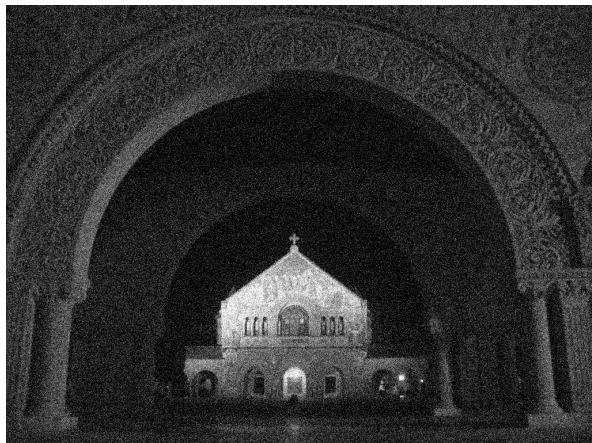


Point operations for combining images

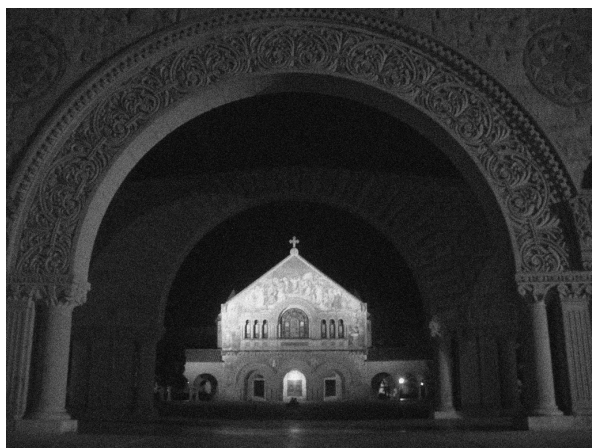
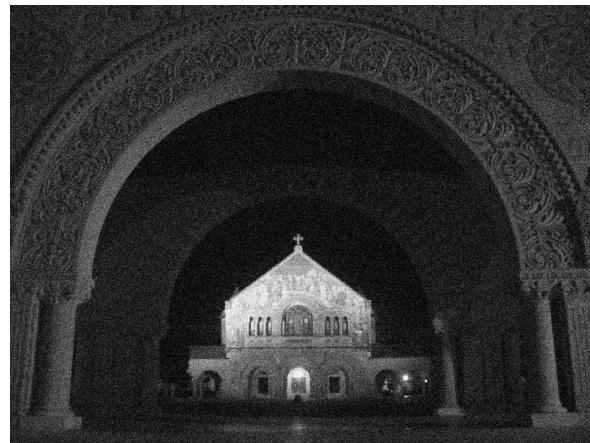
- Image averaging for noise reduction
- Combination of different exposures for high-dynamic range imaging
- Image subtraction for change detection
- Need for accurate alignment

Image averaging for noise reduction

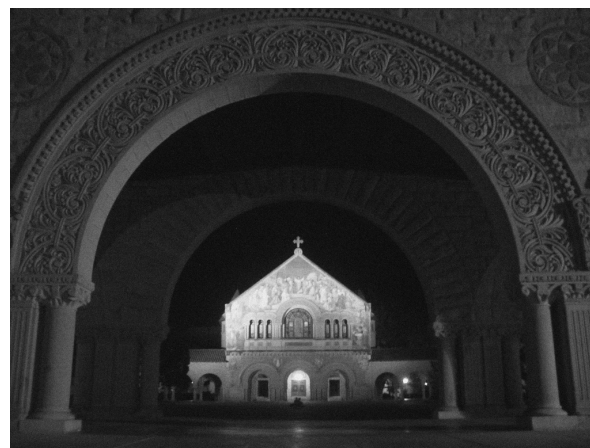
1 image



2 images



8 images



32 images



- Take N aligned images $f_1(x, y), f_2(x, y), \dots, f_N(x, y)$
- Average image: $\overline{f(x, y)} = \frac{1}{N} \sum_{i=1}^N f_i(x, y)$
- Mean squared error vs. noise-free image g

$$\begin{aligned}
 E\left\{\left(\overline{f} - g\right)^2\right\} &= E\left\{\left(\left(\frac{1}{N} \sum_i f_i\right) - g\right)^2\right\} = E\left\{\left(\left(\frac{1}{N} \sum_i (g + n_i)\right) - g\right)^2\right\} \\
 &= E\left\{\left(\frac{1}{N} \sum_i n_i\right)^2\right\} = \frac{1}{N^2} \sum_i E\{n_i^2\} = \frac{1}{N} E\{n^2\}
 \end{aligned}$$

provided $E\{n_i n_j\} = 0 \forall i, j$

$E\{n_i\} = E\{n\} \forall i$

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]



High-dynamic range imaging

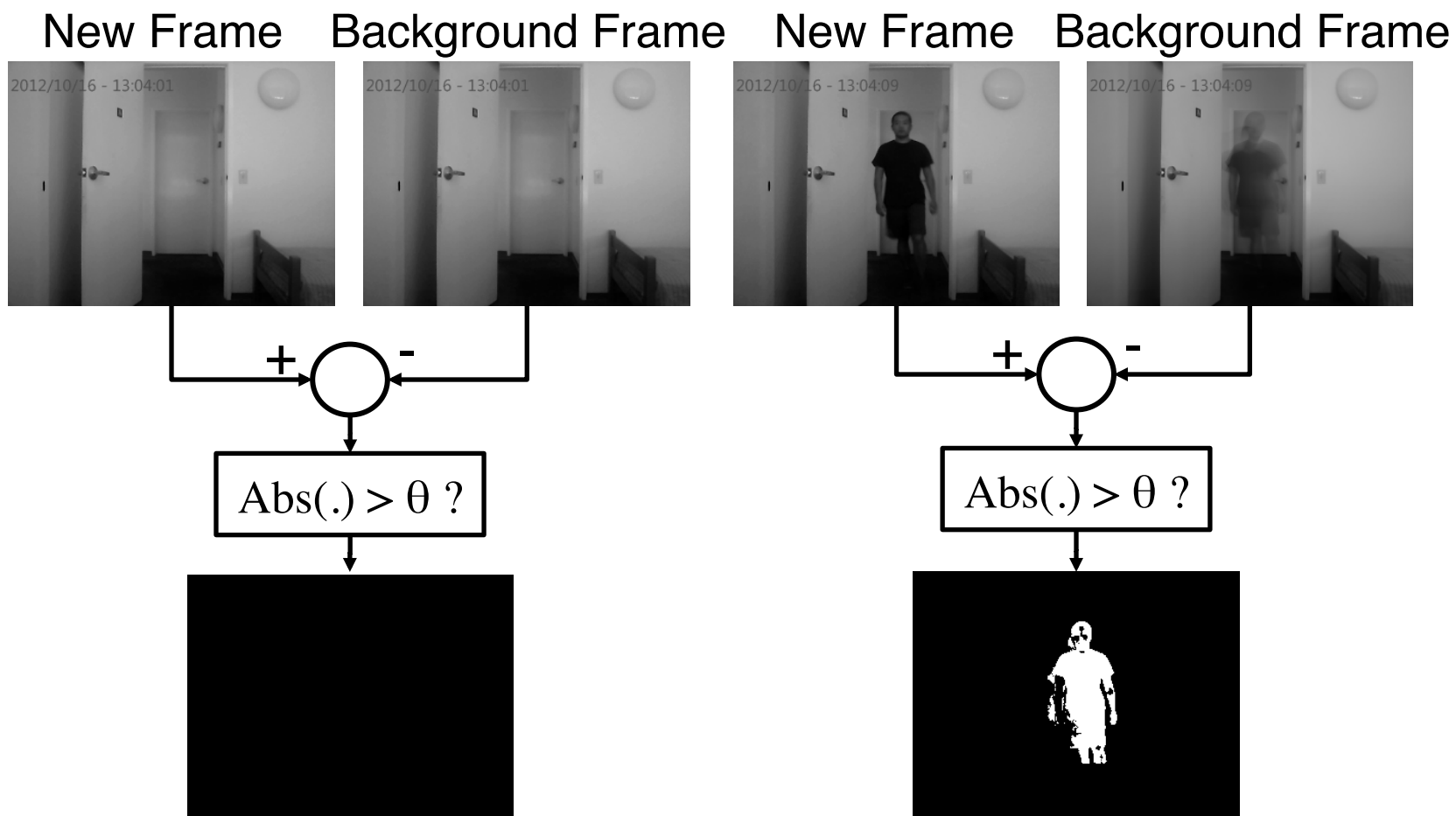


Image subtraction

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



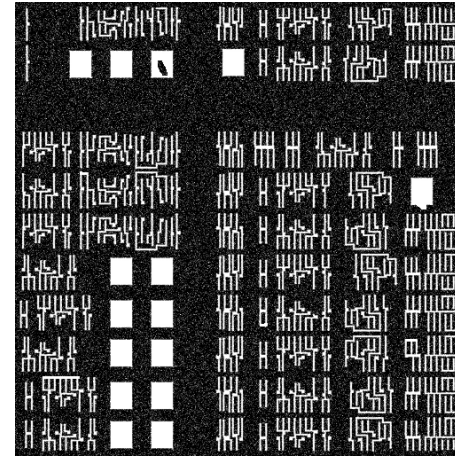
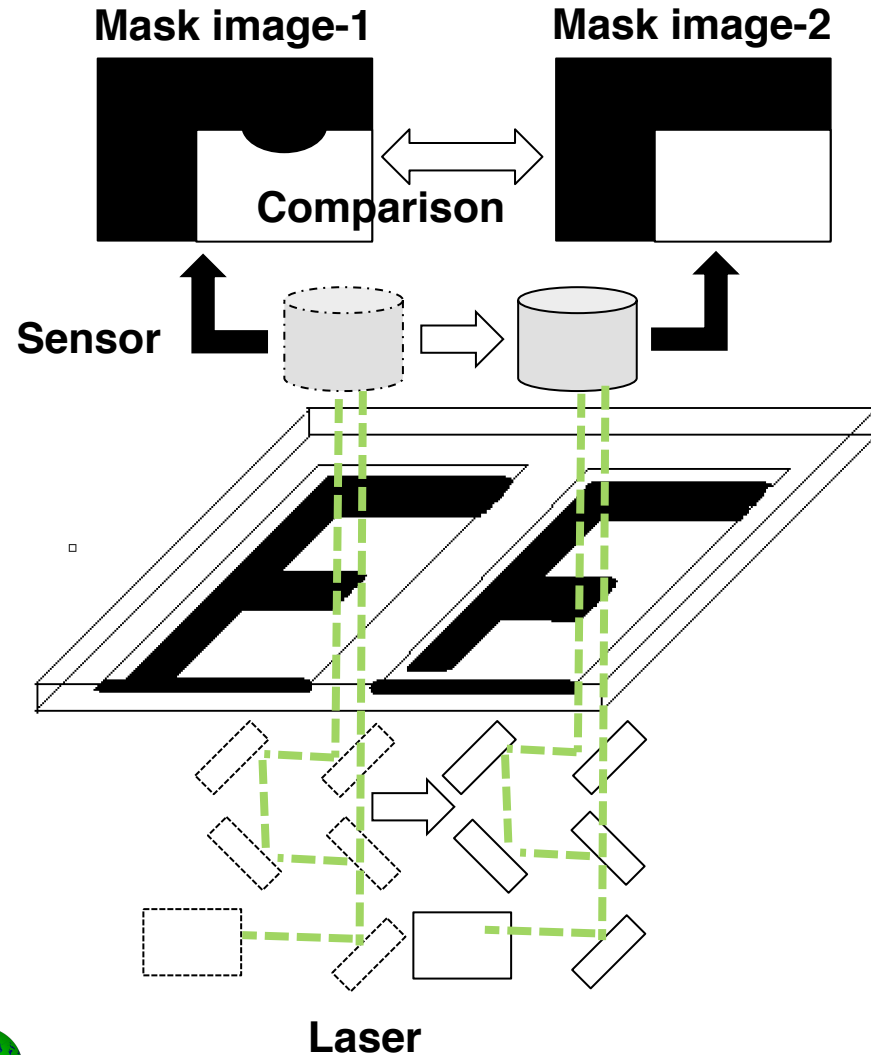
Video background subtraction



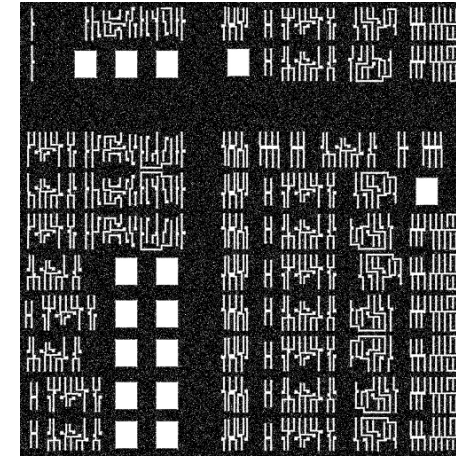
Update:
 $\text{Background}[t] := \alpha \text{Background}[t-1] + (1 - \alpha) \text{New}[t]$



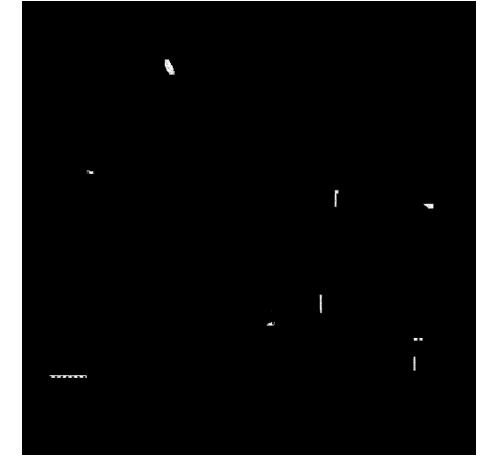
Image subtraction in IC manufacturing: inspection of photomasks



Mask image-1



Mask image-2



Difference image



Where is the defect?

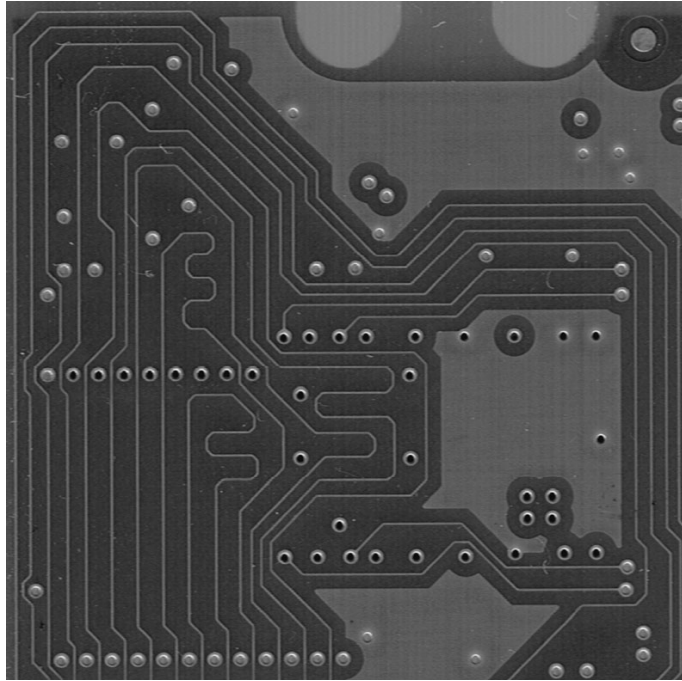


Image $g[x,y]$ (no defect)

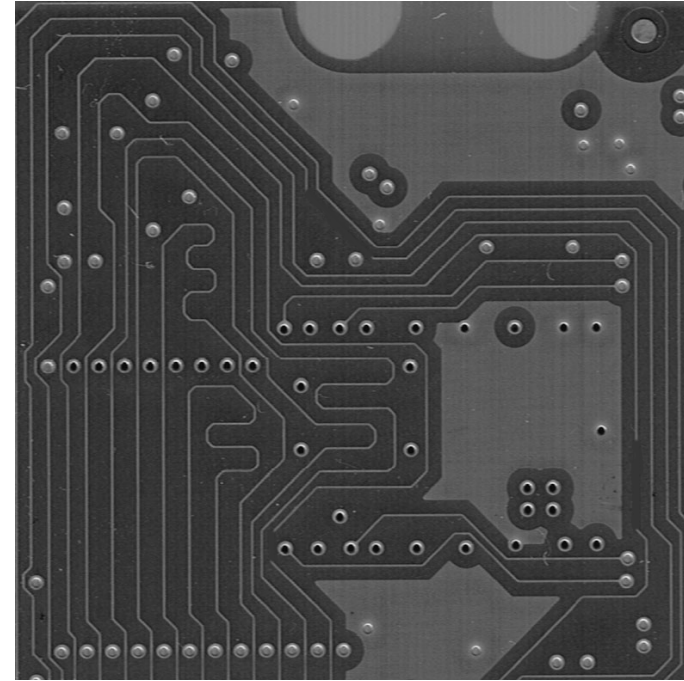
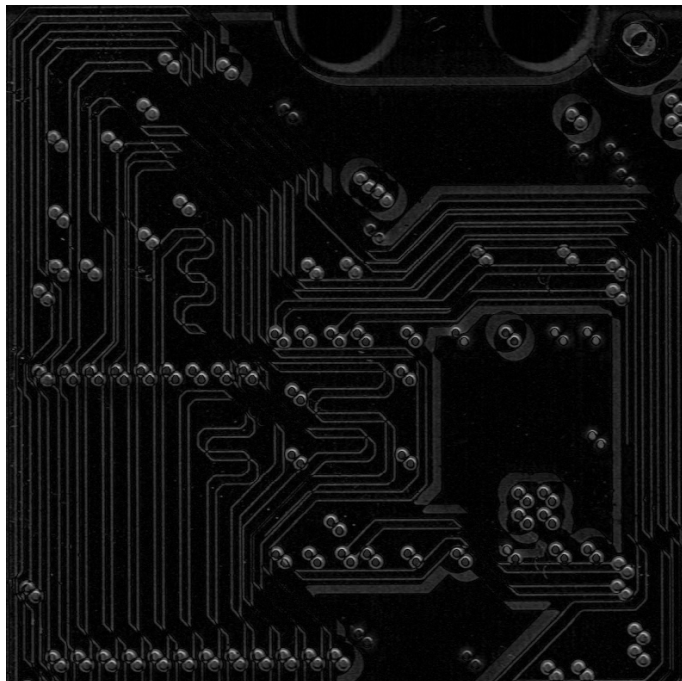


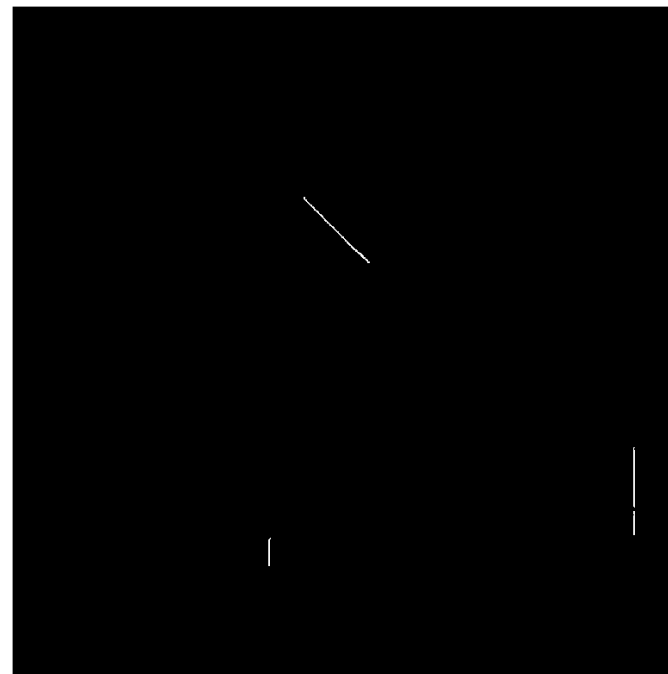
Image $f[x,y]$ (w/ defect)



Absolute difference between two images



$|f-g|$ w/o alignment



$|f-g|$ w/ alignment

