# Point Operations

- How do gray values relate to brightness?
- Quantization
- Weber’s Law
- Gamma characteristic
- Adjusting brightness and contrast

# Quantization: how many bits per pixel?

8 bits

5 bits

4 bits

3 bits

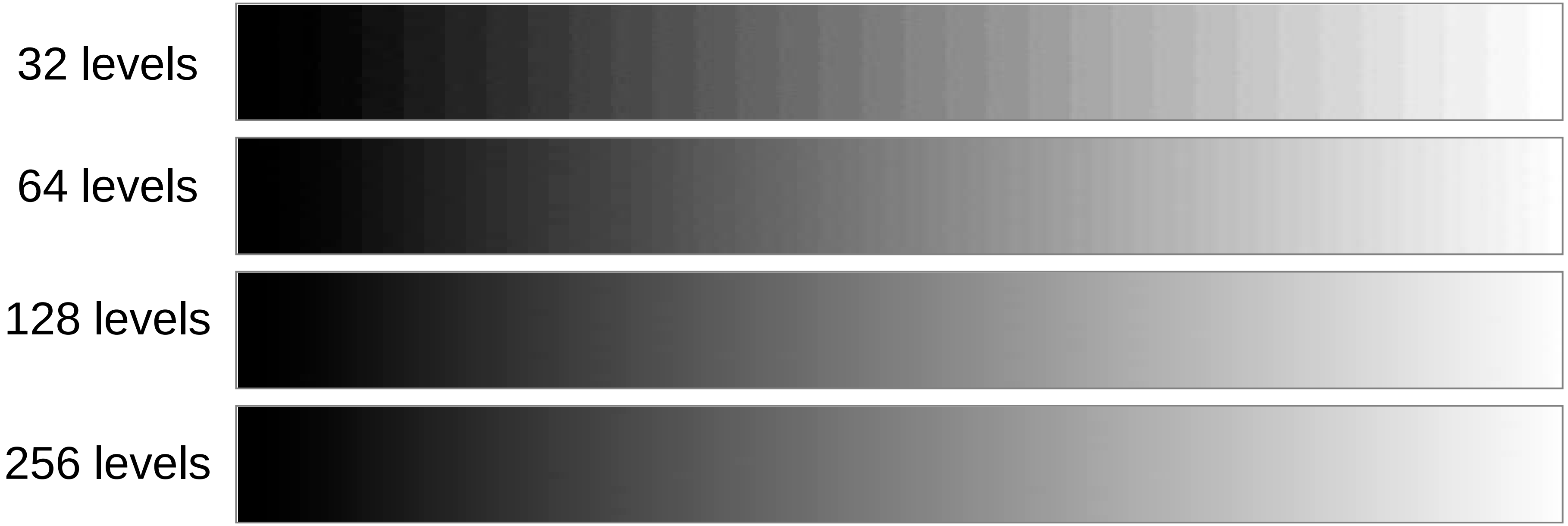
2 bits

1 bit

*„Contouring“*

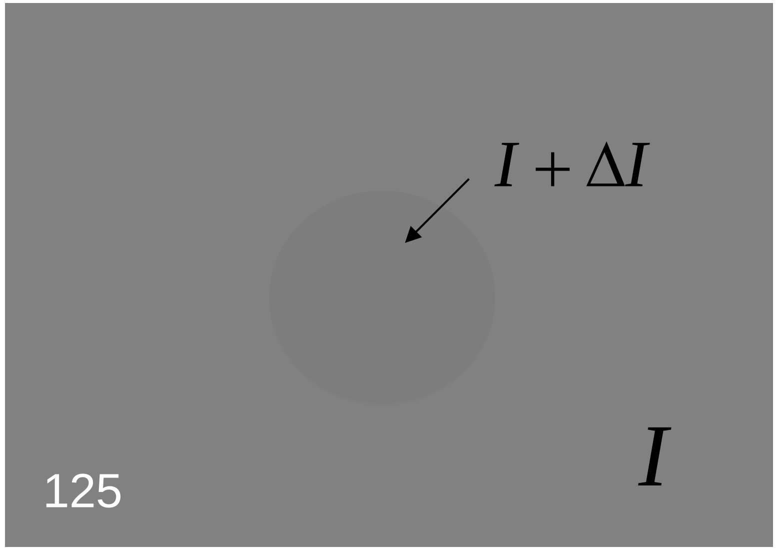
# How many gray levels are required?

- Contouring is most visible for a ramp




- Digital images typically are quantized to 256 gray levels.

# Brightness discrimination experiment




Visibility threshold

$$\Delta I / I \approx 1 \ldots 2\%$$

„Weber fraction“
„Weber‘s Law“

Note: $I$ is luminance, measured in $cd/m^2$

Can you see the circle?

Human brightness perception is uniform in the $\log(I)$ domain („Fechner‘s Law“)

# Contrast ratio without contouring

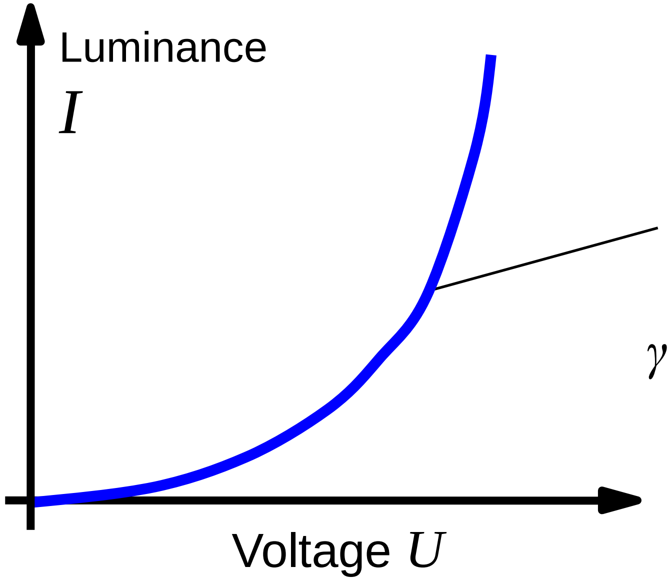
- Luminance ratio between two successive quantization levels at visibility threshold

$$\frac{I_{\max}}{I_{\min}} = \left(1 + K_{Weber}\right)^{N-1}$$

- For $K_{Weber} = 0.01 \cdots 0.02 \quad N = 256 \quad \mathrm{I}_{\max} / \mathrm{I}_{\min} = 13 \cdots 156$
- Typical display contrast ratio
  - Modern flat panel display in dark room 1000:1
  - Cathode ray tube 100:1
  - Print on paper 10:1

# Gamma characteristic

- Cathode ray tubes (CRTs) are nonlinear



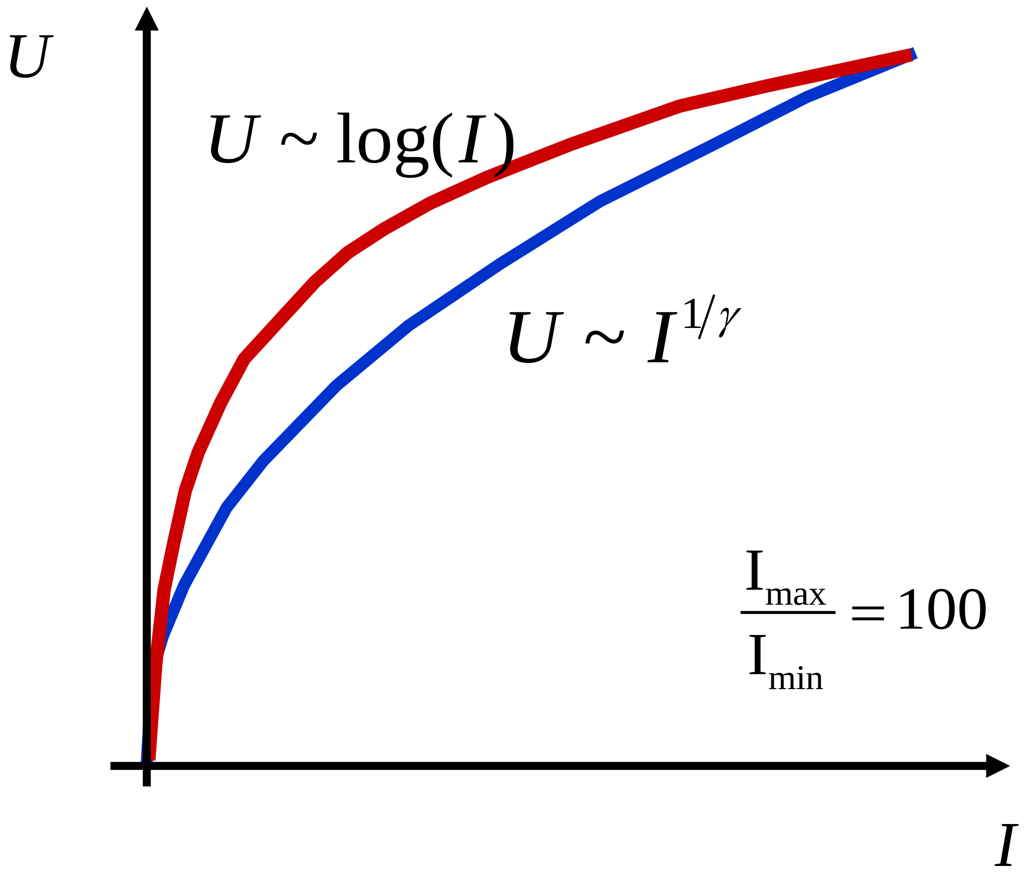

$$I \sim U^{\gamma}$$

$\gamma$ = 2.0 . . . 2.3

- Cameras contain $\gamma$-predistortion circuit

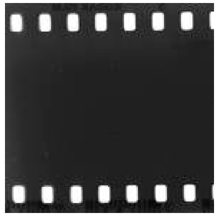
$$U \sim I^{1/\gamma}$$

# log vs. $\gamma$-predistortion

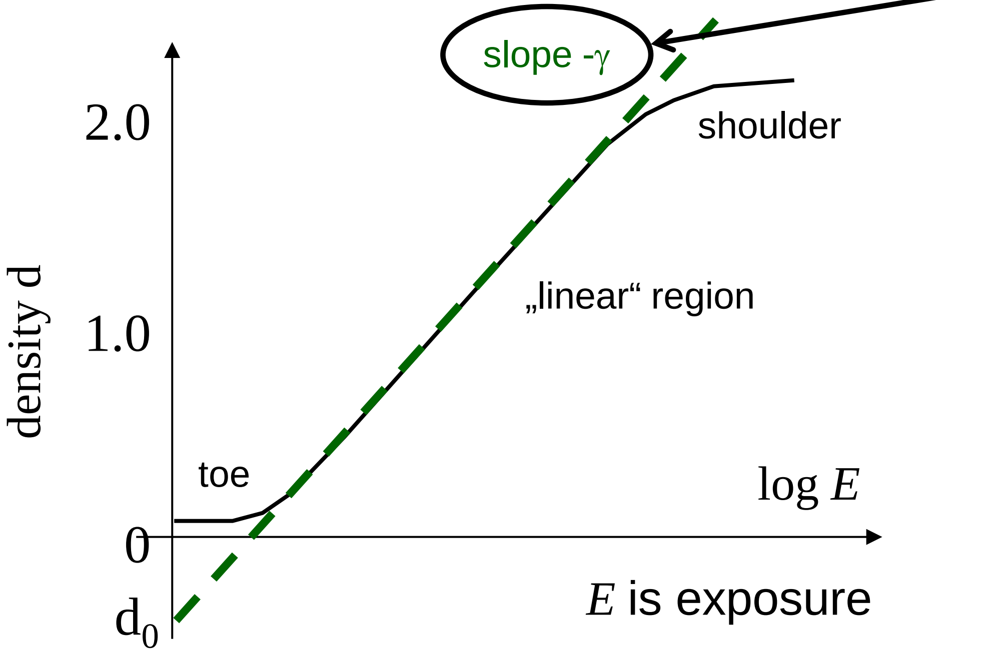



- Weber's Law suggests uniform perception in the $\log(I)$ domain
- Similar enough for most practical applications

# Photographic film



Hurter & Driffield curve (H&D curve)
for photographic negative




**Luminance**

$$
\begin{aligned}
I &= I_0 \cdot 10^{-d} \\
&= I_0 \cdot 10^{-\left(-\gamma \log E + d_0\right)} \\
&= I_0 \cdot 10^{-d_0} \cdot E^{\gamma}
\end{aligned}
$$

$\gamma$ measures film contrast

- General purpose films
  $\gamma$ = -0.7 . . . -1.0
- High-contrast films
  $\gamma$ = -1.5 . . . -10
- Lower speed films tend to have higher absolute $\gamma$

# Brightness adjustment by intensity scaling

Original image

$f[x,y]$

Scaled image

$a \cdot f[x,y]$

Scaling in the γ-domain is equivalent to scaling in the linear luminance domain

$$I \sim \left(a \cdot f[x,y]\right)^{\gamma} = a^{\gamma} \cdot \left(f[x,y]\right)^{\gamma}$$

. . . same effect as changing camera exposure time.

# Contrast adjustment by changing $\gamma$

Original image

$f[x,y]$

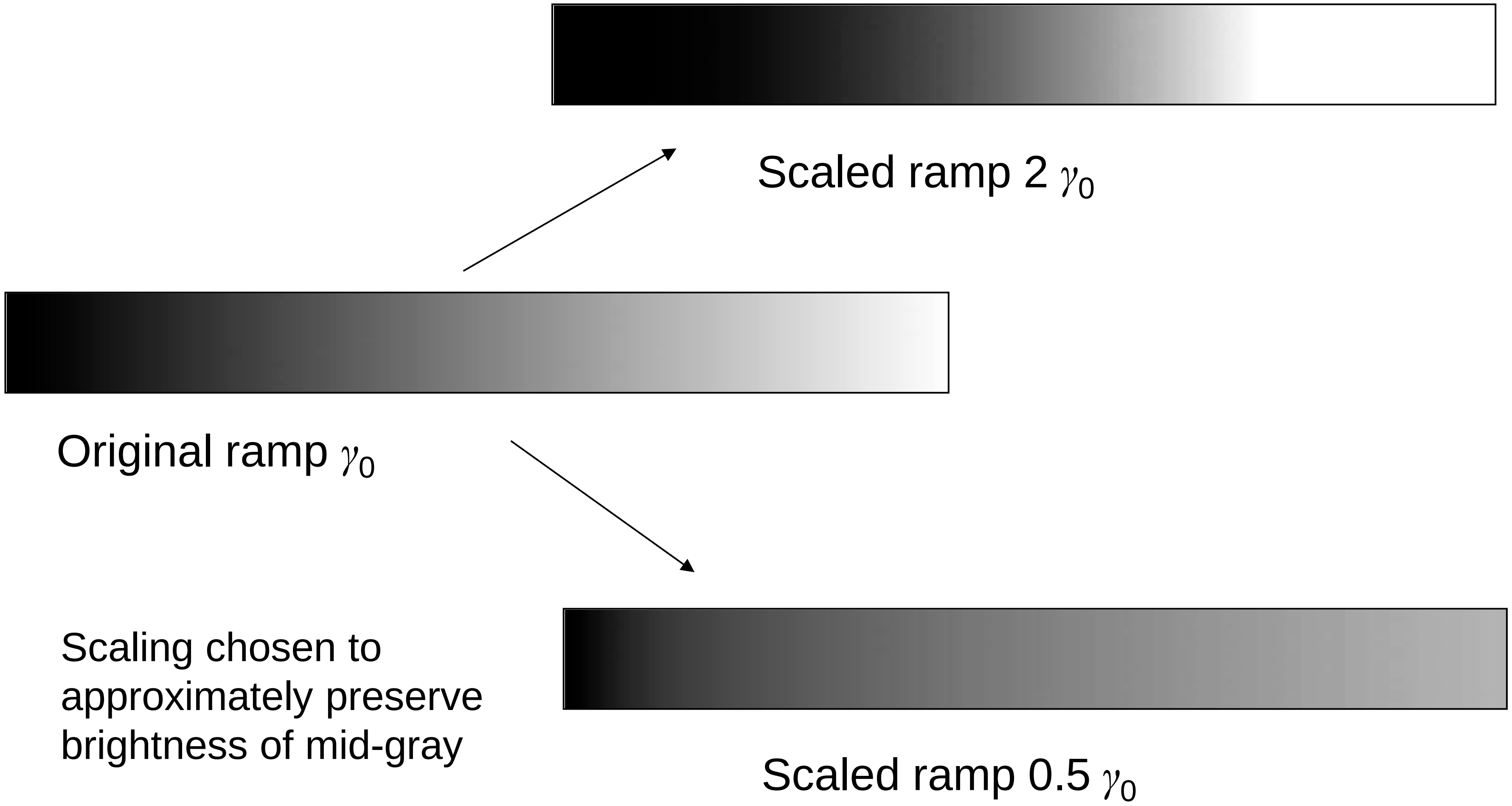
$\gamma$ increased by 50%

$a \cdot (f[x,y])^{\gamma}$

with $\gamma = 1.5$

. . . same effect as using a different photographic film . . .

# Contrast adjustment by changing $\gamma$



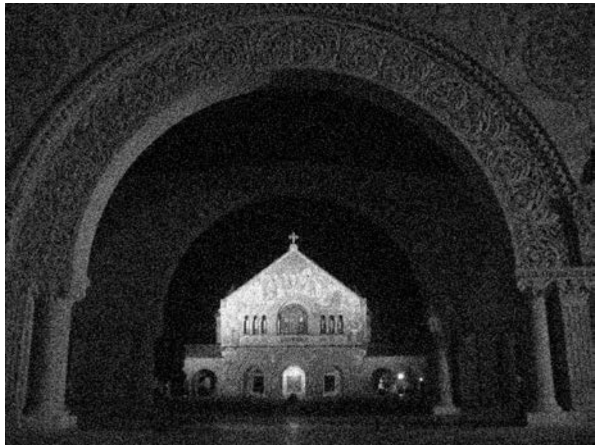

Scaling chosen to approximately preserve brightness of mid-gray

# Point operations for combining images

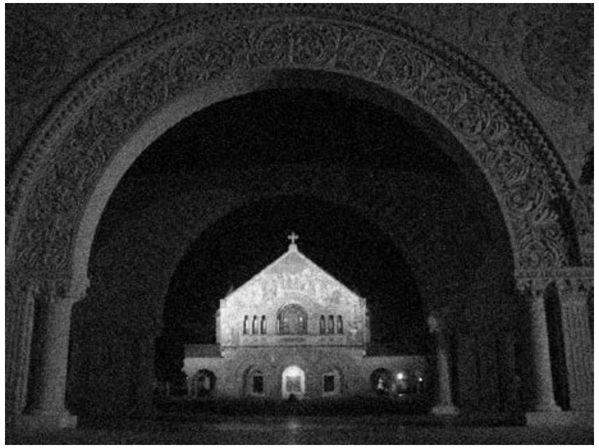
- Image averaging for noise reduction
- Combination of different exposures for high-dynamic range imaging
- Image subtraction for change detection
- Need for accurate alignment

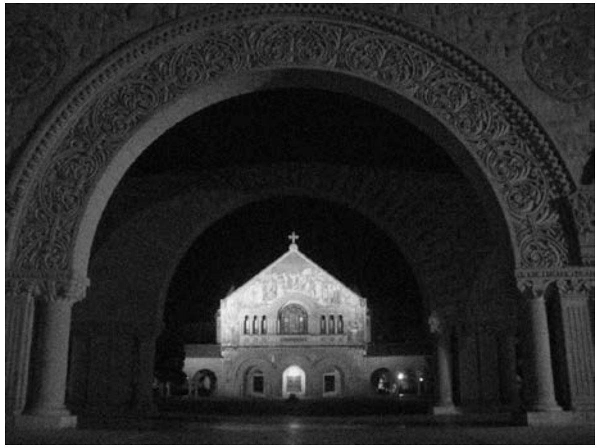
# Image averaging for noise reduction

1 image



2 images





8 images

32 images

# High-dynamic range imaging

-8 f-stops

-2 f-stops

+2 f-stops

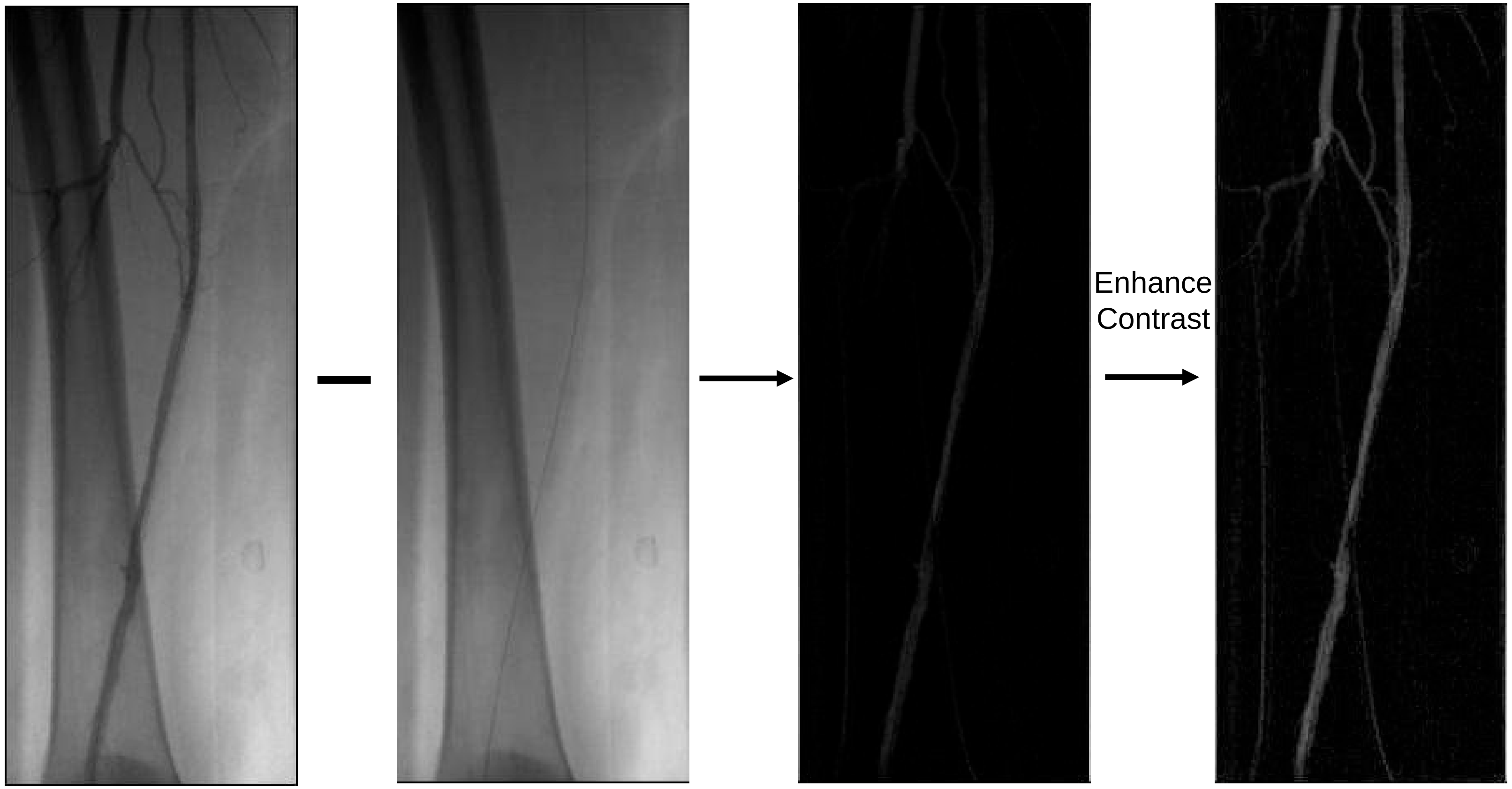
+4 f-stops

Blended image from Exposure Fusion

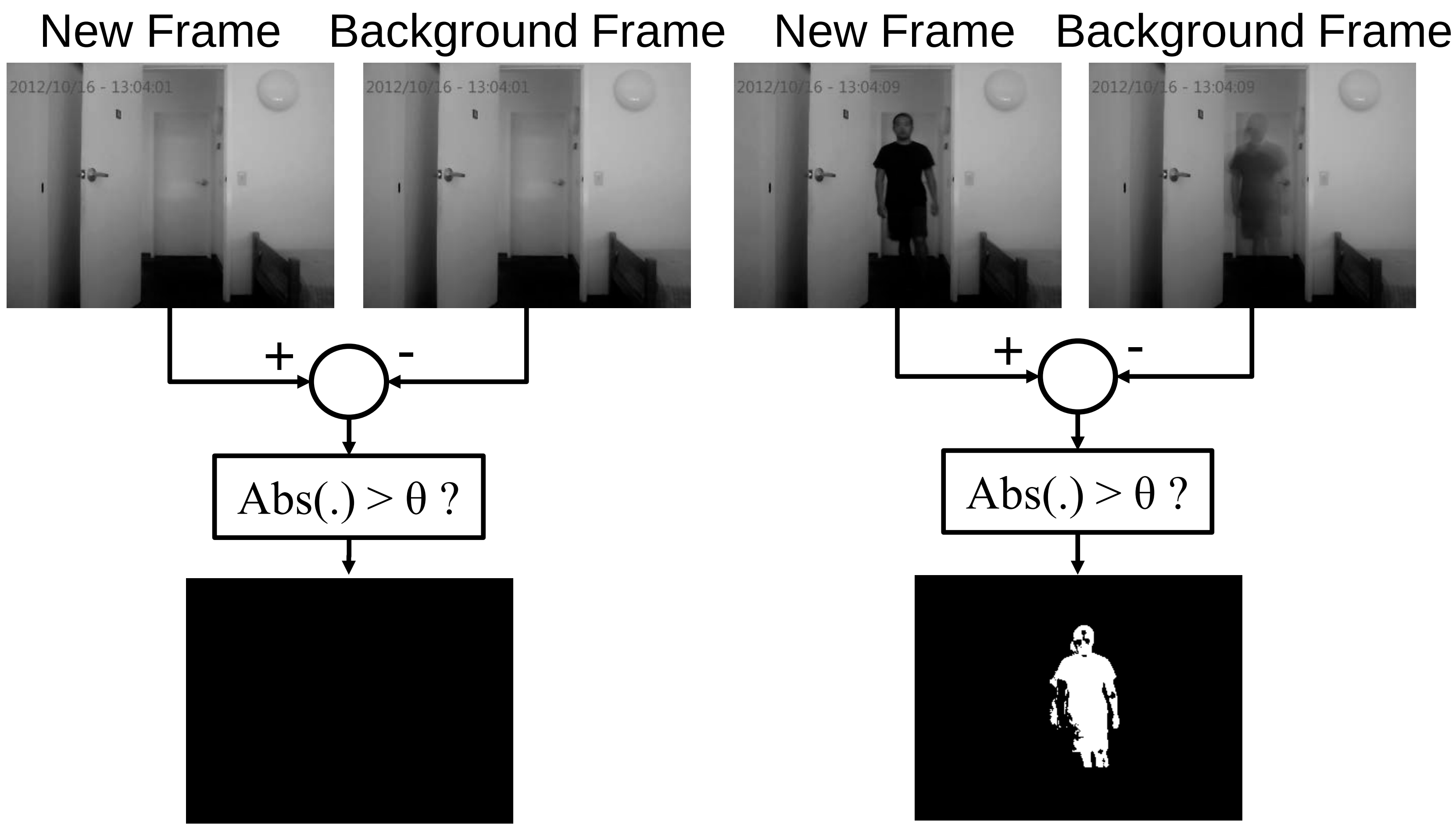
*[Tom Mertens et al. 2007]*

# Image subtraction

- Find differences/changes between 2 mostly identical images
- Example: digital subtraction angiography



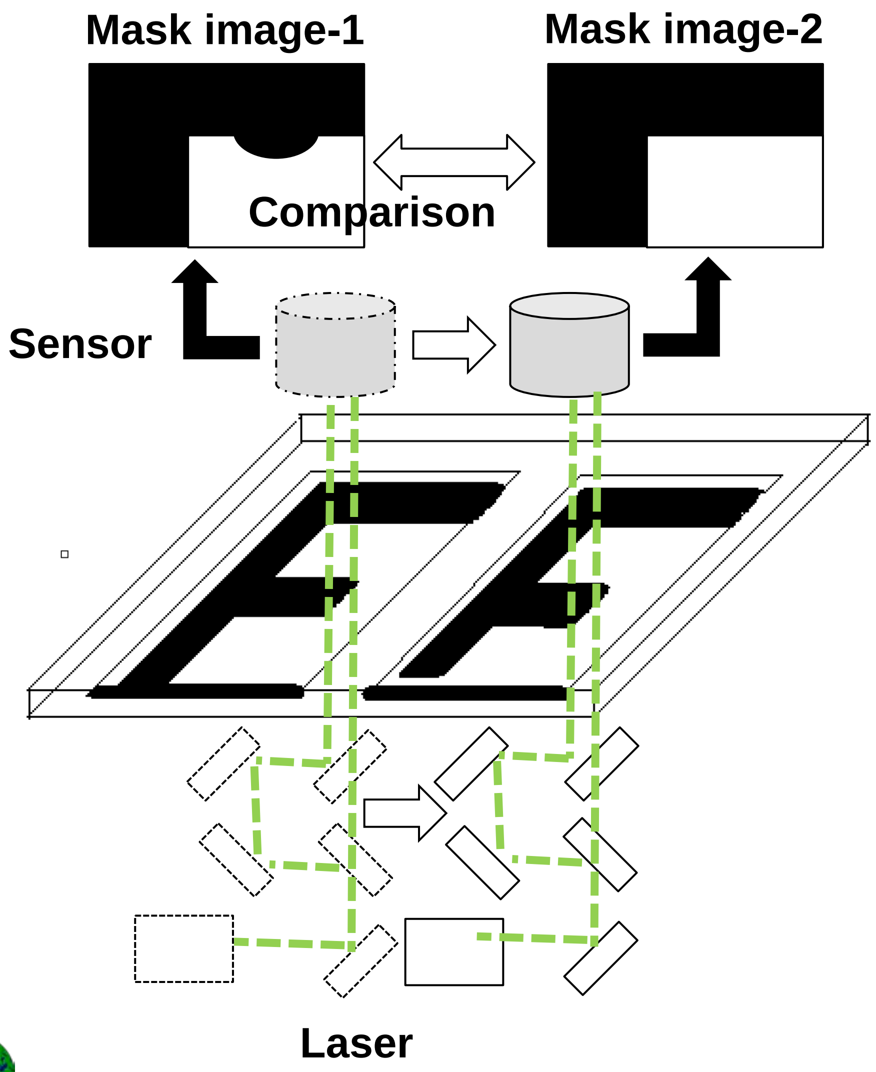
# Video background subtraction

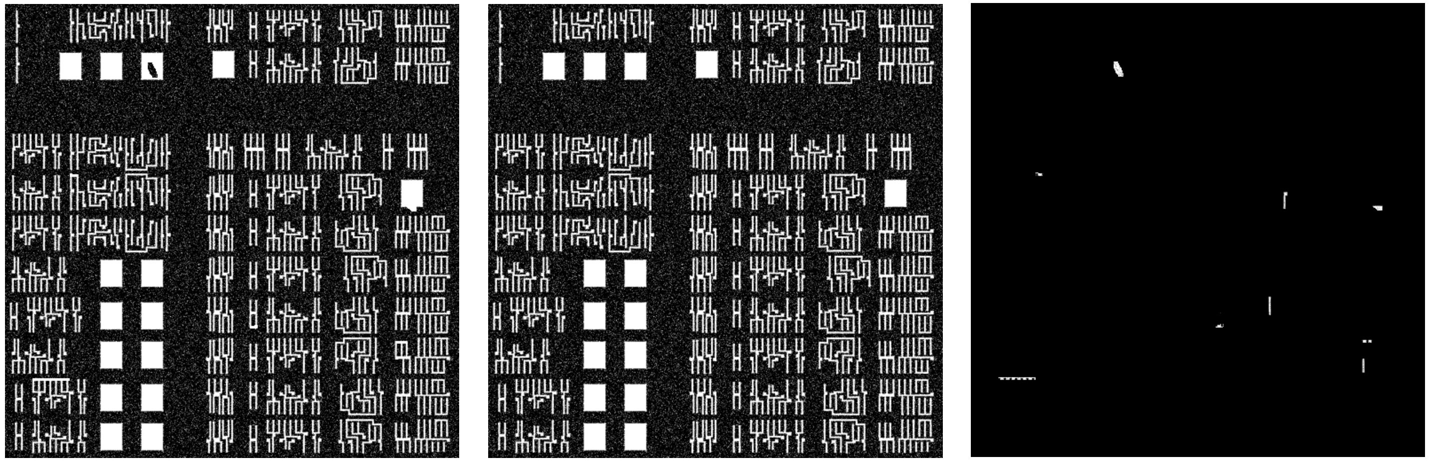



**Update:**

Background[t] := α Background[t-1] + (1- α) New[t]

# Image subtraction in IC manufacturing: inspection of photomasks



Mask image-1 Mask image-2 Difference image

# Where is the defect?

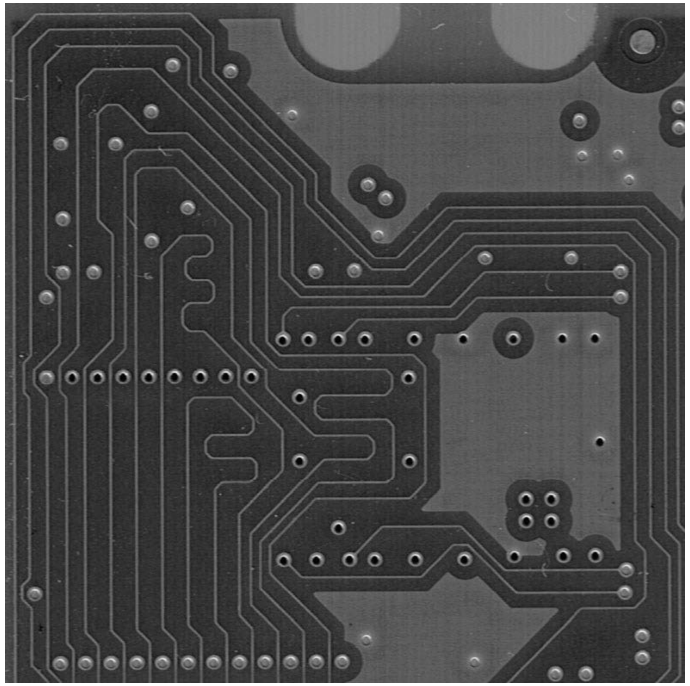


Image $g[x,y]$ (no defect)

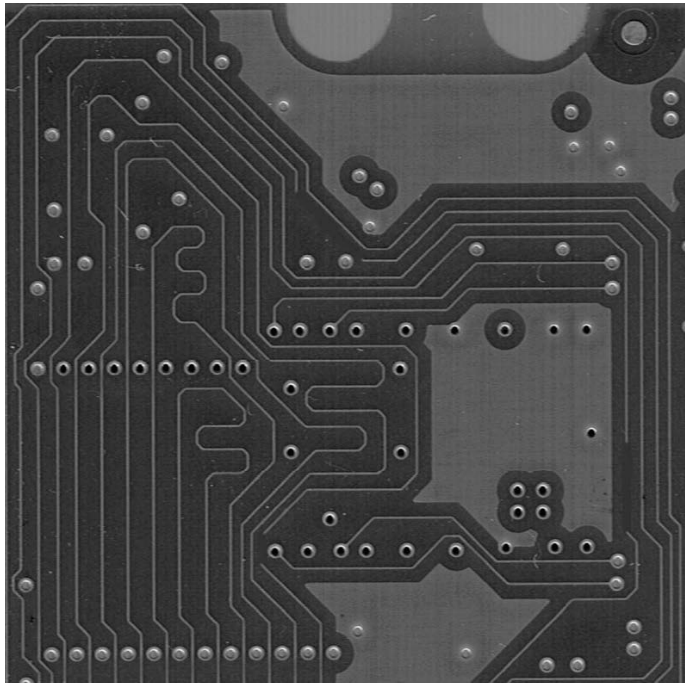
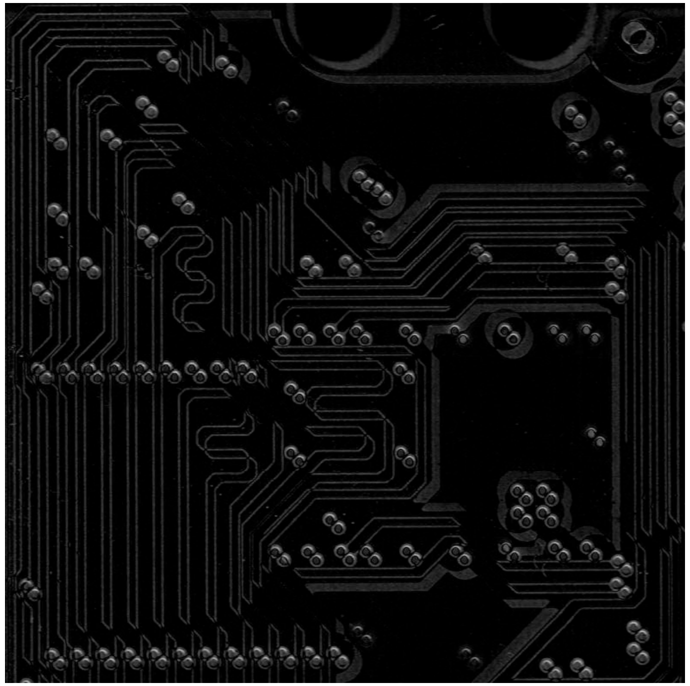
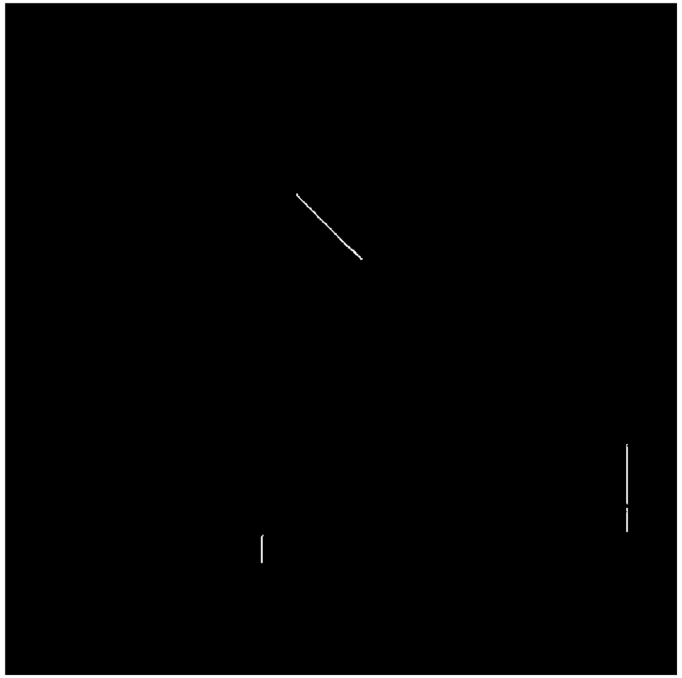


Image $f[x,y]$ (w/ defect)

# Absolute difference between two images



$|f\text{-}g|$ w/o alignment



$|f\text{-}g|$ w/ alignment