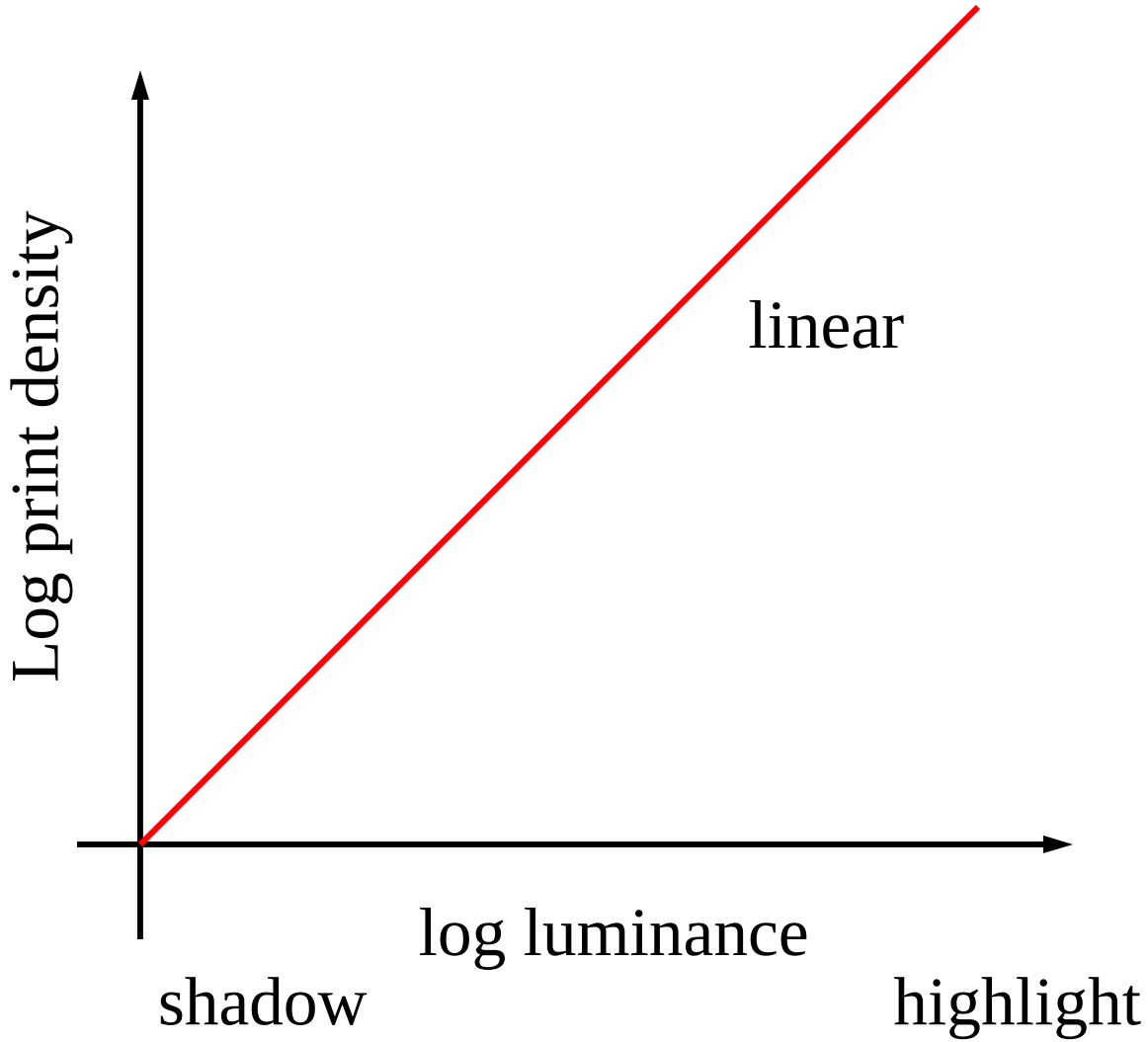
- **Pozzo's ceiling: the Sky is not bright enough**

The limit of illusion

- **Bruneleschi's experiment**
  - Used a mirror for the sky

Tone Reproduction

- **Not linear**



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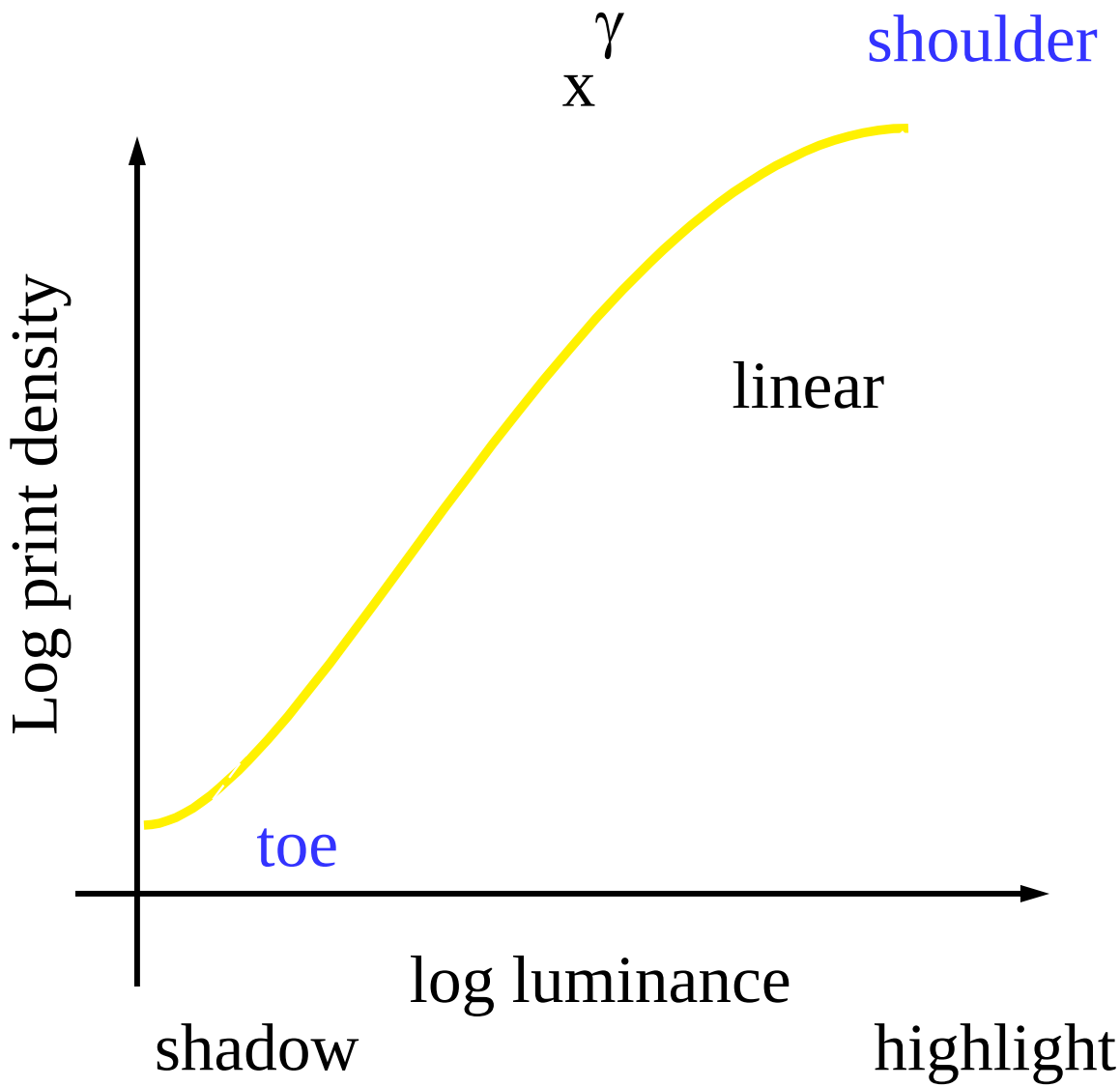
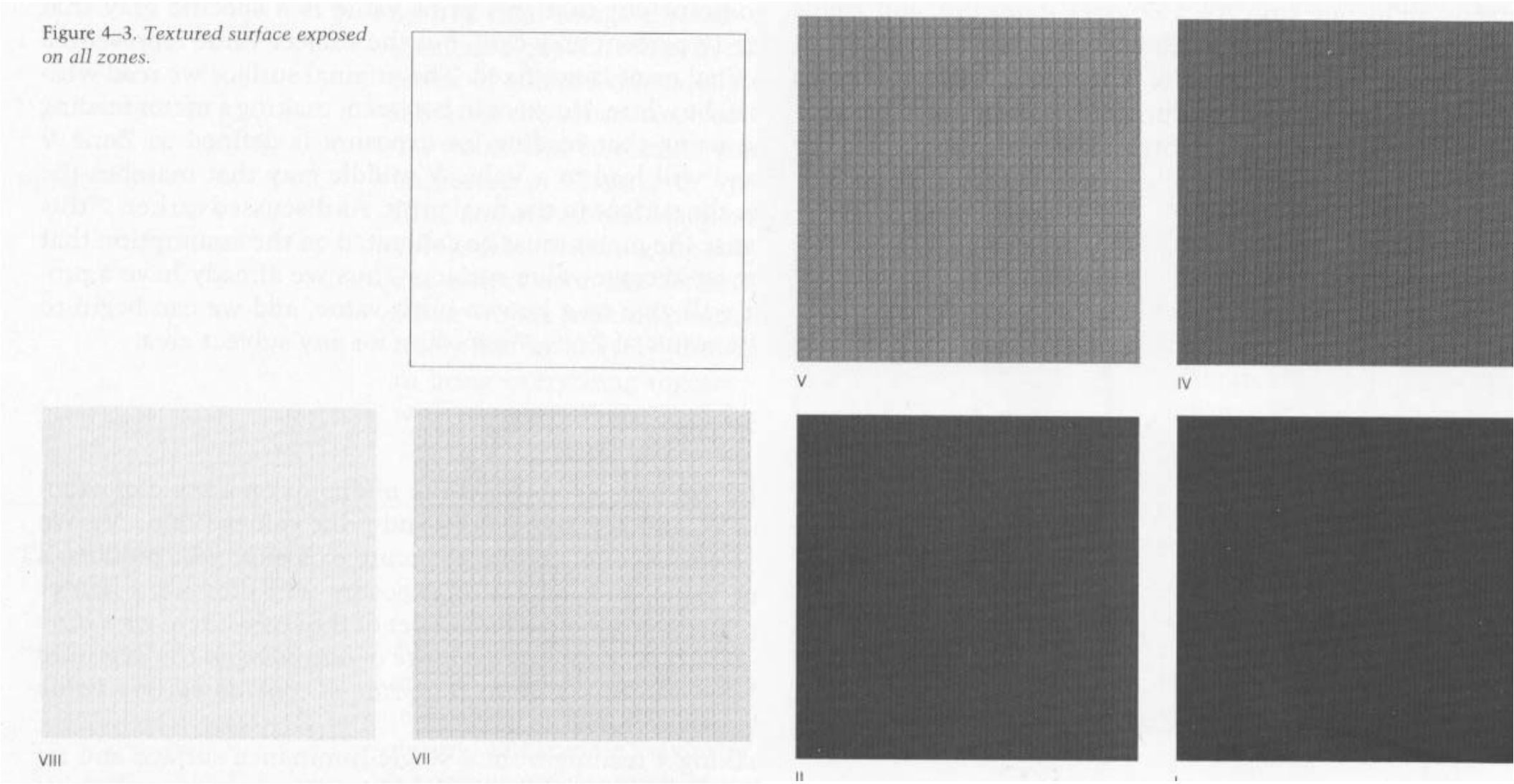
Tone Reproduction

- **Not linear**
- **Gamma correction**



Texture and contrast



The Zone System

The Zones

0 Solid black; the same as the film rebate

I Nearly black; just different from Zone 0

II The first hint of texture

III Textured shadow; the first recognizable shadow detail

IV Average shadow value on Caucasian skin, foliage and buildings

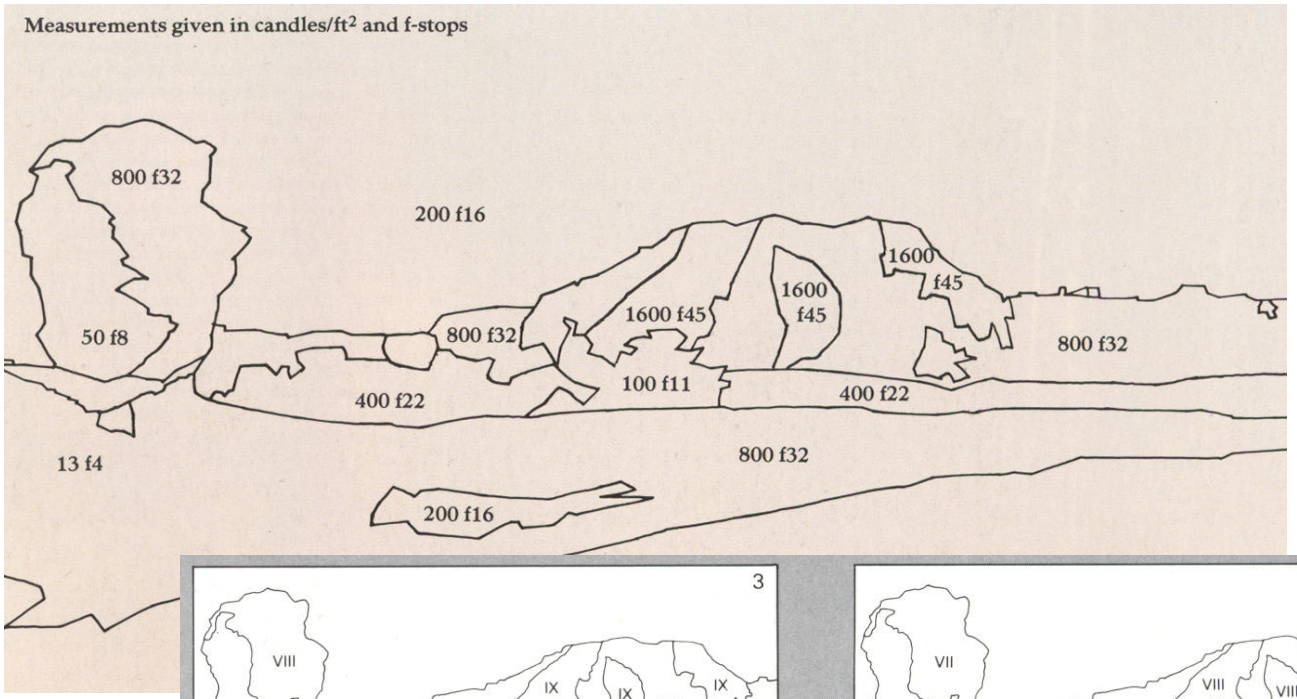
V Middle grey: the pivot value; light foliage, dark skin

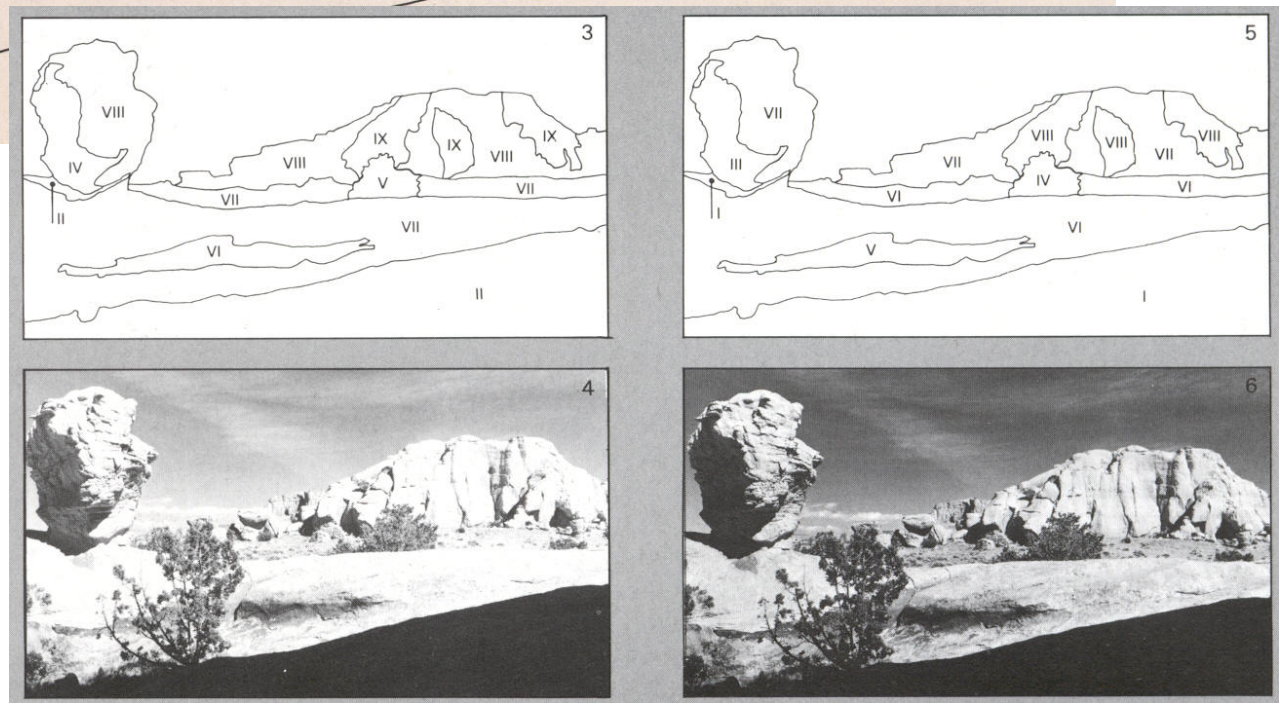
VI Caucasian skin, textured light grey; shadow on snow

VII Light skin; bright areas with texture, such as snow in low sunlight

VIII Highest zone with any texture

IX Pure untextured white





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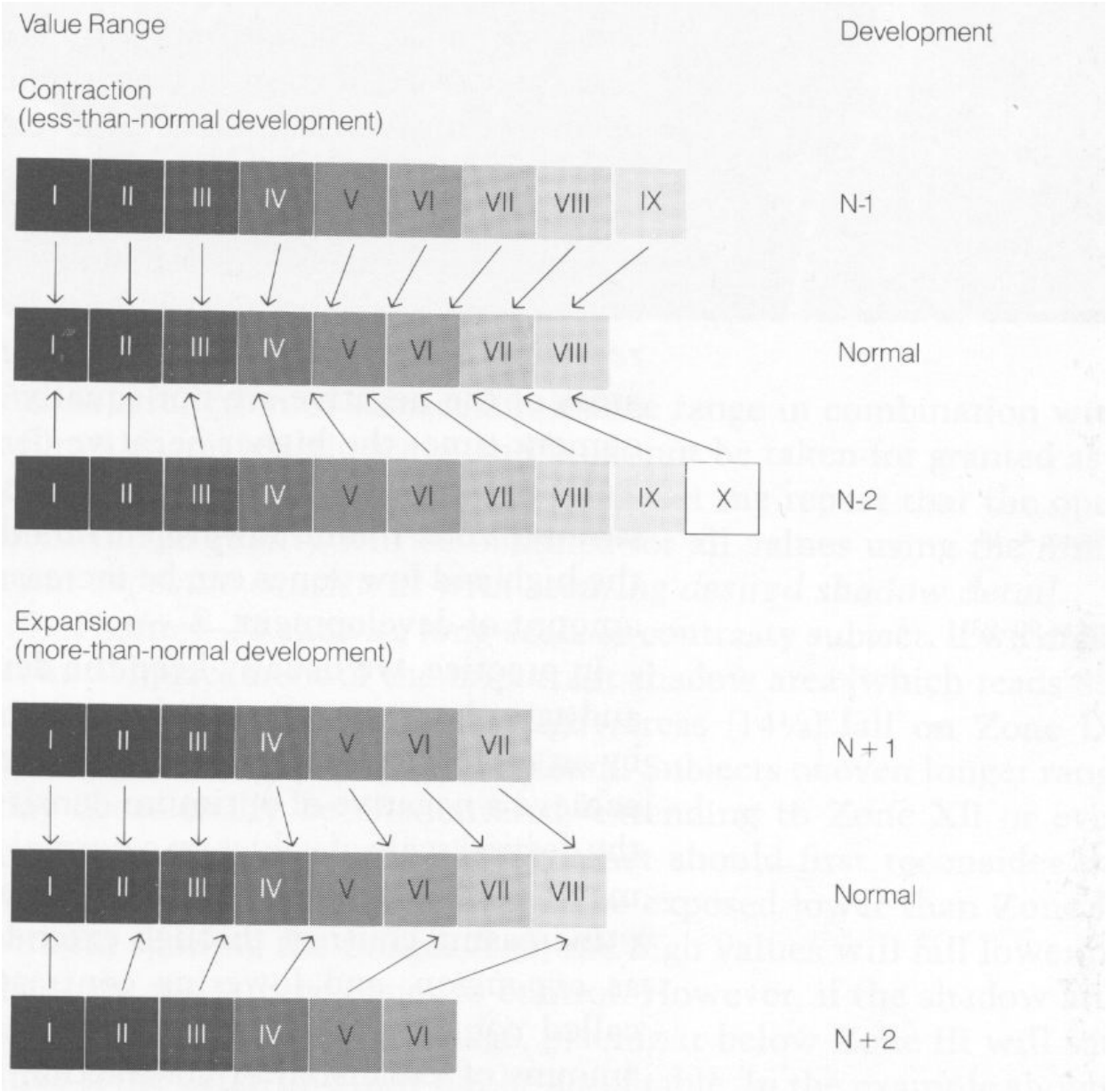
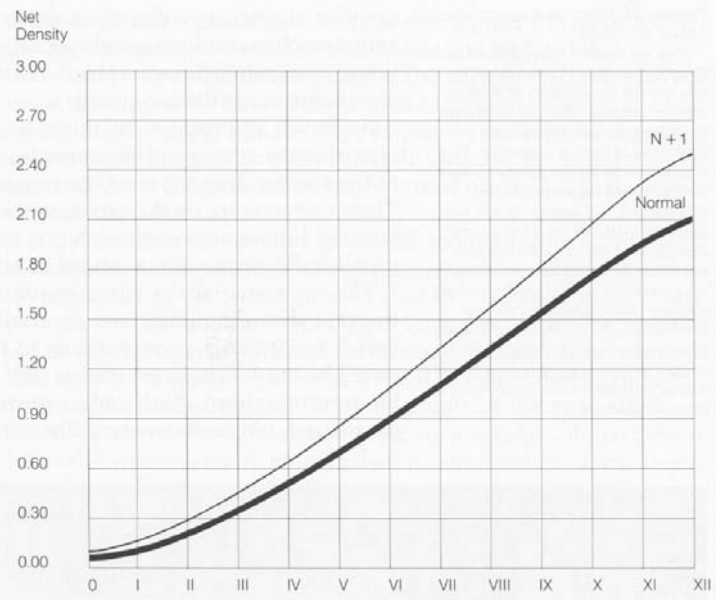
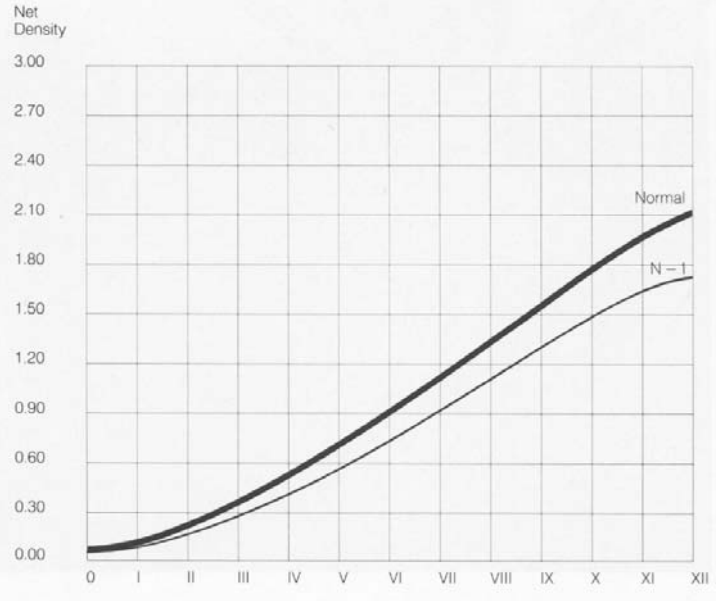
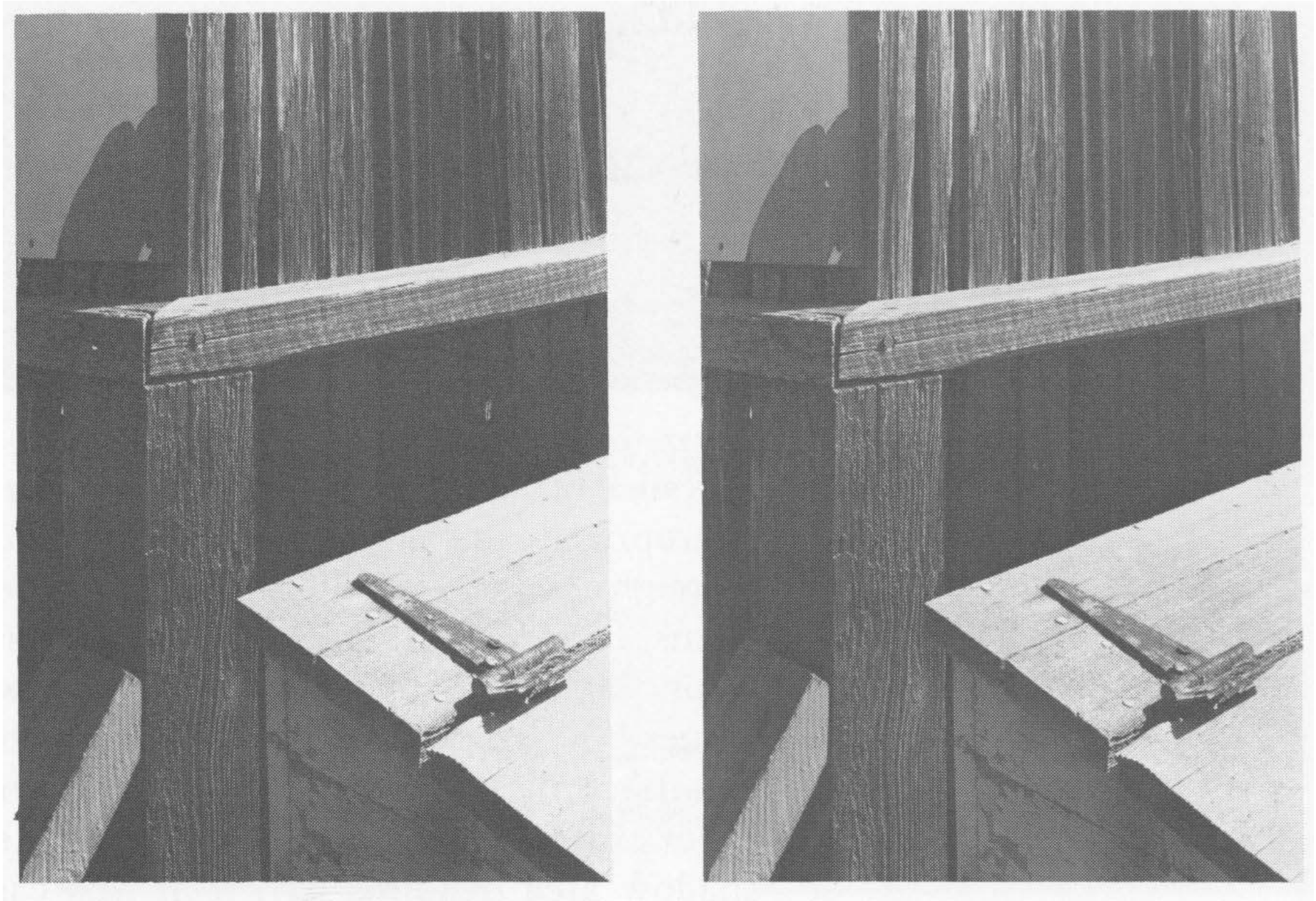
Expansion and contraction







Contraction



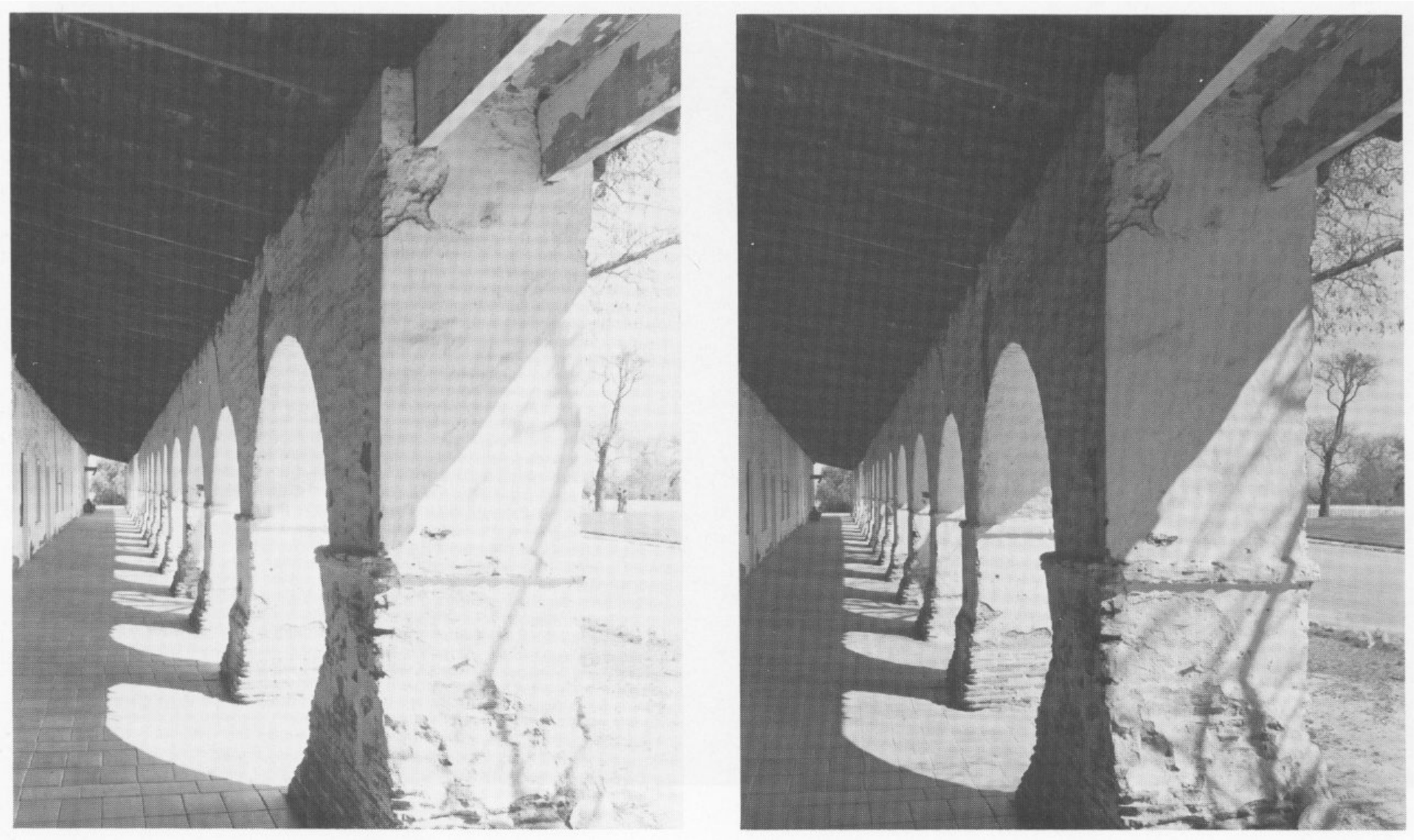
Pre- exposure

- **Expose with uniform white before taking the photo**
- **Raise the dark tones**

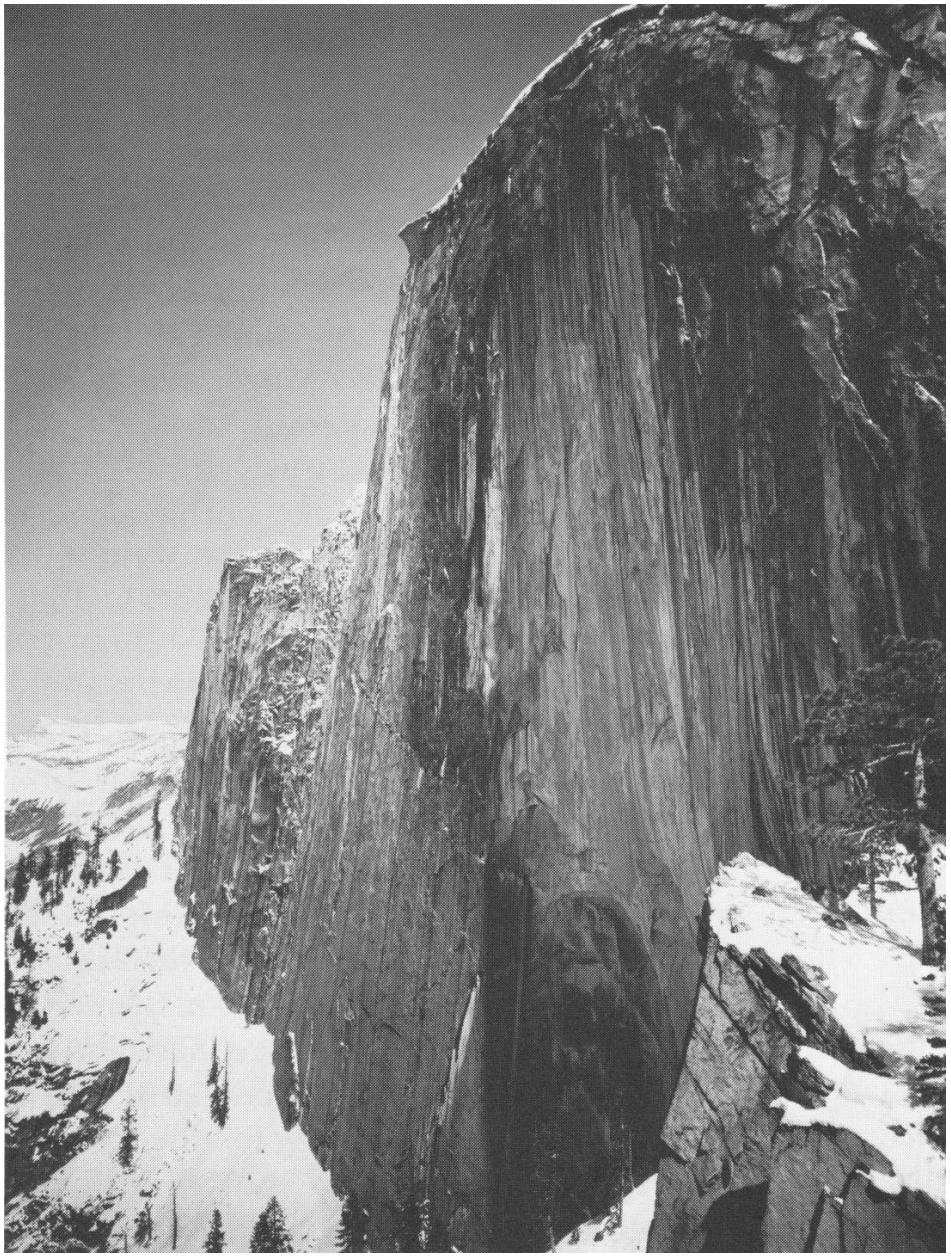
Pre- exposure

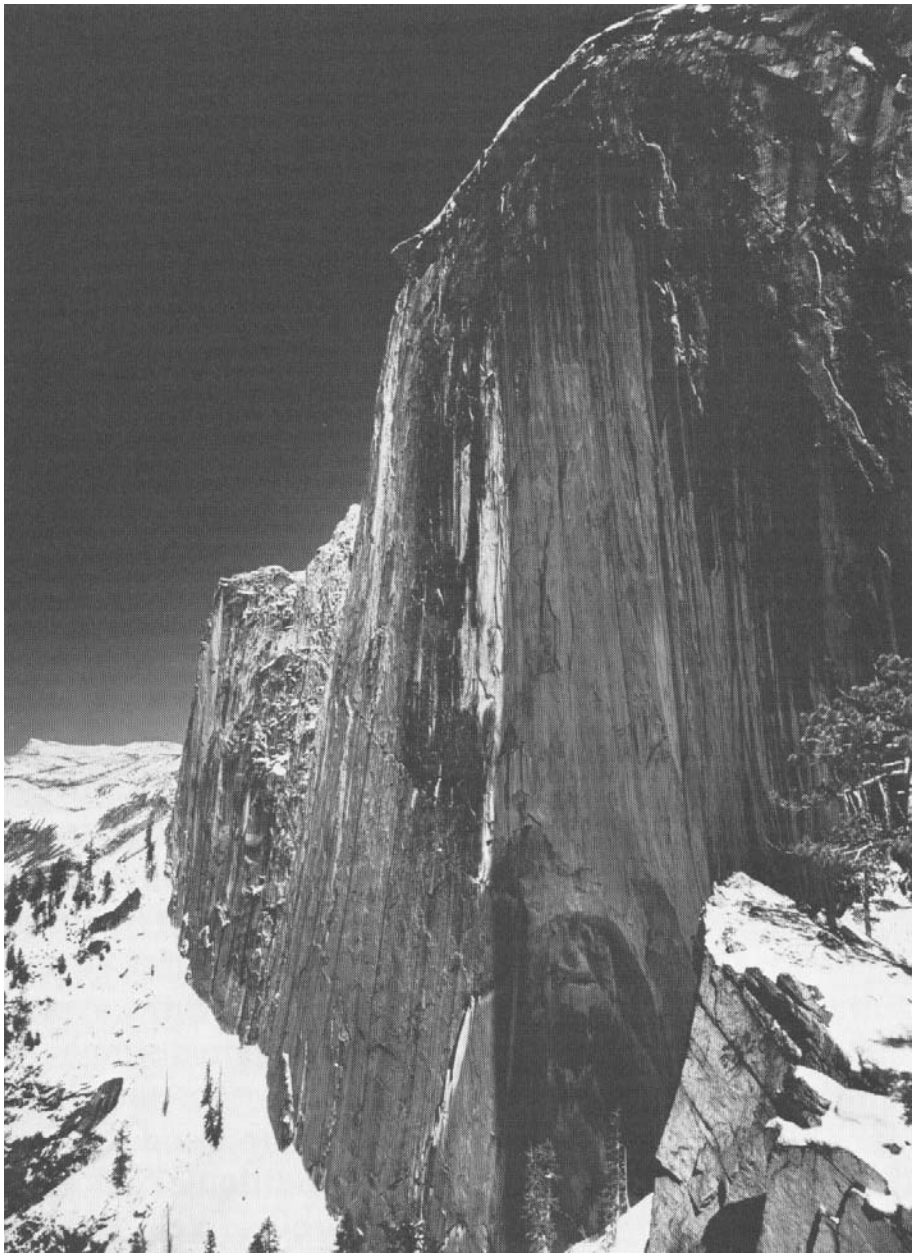
Two-solution development

- **Different development of high and low value**



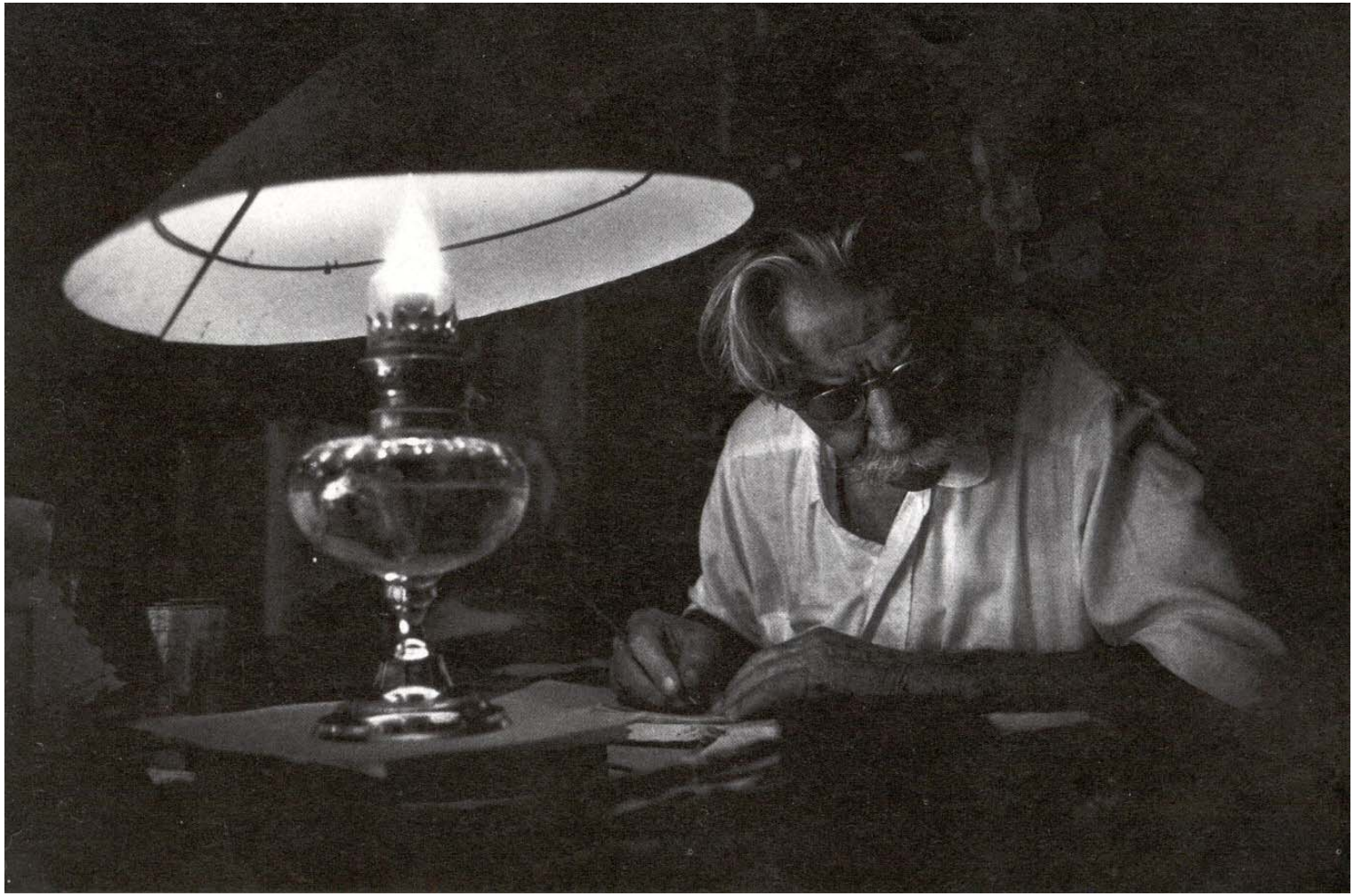
Red Filter





The Print

- **W. Eugene Smith photo of Albert Schweitzer**
- **5 days to print!**



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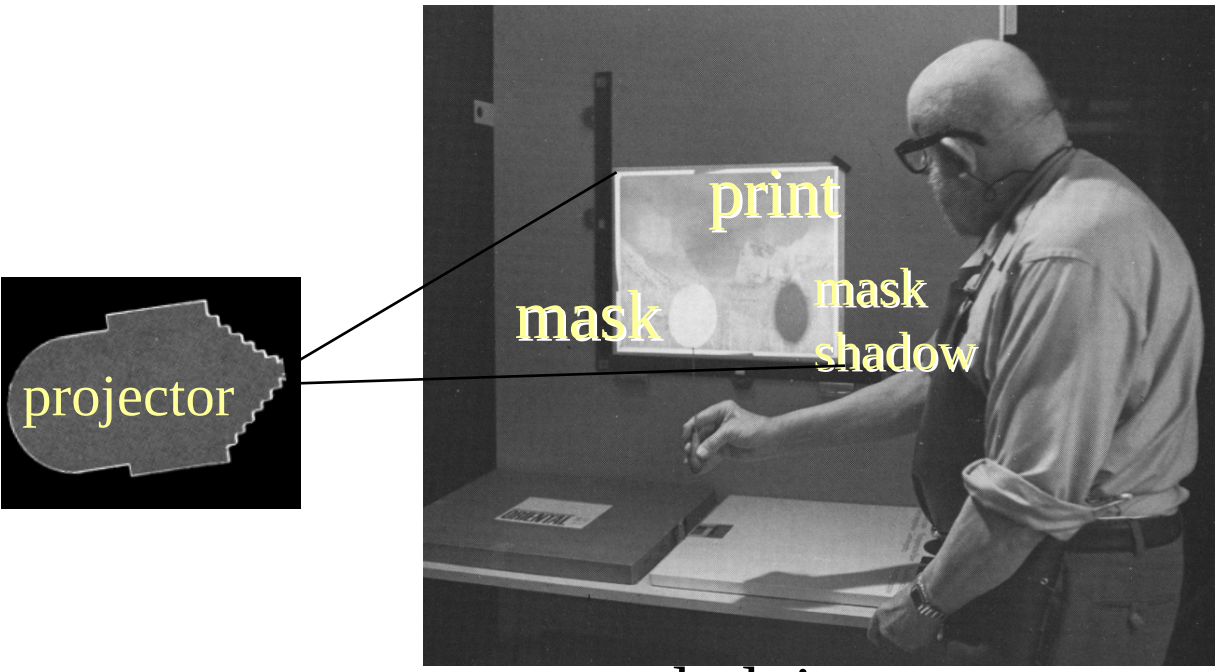
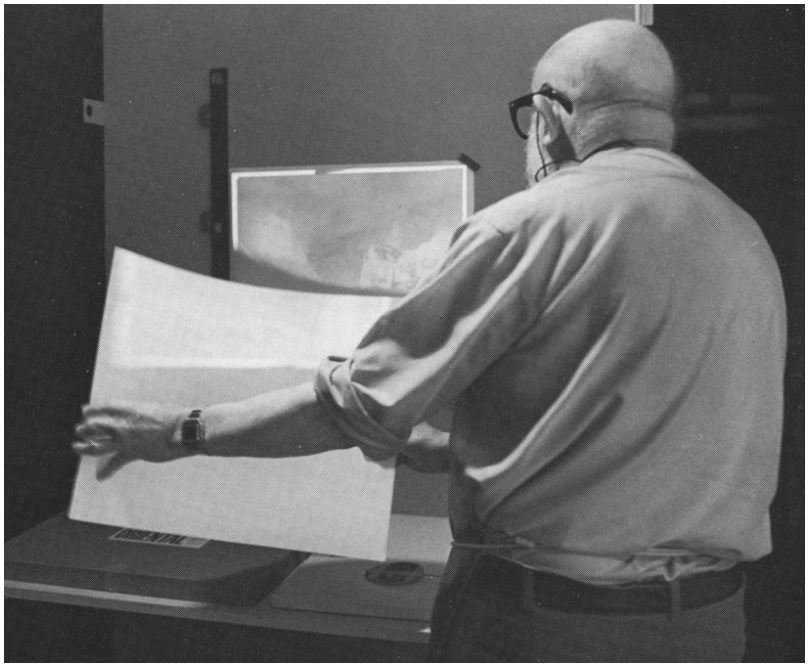
Traditional craft: dodging and burning

- **The artist at work**



dodging

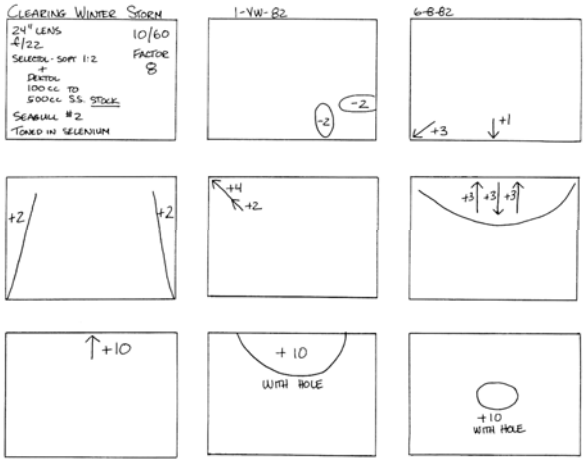


burning

- **Problems with dodging and burning**
  - Tedious
  - Must move mask to avoid artifacts
  - Haloing for complex edges

Traditional craft: dodging and burning

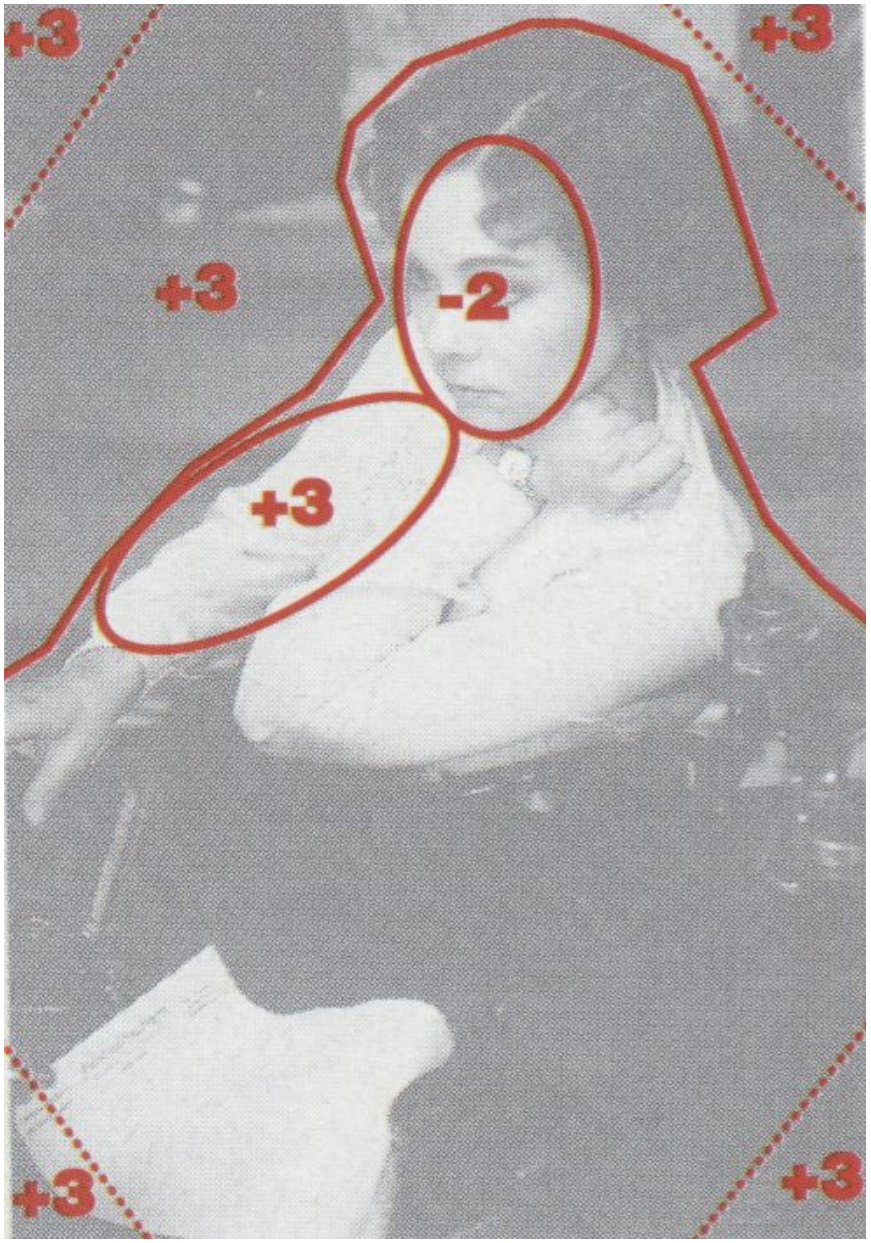
- ***Clearing Winter Storm***
  by Ansel Adams



Straight print

After dodging and burning

Dodging/burning



Neutral density Gradient Filter

- **The sky is too bright**
  - Gradient filter for the top of the photo
- **The house is too dark**
  - Gradient filter for the bottom of the photo

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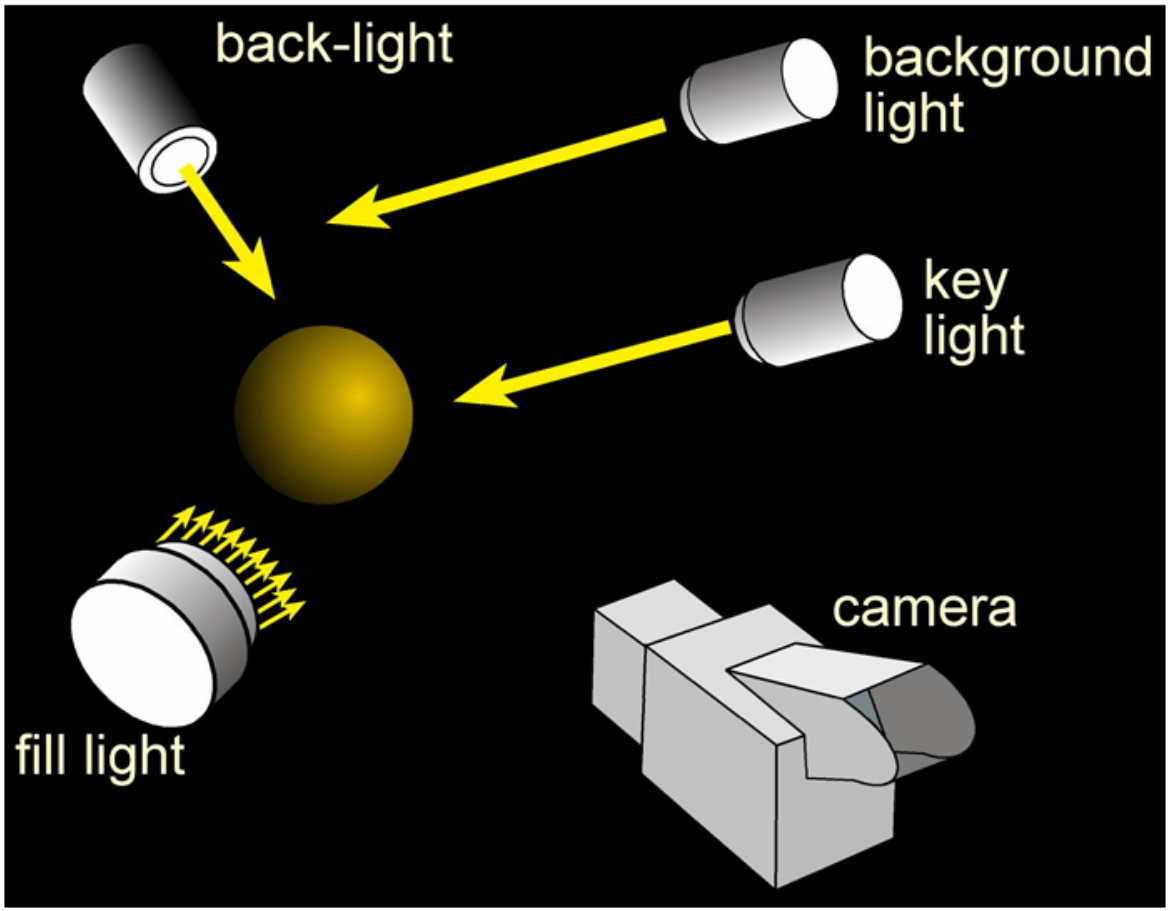
Art Wolf

- **From Edge of the Earth, Corner of the Sky**

Three Point Lighting

- **Key light**
  - Main and visible lighting
- **Fill light**
  - Fill-in shadows
- **Back light**
  - Emphasize silhouette
  - Make subject stand out
- **Independent lighting**

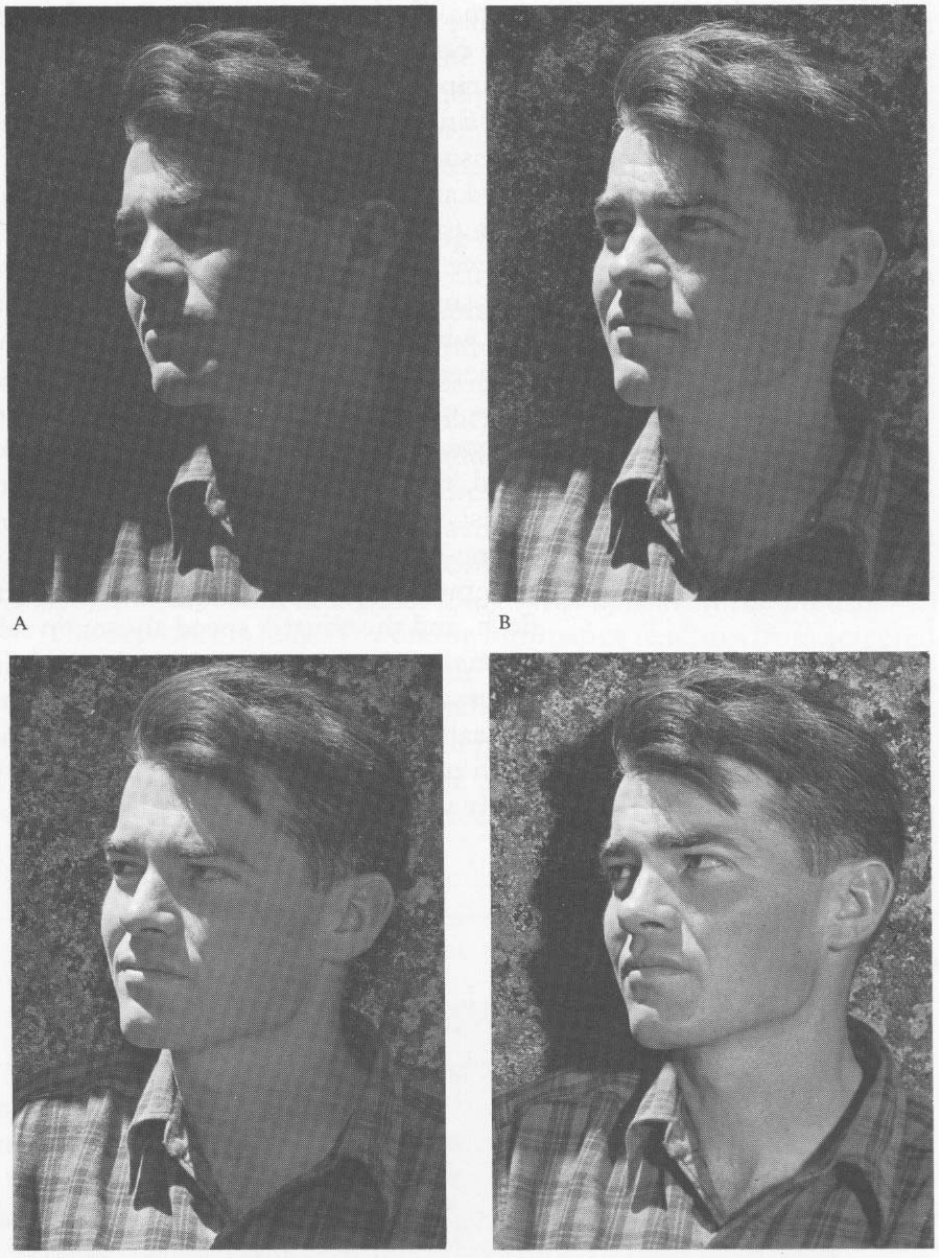


Lighting

- **Fill light**

Portrait Lighting

- **Ansel Adams**



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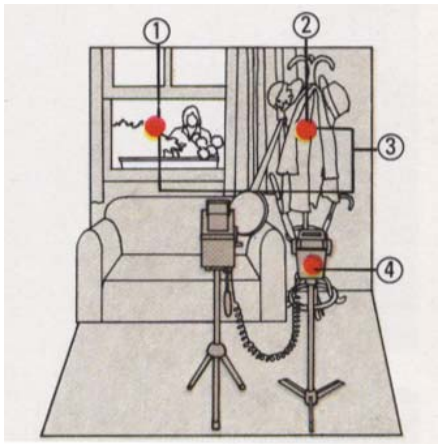
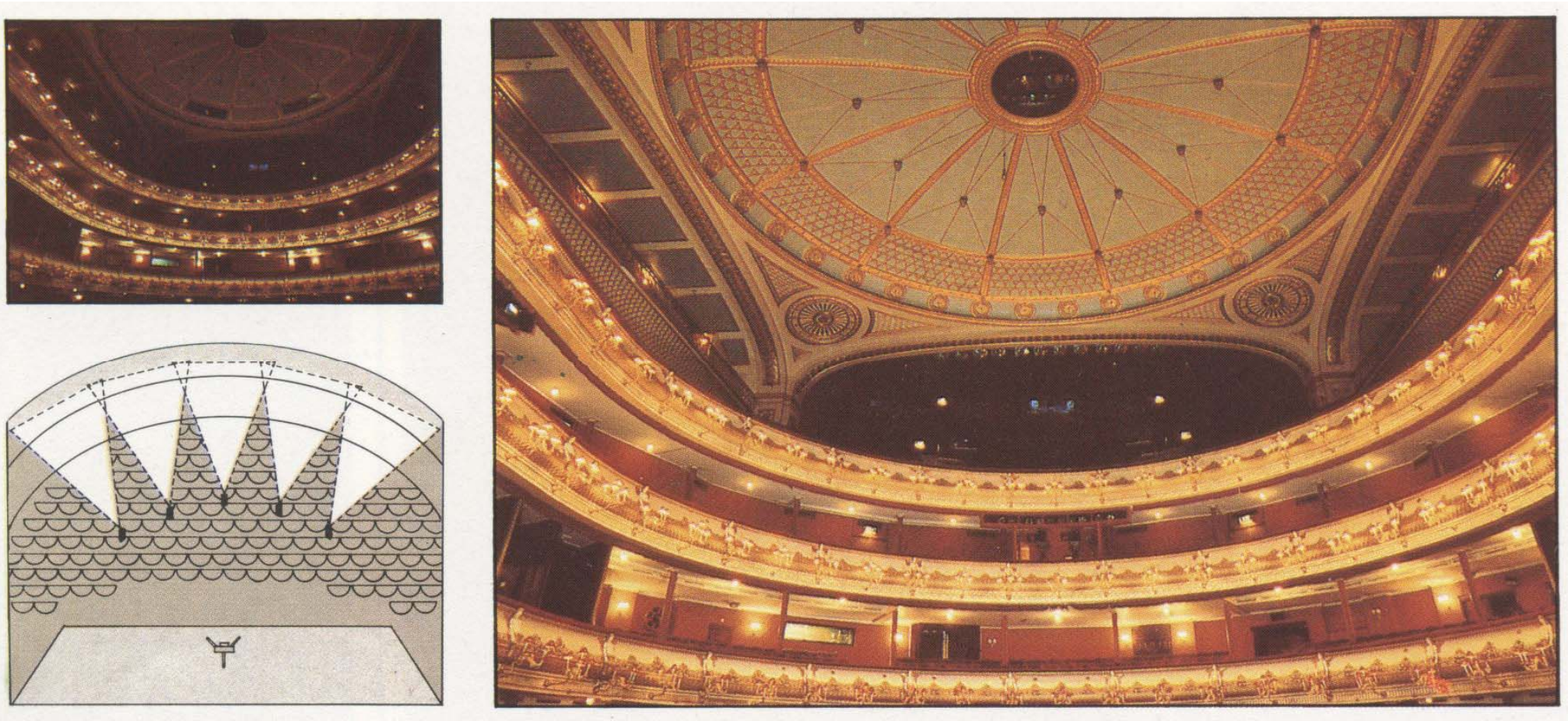
Fill-in



Snapshot-Perspective-Speed, aperture-Filter-**Lighting**-Processing & Print-Make up-Retouching

Lighting

- **Painting with light**

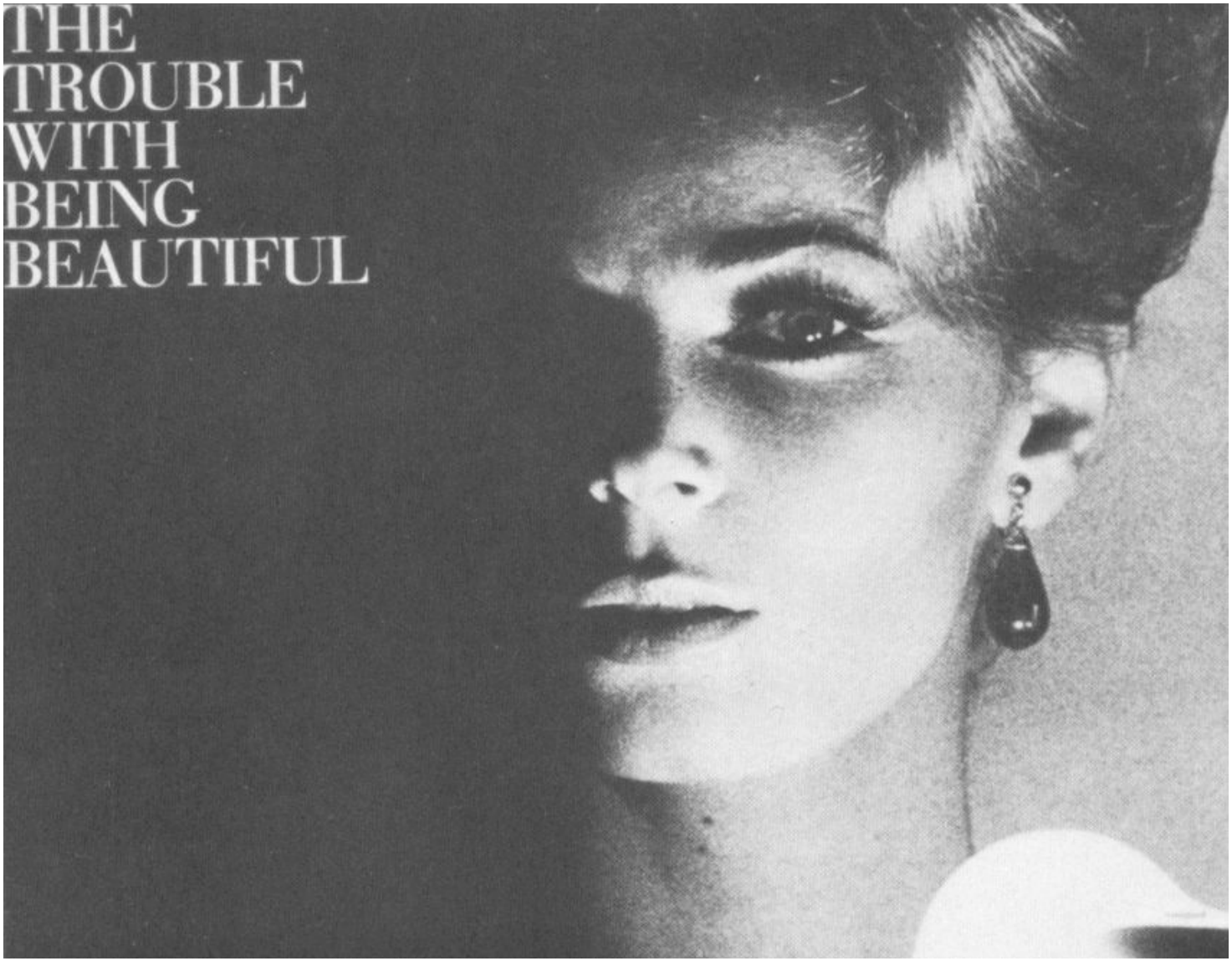


Silhouette

- **Wolfrang Weber**
  The Lash Bird Dancer On Madagascar
  Late 20s

Contrast

- **Bert Stern**



The digital world

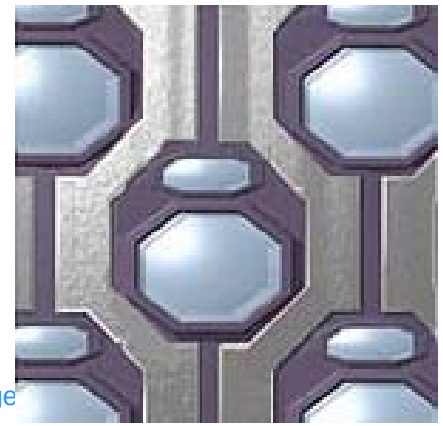
- **2 big problems**
  - Acquisition
  - Tone mapping

Half of the job: acquisition

- **Not my job! (Charlie Sodini's job)**
- **Multiple exposure photo [Debevec & Malik 1997]**

Recover response curve

HDR value for each pixel



Multiple exposure photography

- **Demo!**
- **Cf. assignment**
- **http://www.debevec.org/Research/HDR/**

Tone mapping with Bilateral filter

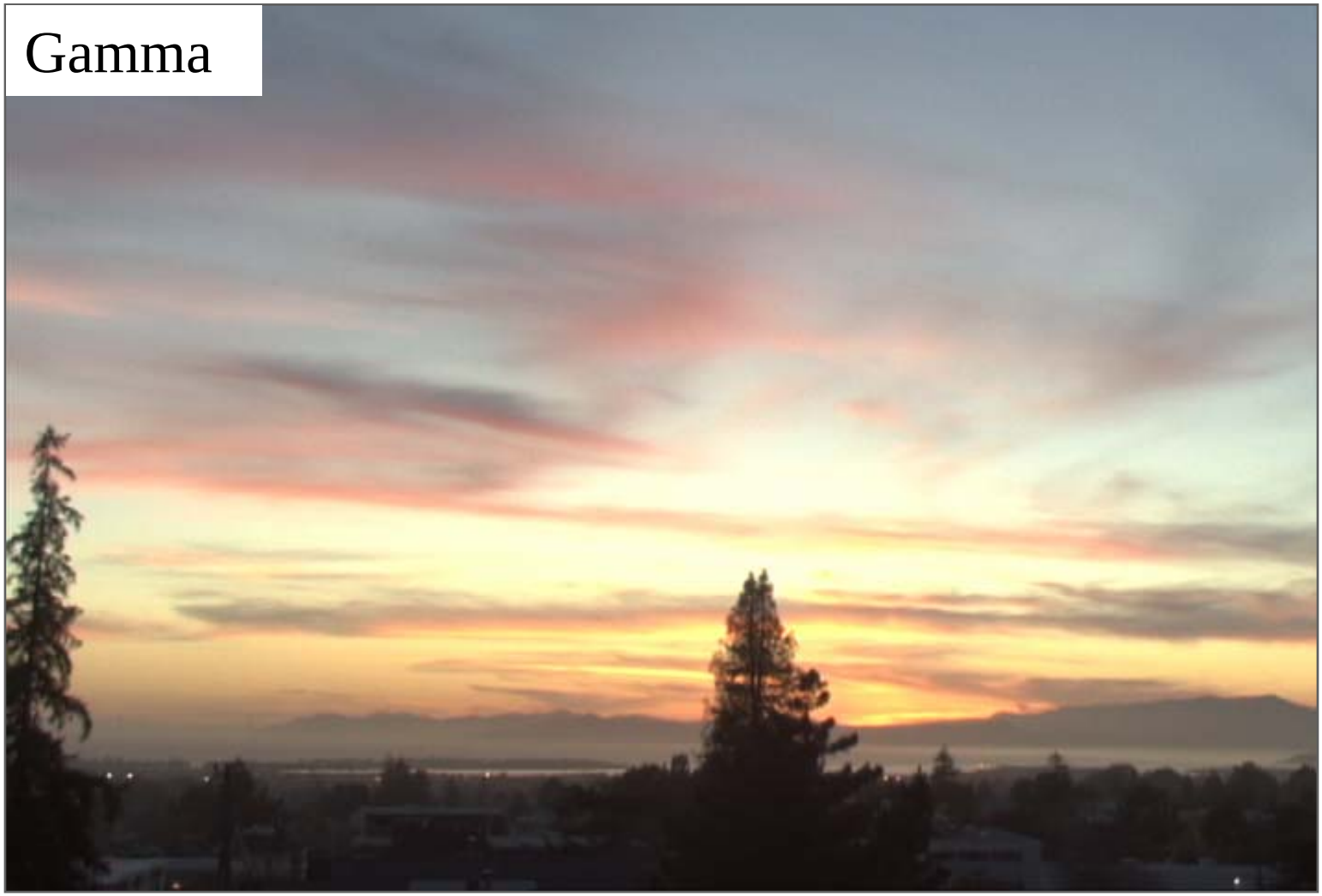
- **Input: high-dynamic-range image**
  - (floating point per pixel)

Naïve technique

- **Scene has *K* orders of magnitude, image has *N***
- **Simplest contrast reduction?**
- **1: $X \rightarrow X * N / K$**
- **2: $X \rightarrow X * K / N$**
- **3: $X \rightarrow X^{N/K}$**
- **4: $X \rightarrow X^{K/N}$**
- **5: $X \rightarrow N/K \log X$**
- **6: $X \rightarrow K/N \log X$**

Naïve: Gamma compression

- $X \rightarrow X^{N/K}$, a.k.a. $X \rightarrow X^{\gamma}$
- **Colors are washed-out**

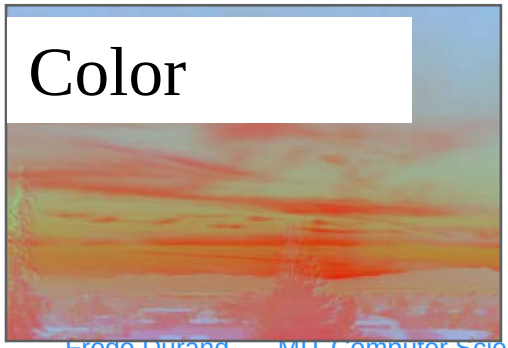


Gamma compression on intensity

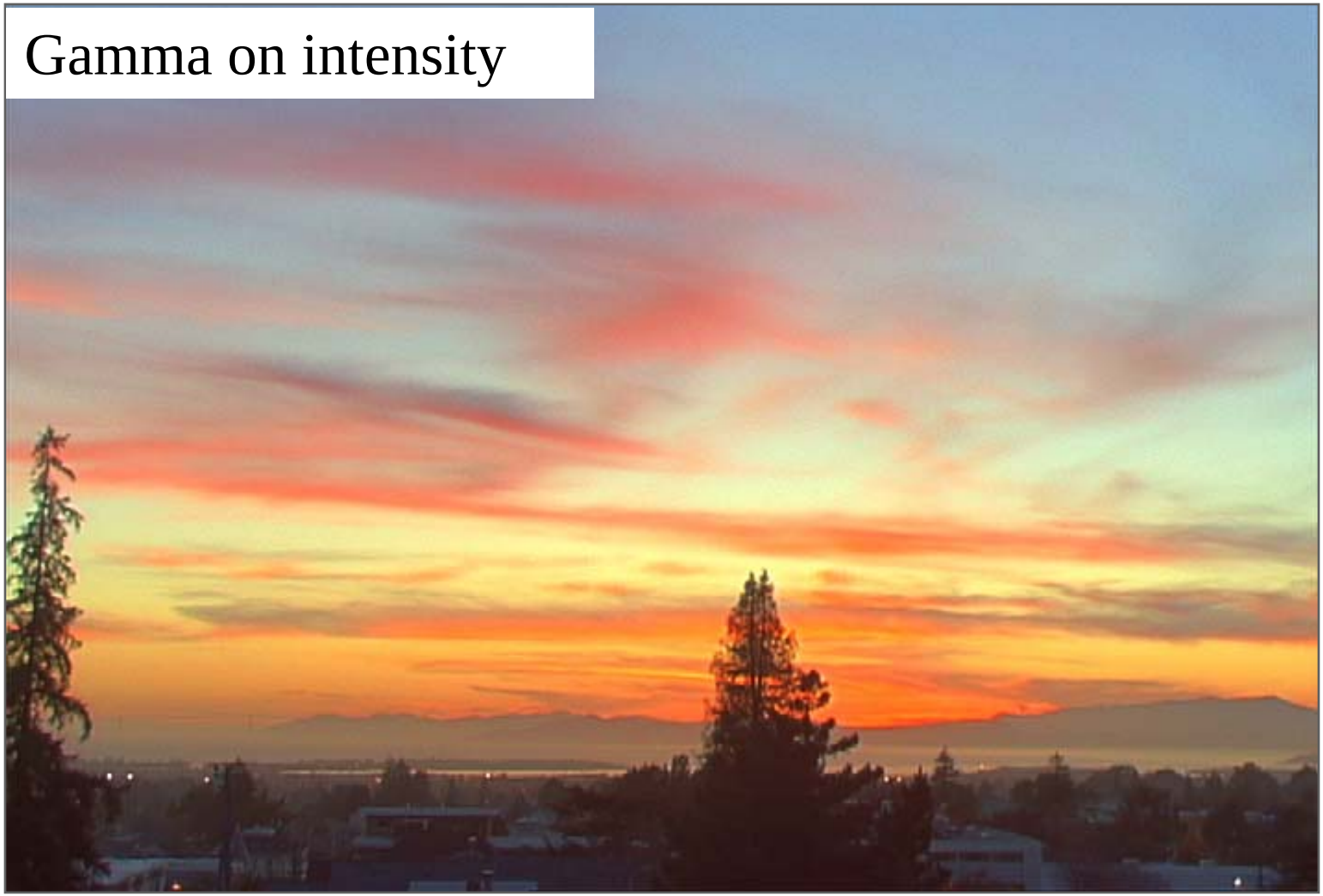
- **Colors are OK,**
  but details (intensity high-frequency) are blurred

Intensity

Color

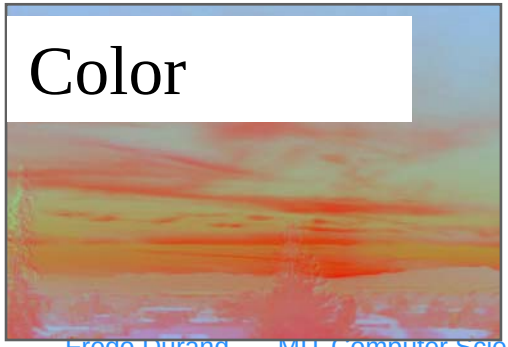


Gamma on intensity



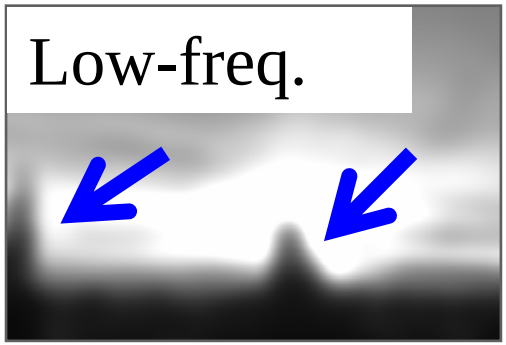
Chiu et al. 1993

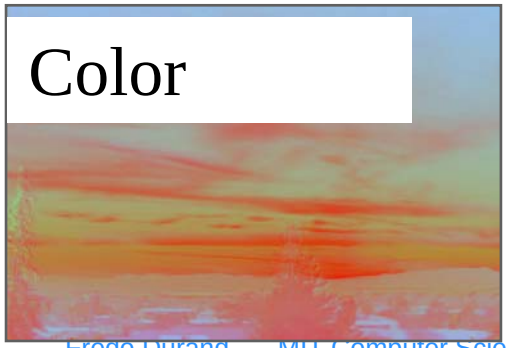
- **Reduce contrast of low-frequencies**
- **Keep high frequencies**

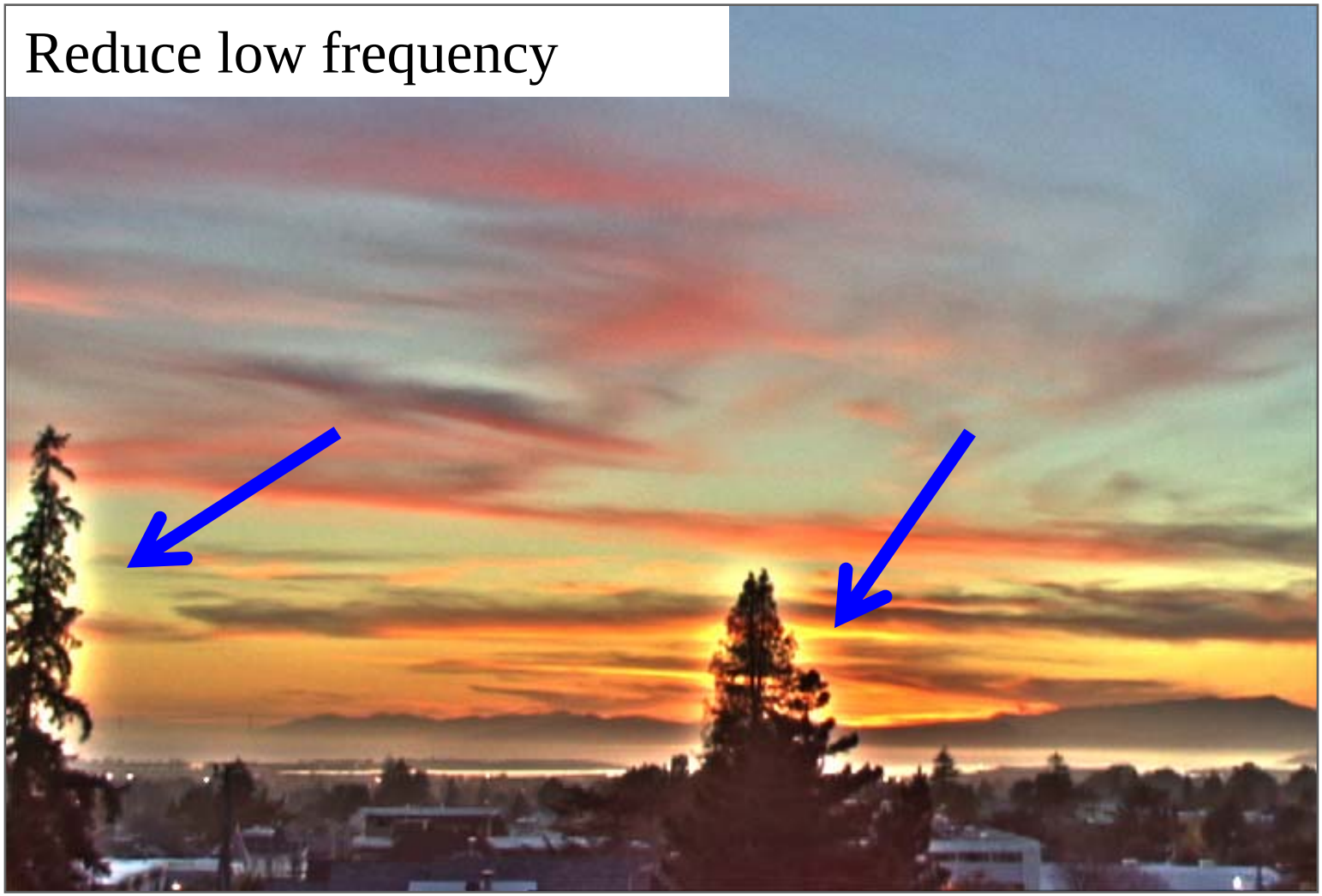


The halo nightmare

- **For strong edges**
- **Because they contain high frequency**

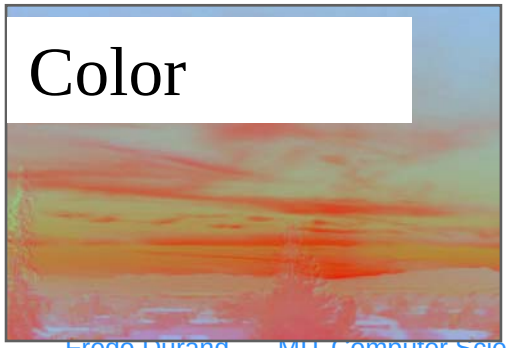


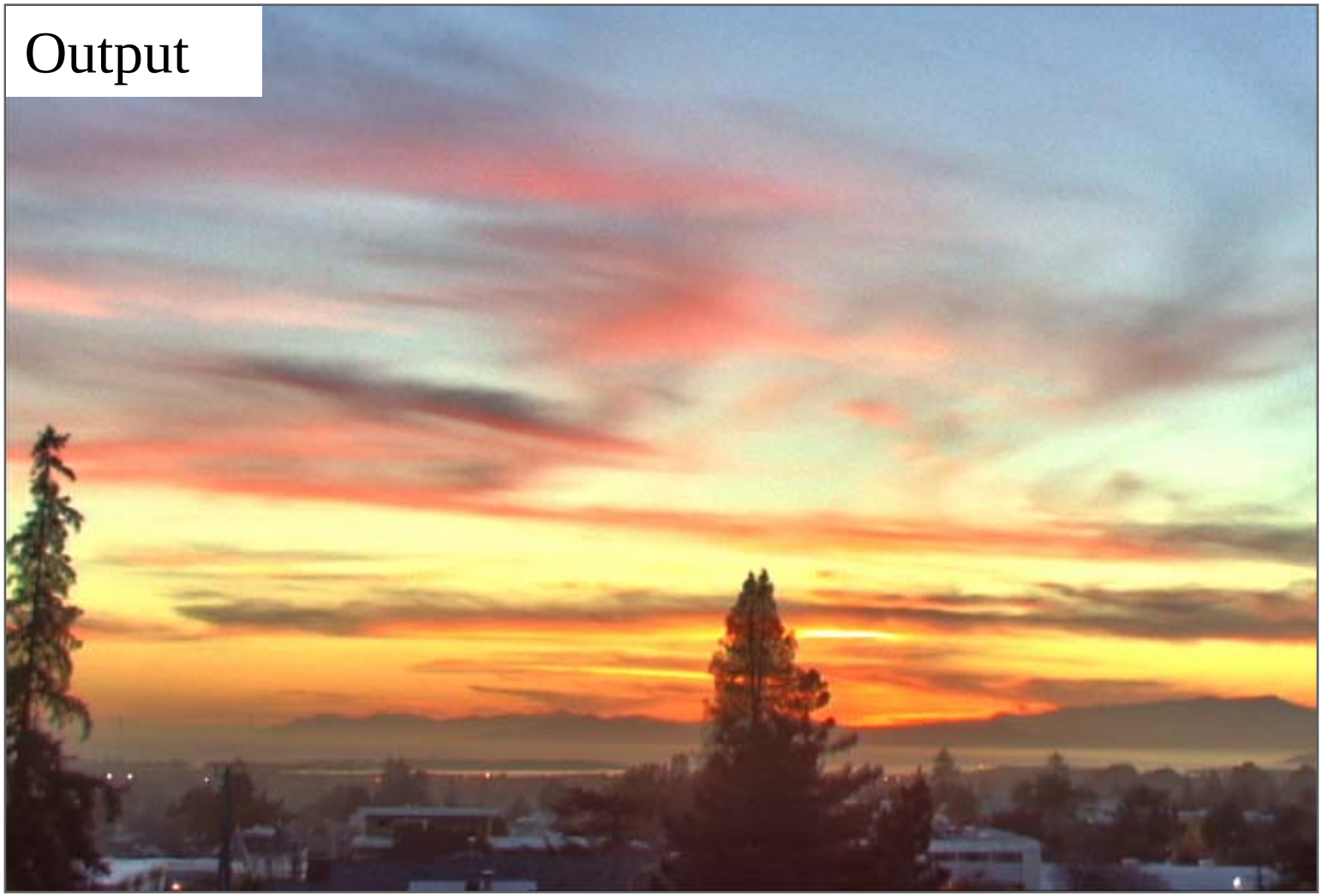




Our approach

- **Do not blur across edges**
- **Non-linear filtering**



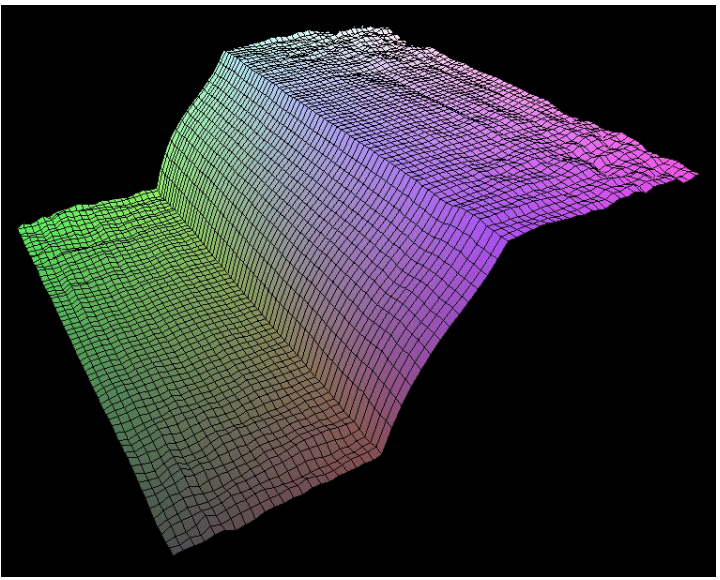


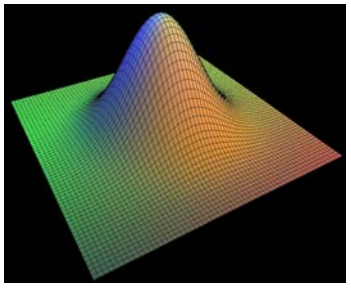
Review: Bilateral filtering

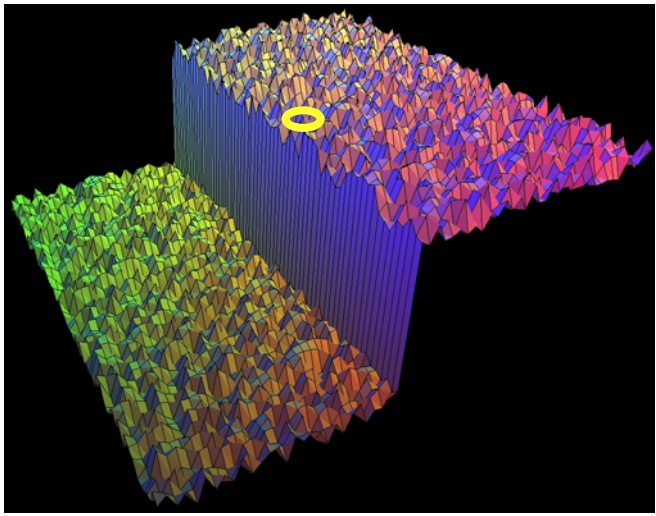
[Tomasi and Manduchi 1998], SUSAN, sigma filter

- **Spatial Gaussian f**

$$J(x) = \sum_{\xi} f(x,\xi) \quad I(\xi)$$







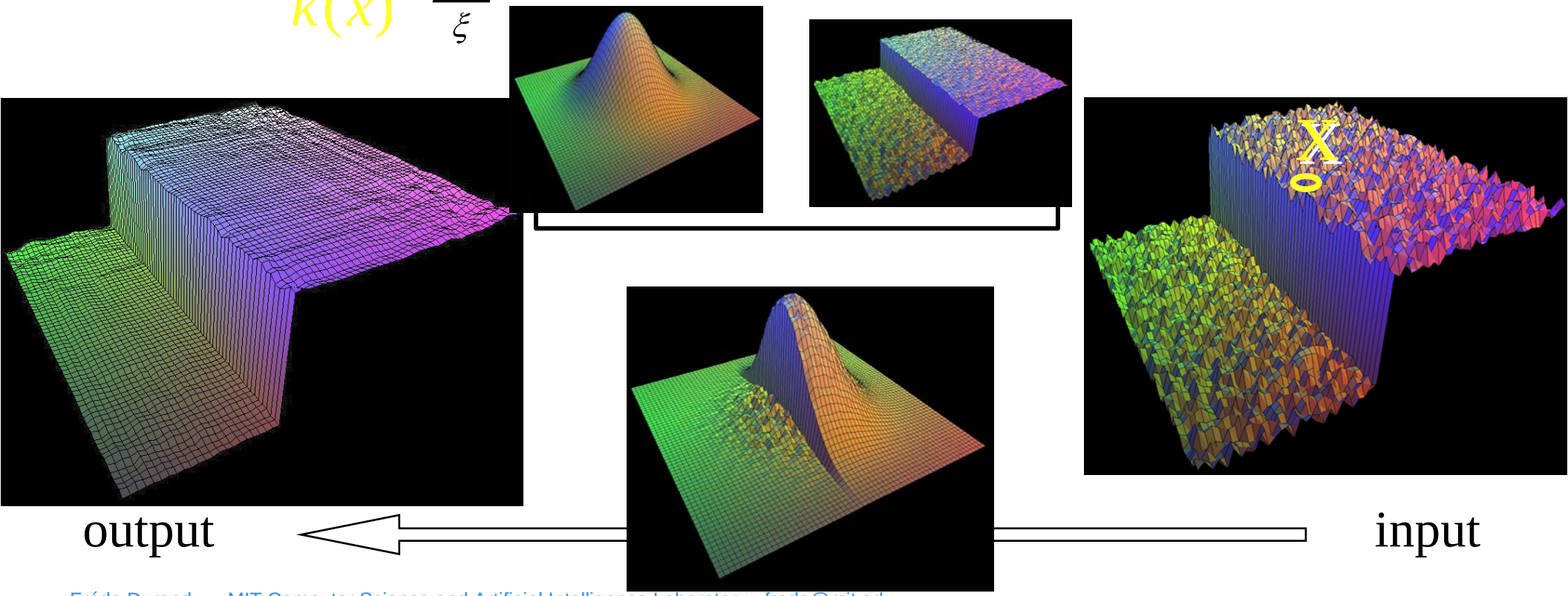
output ⟵ input

Review: Bilateral filtering

[Tomasi and Manduchi 1998]

- **Spatial Gaussian f**
- **Gaussian g on the intensity difference**

$$J(x) = \frac{1}{k(x)} \sum_{\xi} f(x,\xi) \quad g(I(\xi) - I(x)) \quad I(\xi)$$



Theoretical framework

- **Framework of robust statistics**
  - Output = estimator at each pixel
  - Less influence to outliers (because of g)
- **Unification with anisotropic diffusion**
  - Mostly equivalent
  - Some differences

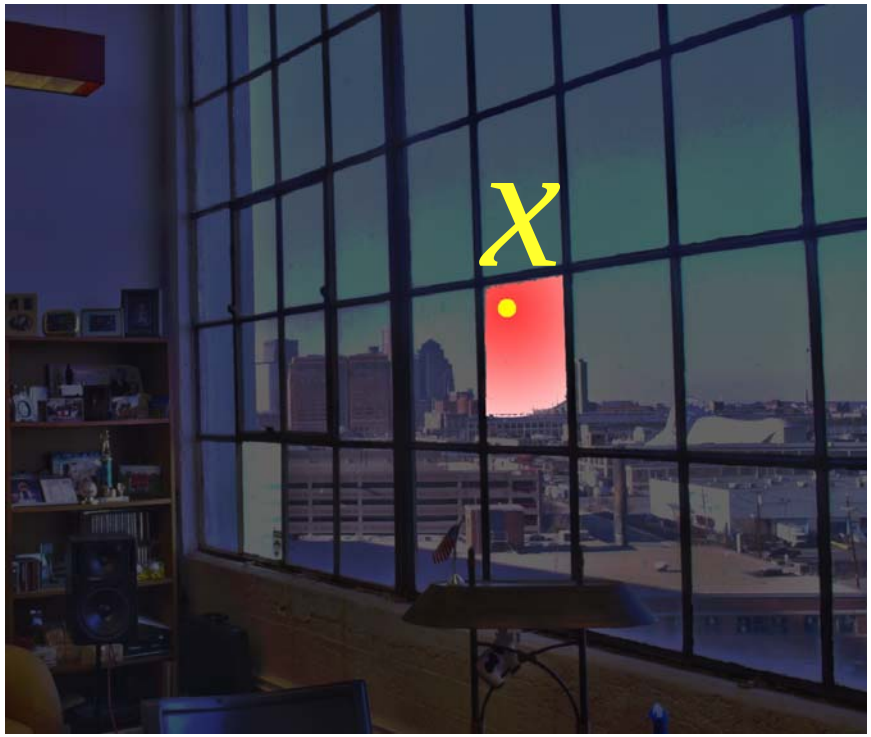
- **Details and other insights in paper**

Spatial support

- **Exterior is much brighter than window frame**
  - Image has had its contrast reduced for visualization
- **Estimate at point x: Which pixels contribute?**

Support: bilateral vs. diffusion

- **Guess which one is the bilateral filter (the other one is anisotropic diffusion)**

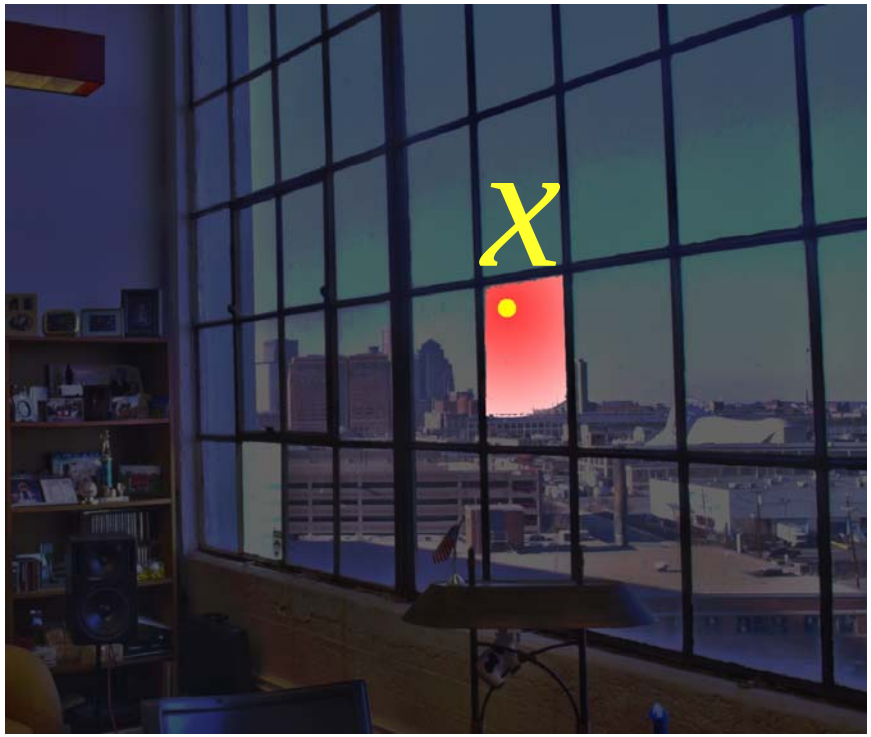


1

2

Spatial support

- **Anisotropic diffusion cannot diffuse across edges**
- **Bilateral filtering can**
- **Larger support => more reliable estimator**

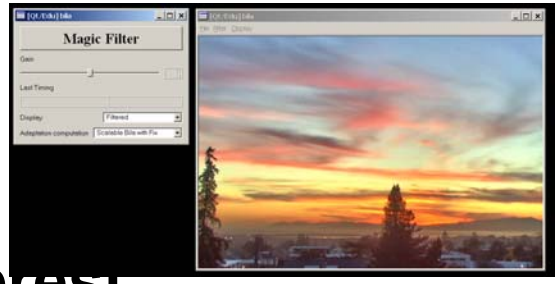


Support of anisotropic diffusion

Support of bilateral

Live demo

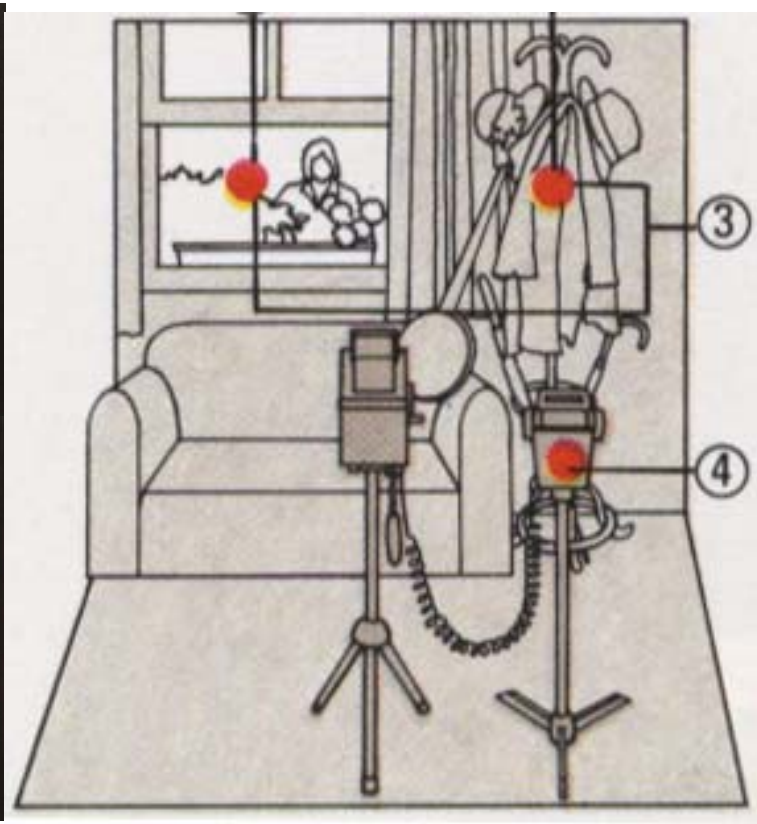
- **Whatever GHz Pentium 4**

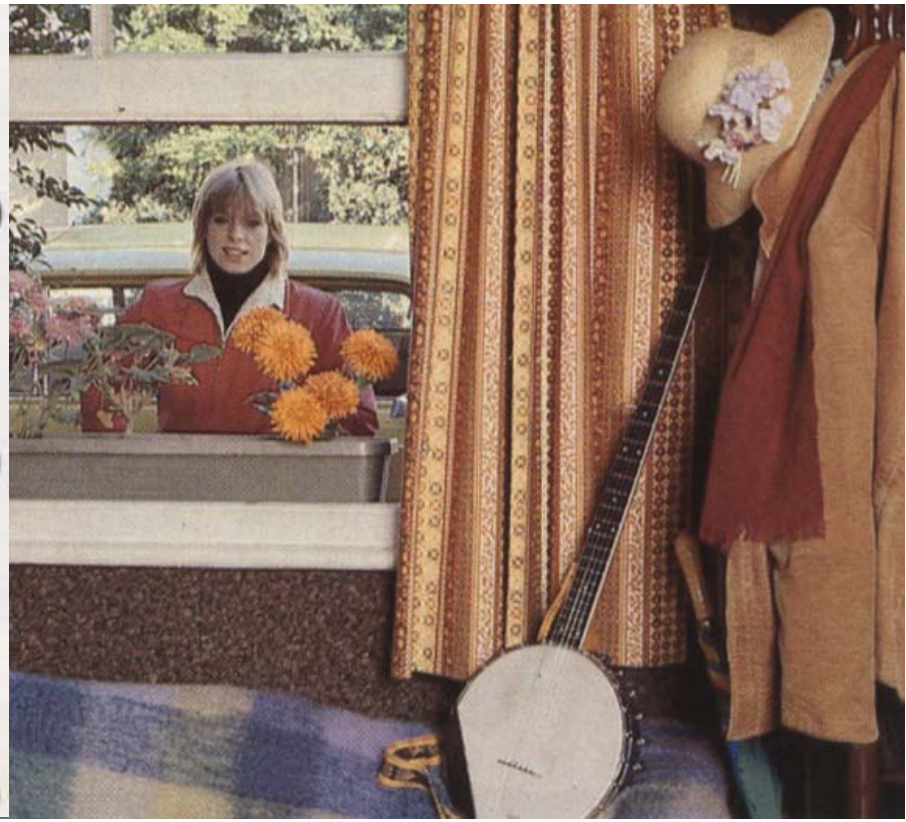


- **Industrial interest**
  - Embedded in the camera
  - In the download software
  - For surveillance

Traditional photo craft: Fill-in

- **Flash to illuminate the interior**
- **Brings interior intensity to level of exterior**

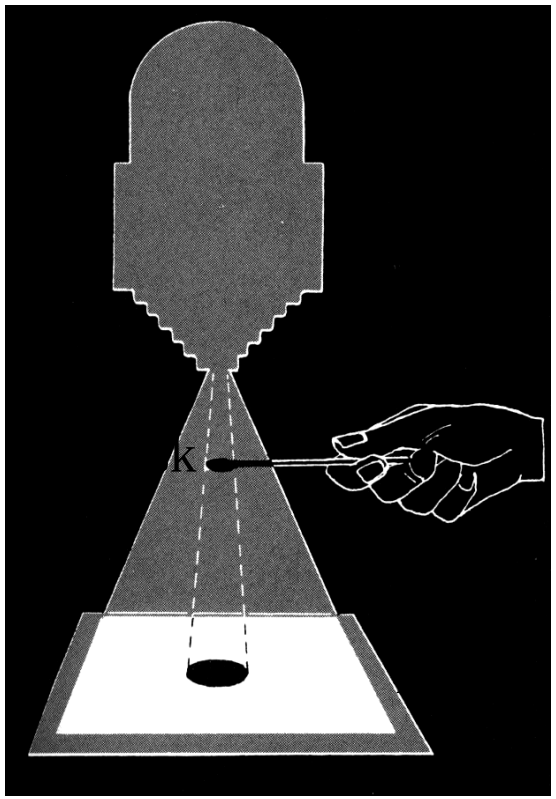




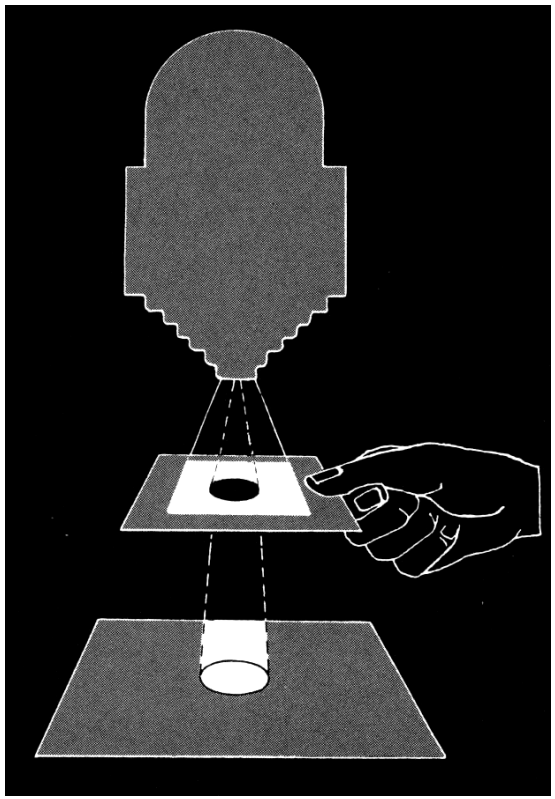
Without fill in Flash set up With fill in

Traditional craft: dodging and burning

- **Locally darken or lighten**
- **Mask to expose some areas less**



dodging



burning

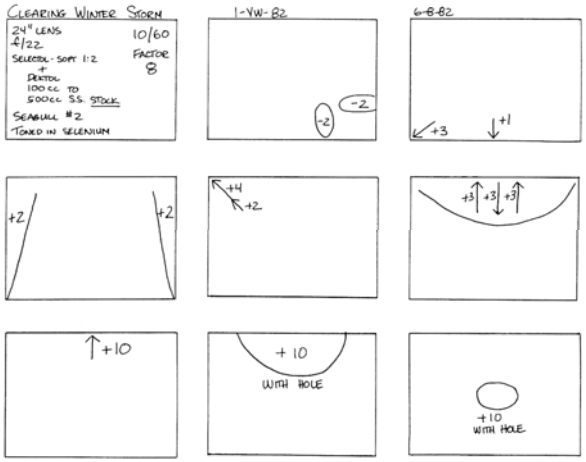
Does masking make an area

A: Darker

B: Brighter

Traditional craft: dodging and burning

- ***Clearing Winter Storm***
  by Ansel Adams

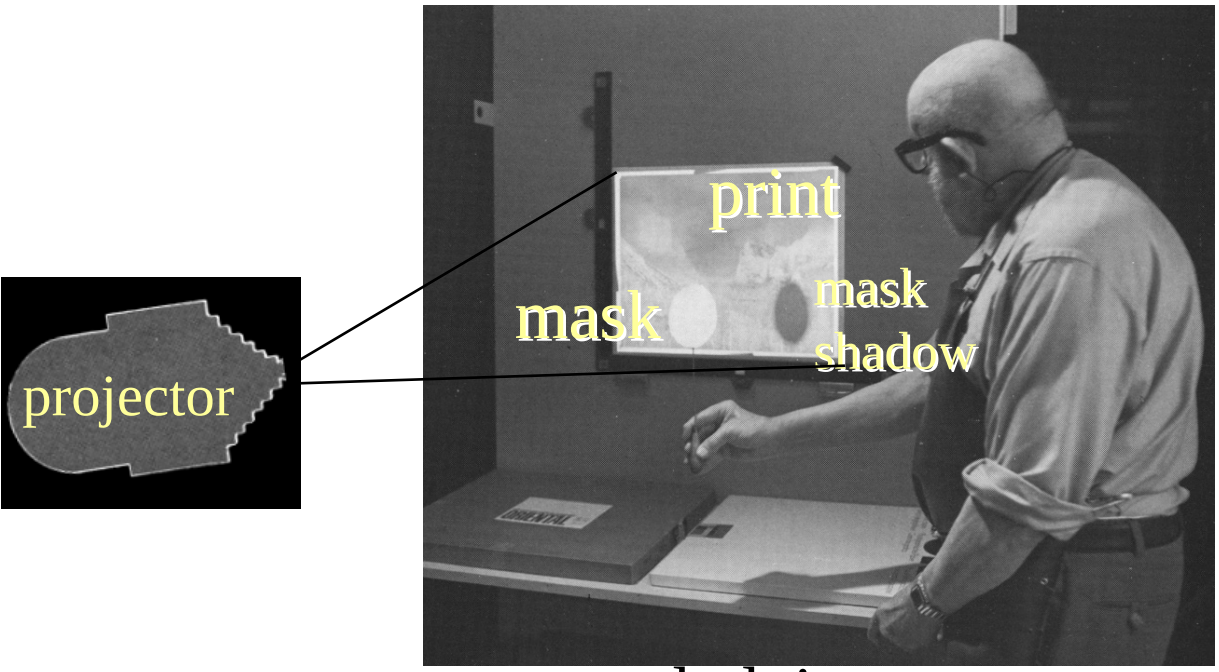


Straight print

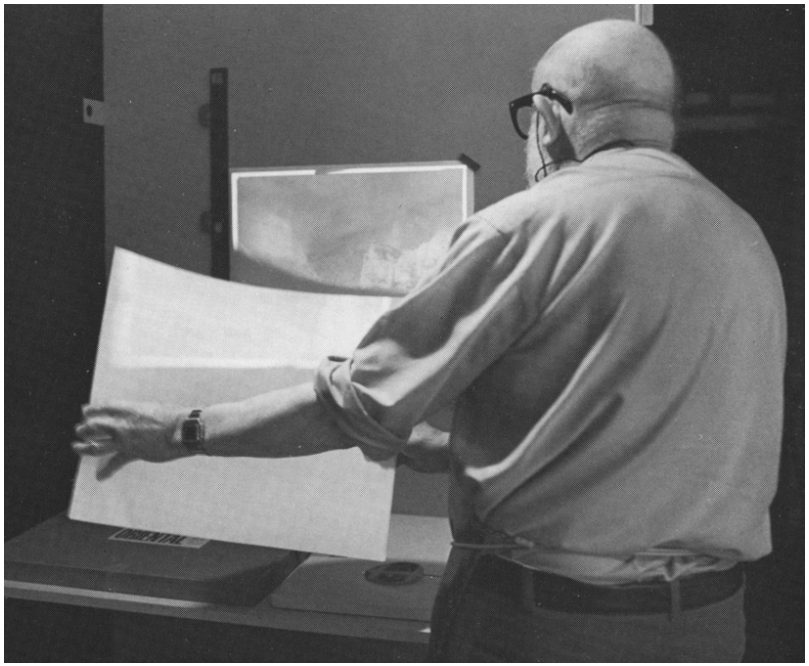
After dodging and burning

Traditional craft: dodging and burning

- **The artist at work**



dodging



burning

- **Problems with dodging and burning**
  - Tedious
  - Must move mask to avoid artifacts
  - Haloing for complex edges