CSE185
Introduction to Computer Vision
Lab 05: Image Pyramid and Template Matching

Instructor: Prof. Ming-Hsuan Yang

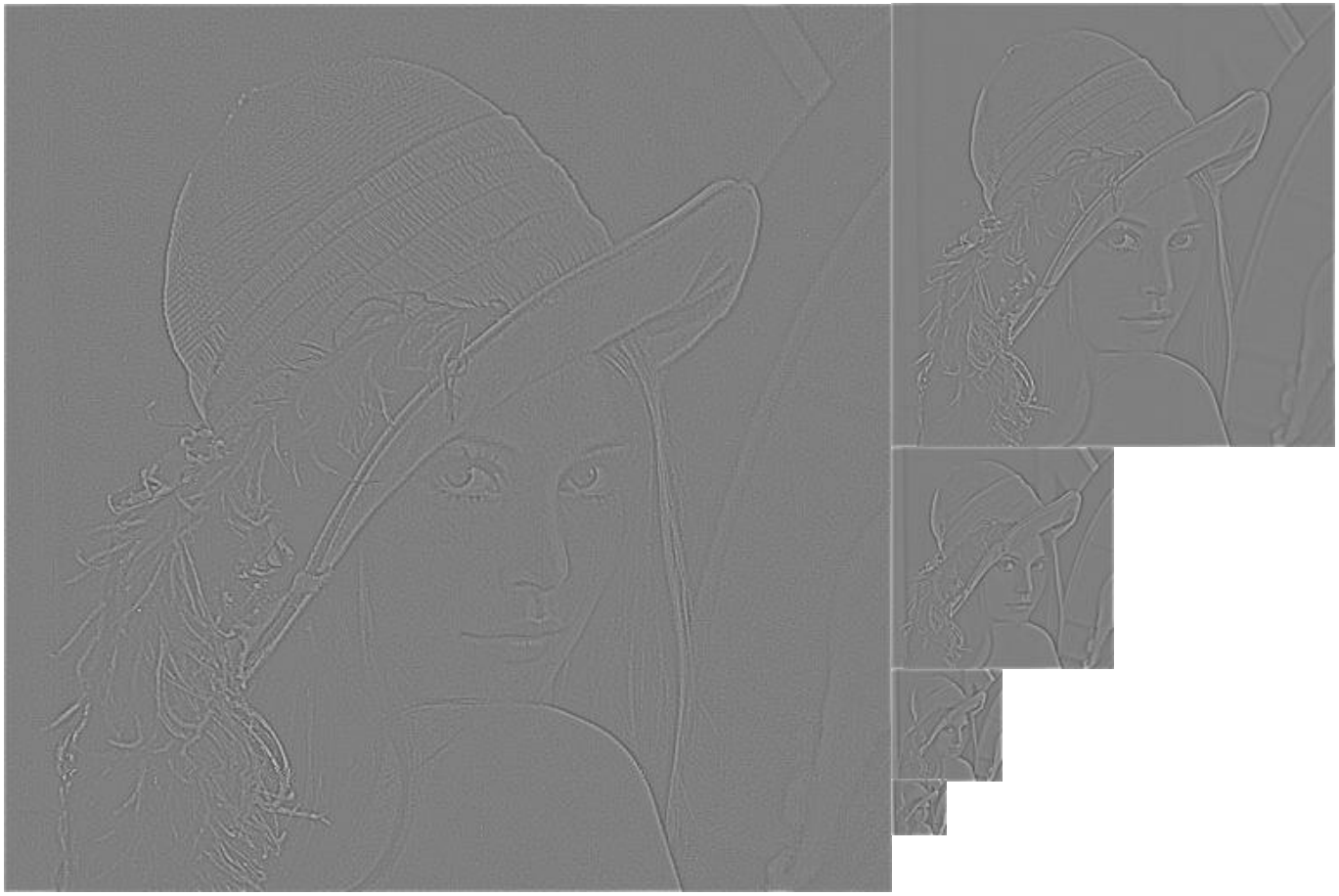
TA: Chun-Han Yao & Yi-Wen Chen

Overview

- Task 1: Gaussian Pyramid

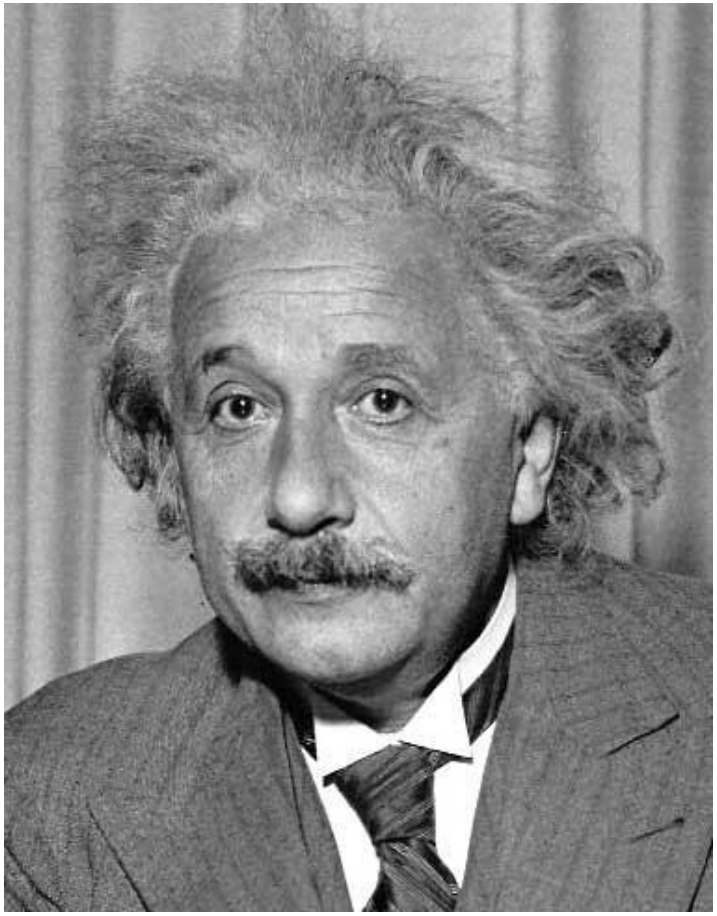
Overview

- Task 1: Laplacian Pyramid



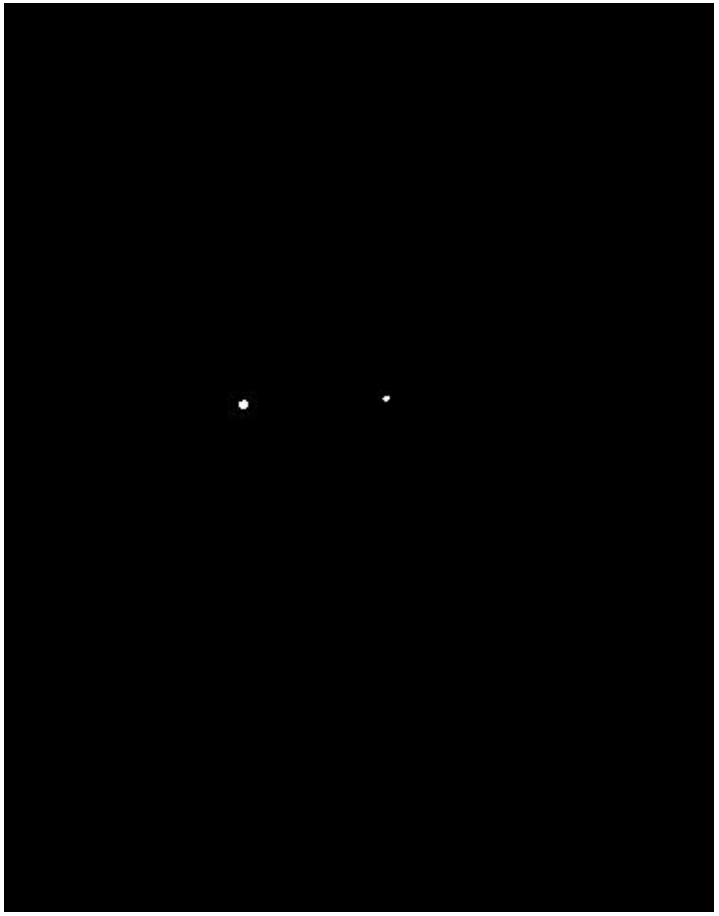
Overview

- Task 2: Template Matching



Input Image

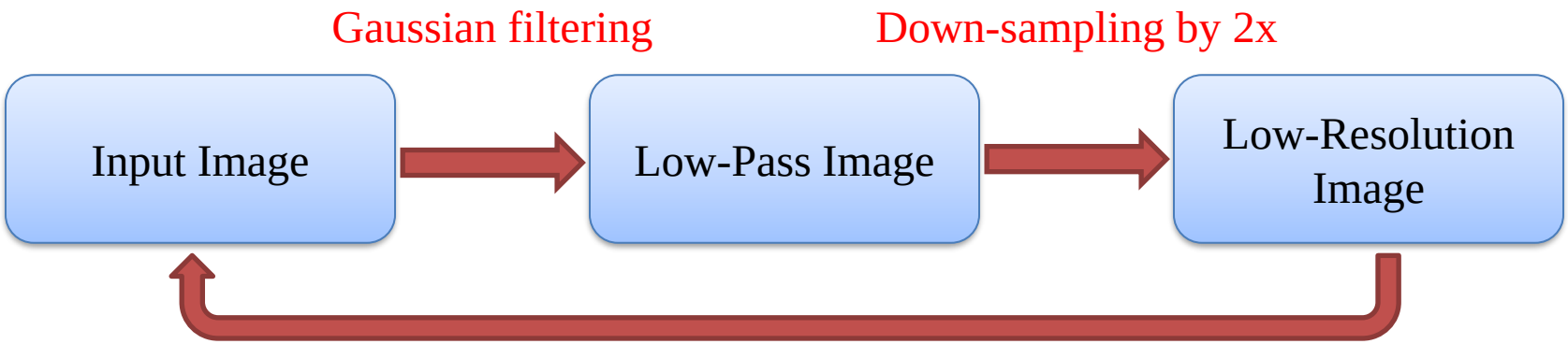
template



Match regions

Gaussian Pyramid

- Given an input image, a Gaussian kernel, construct a Gaussian Pyramid with *N* scales:



- Gaussian filter: use `imfilter` and `fspecial` or your `Gaussian_filter.m` in lab03.

- Down-sample: use `imresize` or your implementation in lab02.

Gaussian Pyramid

scale = 1

scale = 2

scale = 3

scale = 4

scale = 5

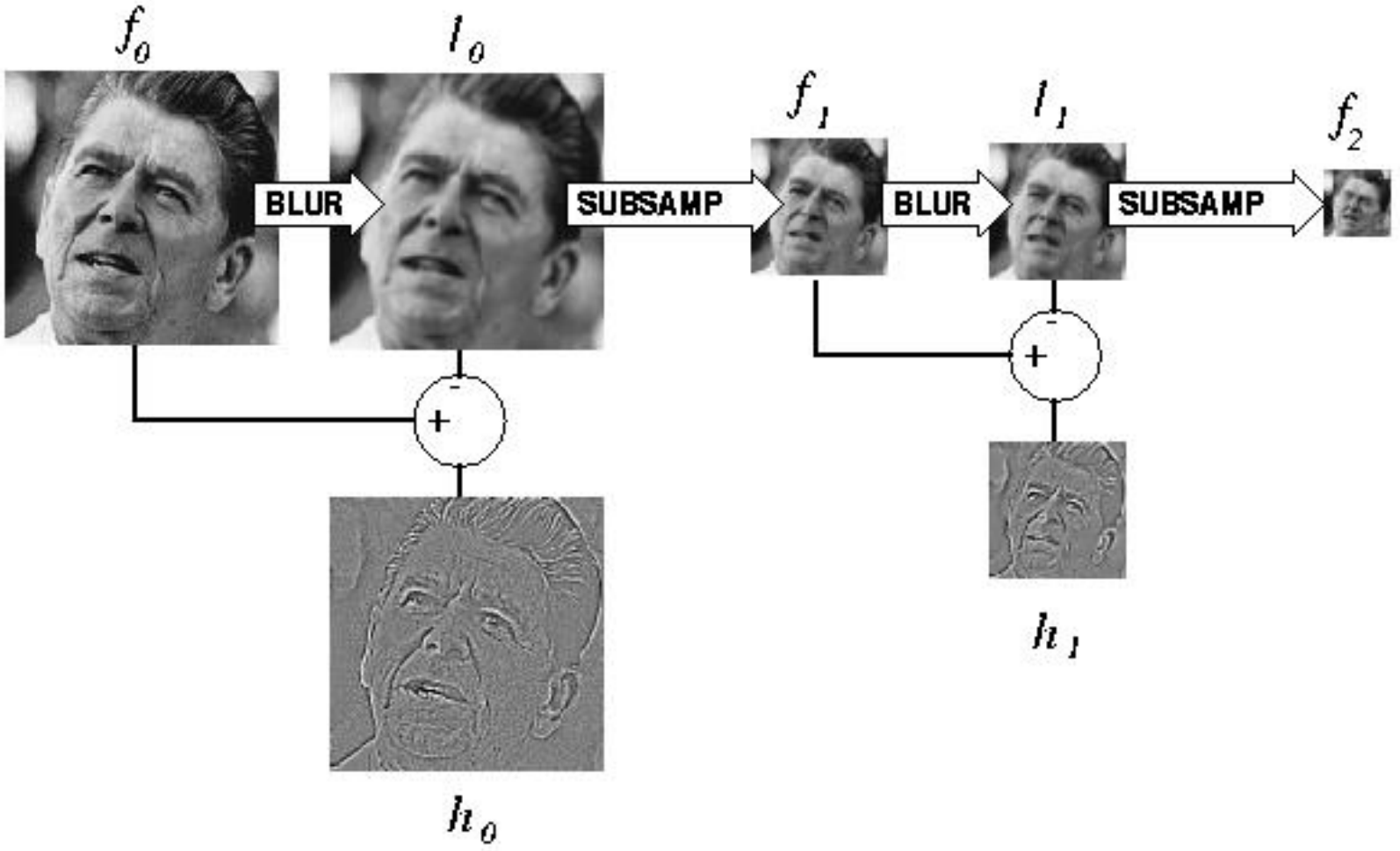
Gaussian Pyramid

- In `lab05_task1.m`:

```
img = im2double(imread('lena.jpg'));

sigma = 2.0;
hsize = 7;
scale = 5;

%% Gaussian Pyramid
I = img;
for s = 1 : scale

    % Gaussian filter

    % Save or show image
    imwrite(I, sprintf('Gaussian_scale%d.jpg', s));

    % Down-sampling

end
```

Laplacian Pyramid

- Laplacian filtering output = Input image – Gaussian filtering output



Laplacian Pyramid

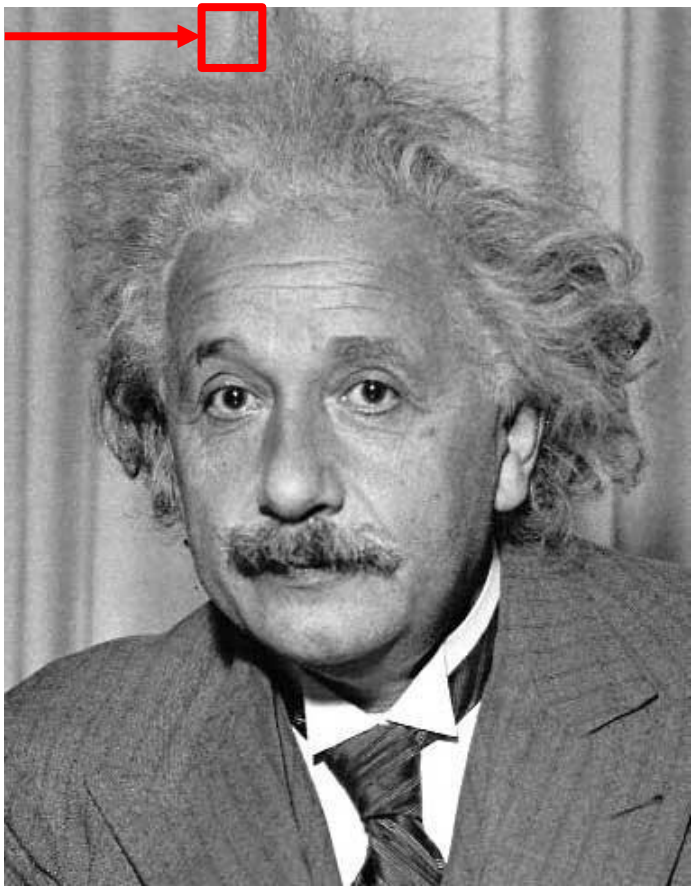
- In `lab05_task1.m`:

```
%% Laplacian Pyramid
for s = 1 : scale

    % Gaussian filtering

    % Laplacian filtering

    % Save or show image
    imwrite(I + 0.5, sprintf('Laplacian_scale%d.jpg',
s));

    % Down-sampling

end
```

Add 0.5 to better visualize negative values

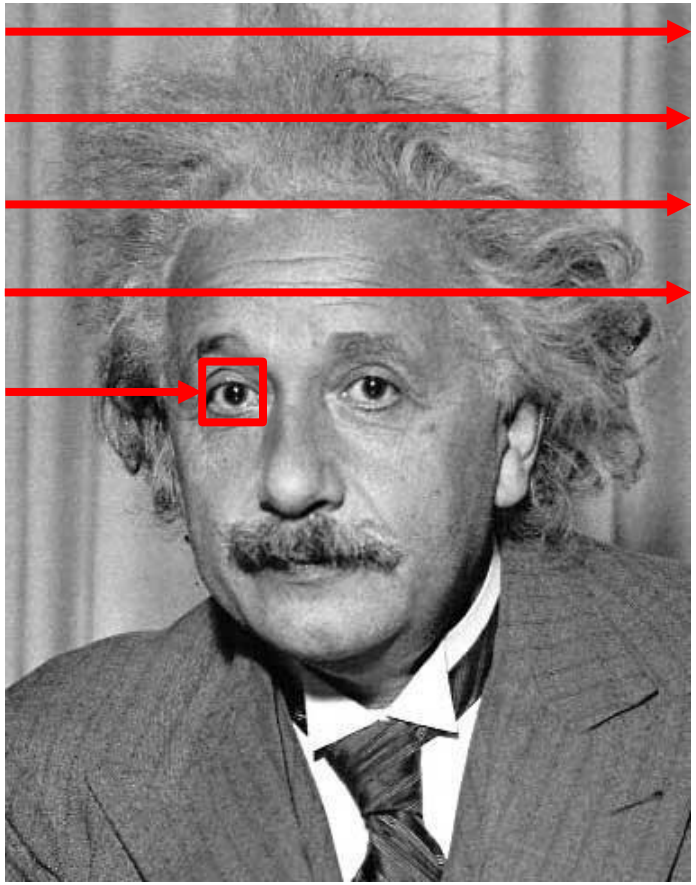
Template Matching

- Goal: given a template (patch)  , find matched regions in the input image
- use sliding window:



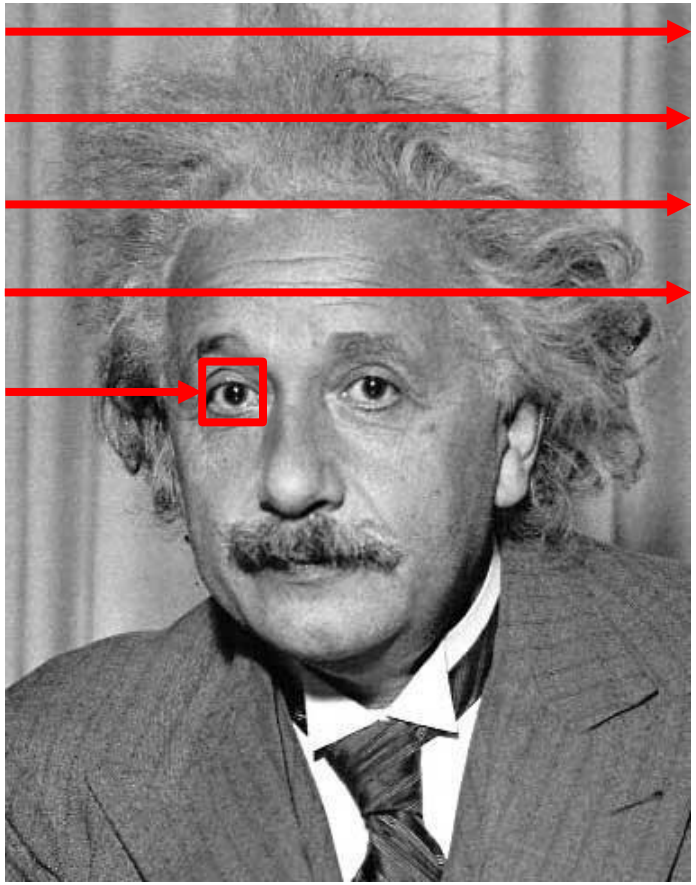
Template Matching

- Goal: given a template (patch)  , find matched regions in the input image
- use sliding window:



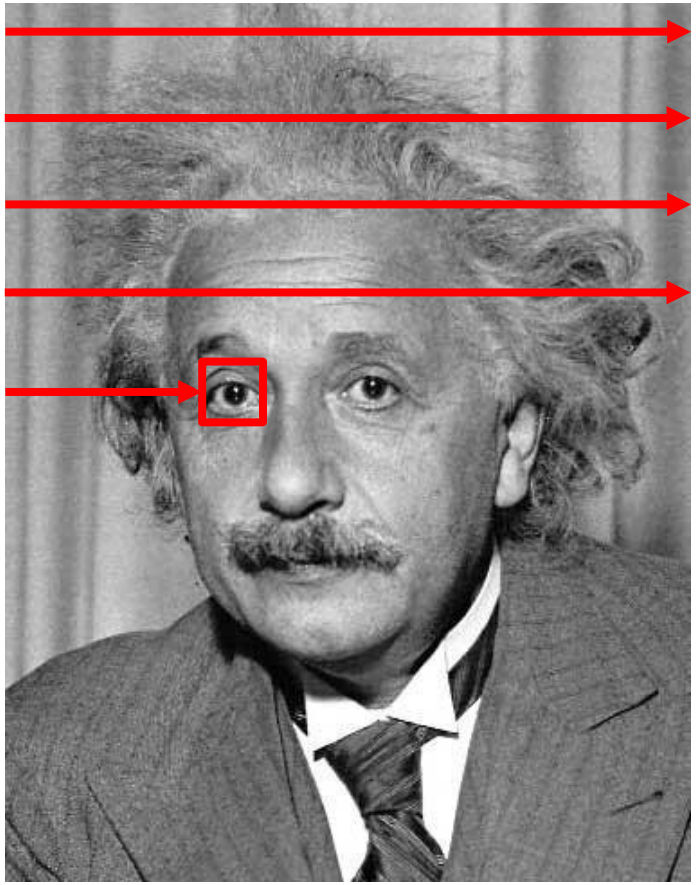
Template Matching

- Goal: given a template (patch)  , find matched regions in the input image
- use sliding window:
  - similar to spatial filtering!



Template Matching

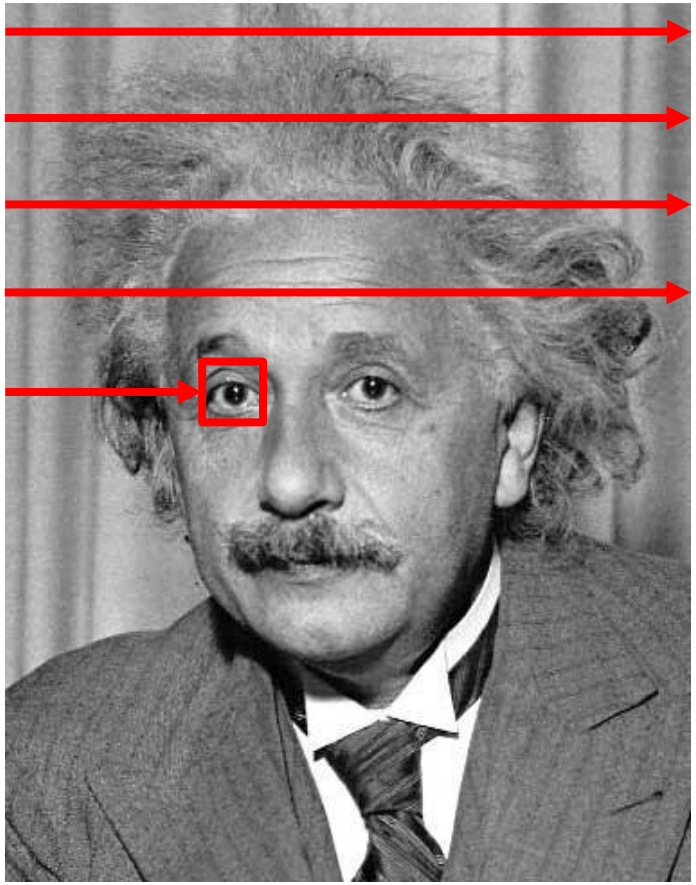
- Goal: given a template (patch)  , find matched regions in the input image
- use sliding window:
  - similar to spatial filtering!



- Matching criteria:
  - correlation
  - zero-mean correlation
  - Sum of Square Difference (SSD)
  - Normalized Cross-Correlation (NormCorr)

Template Matching

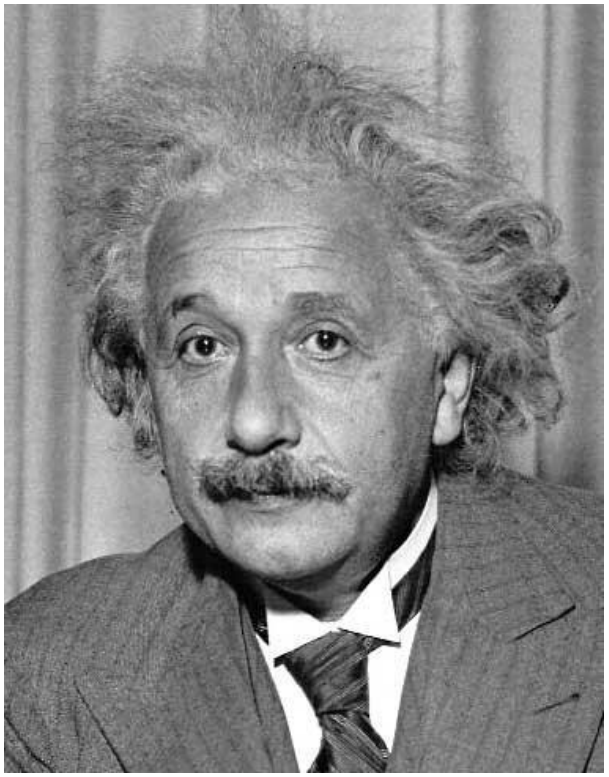
- Goal: given a template (patch)  , find matched regions in the input image
- use sliding window:
  - similar to spatial filtering!
- Matching criteria:
  - correlation
  - zero-mean correlation
  - Sum of Square Difference (SSD)
  - Normalized Cross-Correlation (NormCorr)

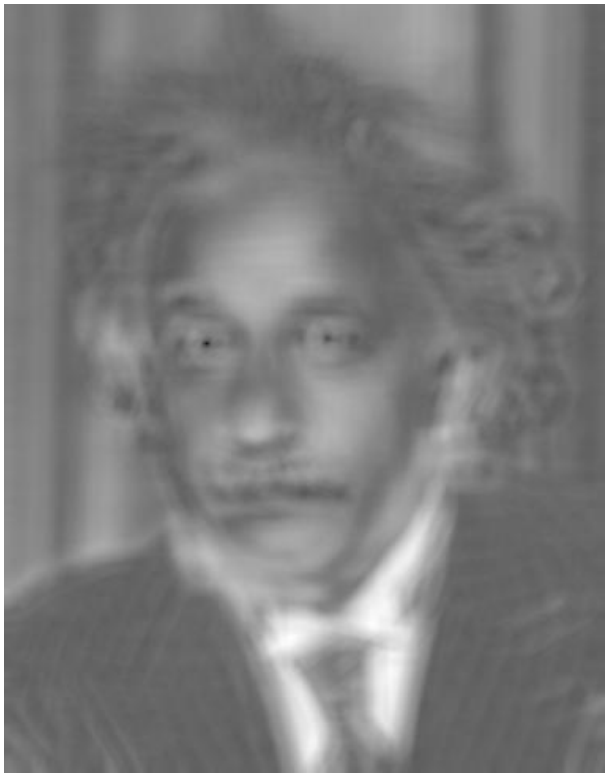


Template Matching with SSD

- SSD: calculate the difference between the template and each image patch

$$I'(u,v) = \sum_i \sum_j [I(u+i, v+j) - H(i,j)]^2$$

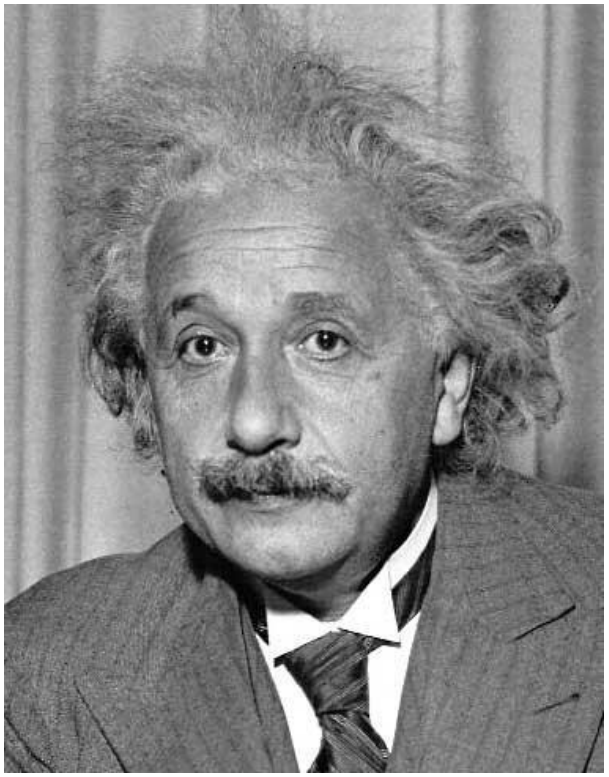




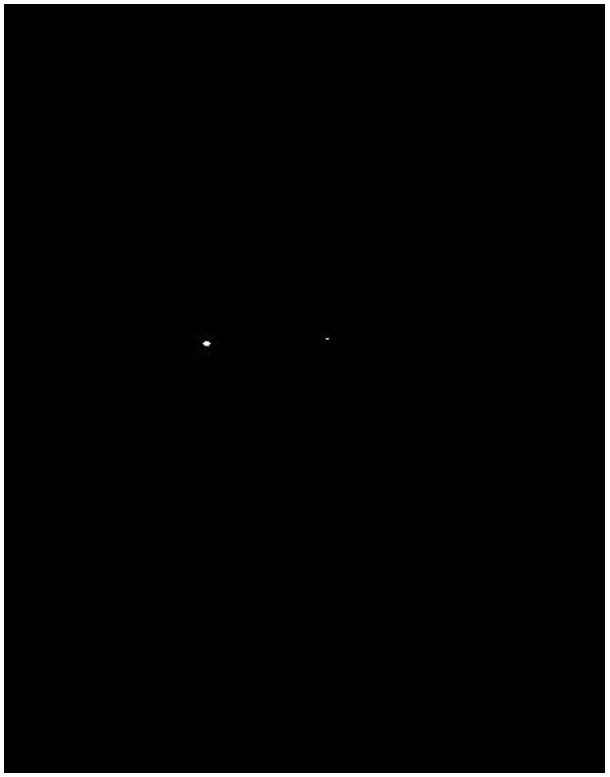
Template Matching with SSD

- SSD: calculate the difference between the template and each image patch

$$Match\ Regions = (output < threshold)$$



threshold = 25



Template Matching with SSD

- In `template_matching_SSD.m`

```
for u = 1 + shift_u : size(I1, 2) - shift_u
    for v = 1 + shift_v : size(I1, 1) - shift_v

        x1 = ???; x2 = ???;
        y1 = ???; y2 = ???;
        patch = I1(y1:y2, x1:x2);

        % SSD
        value = ???;
        output(v, u) = value;

    end
end

match = (output < threshold);
```

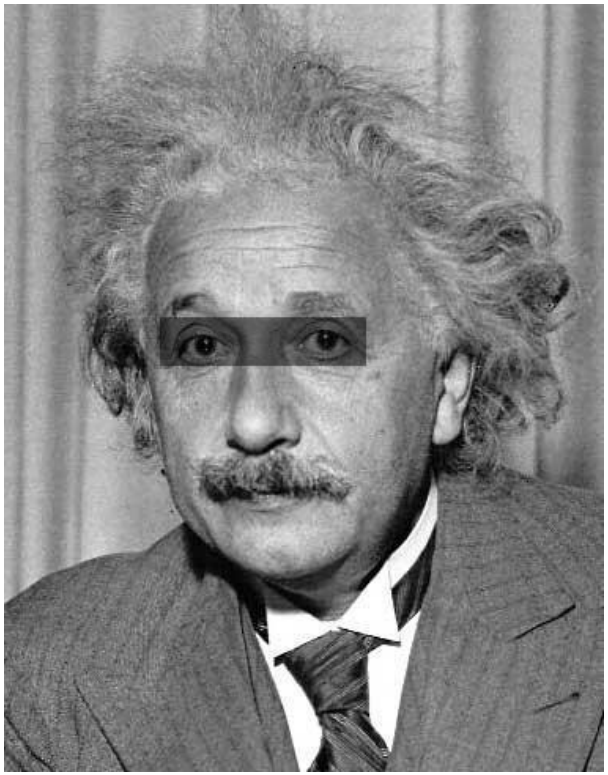
Template Matching with SSD

- In `lab05_task2.m`

```
name = 'einstein1';
%name = 'einstein2';

img = im2double(imread(sprintf('%s.jpg', name)));
template = im2double(imread('template.jpg'));

%% SSD
threshold = ???;
[output, match] = template_matching_SSD(img,
template, threshold);

figure, imshow(output ./ max(output(:))); title('SSD
output');
figure, imshow(match); title('SSD match');

imwrite(output ./ max(output(:)),
sprintf('%s_ssd_output.jpg', name));
imwrite(match, sprintf('%s_ssd_match.jpg', name));
```

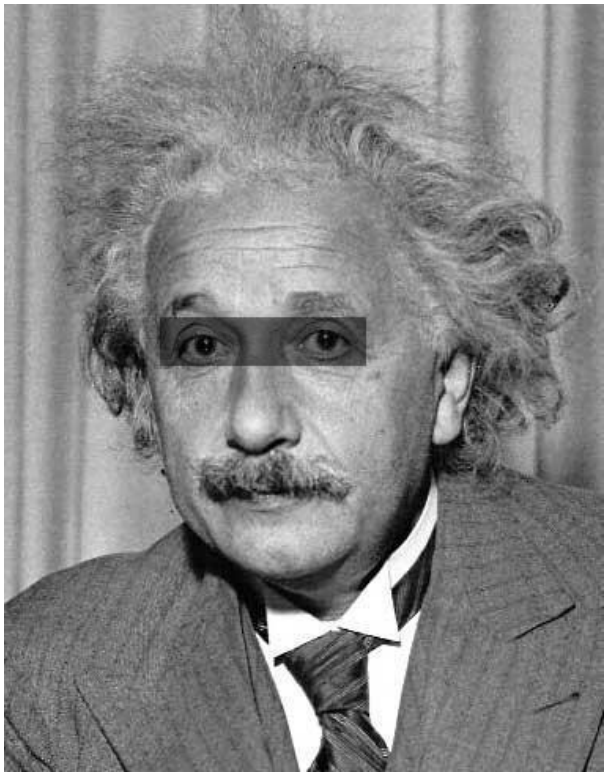
Template Matching with SSD

- However, SSD is sensitive to intensity change

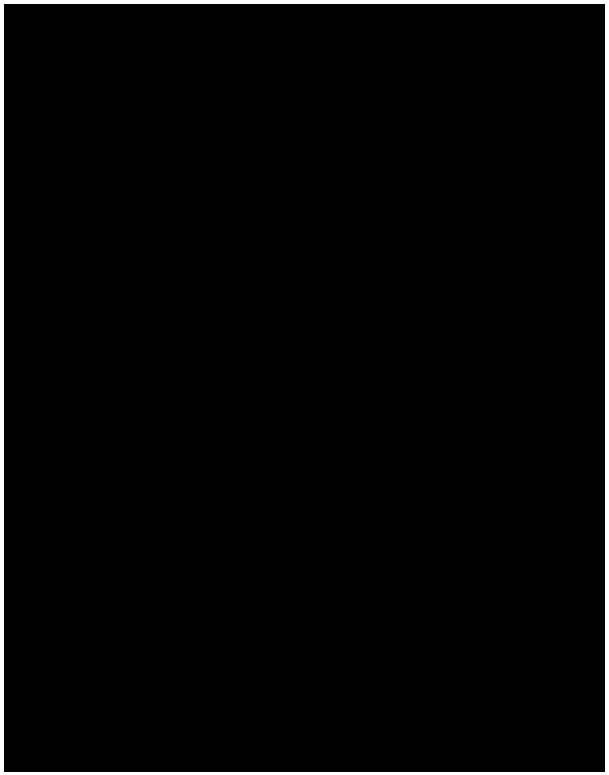


Template Matching with SSD

- However, SSD is sensitive to intensity change
  - hard to define the threshold value

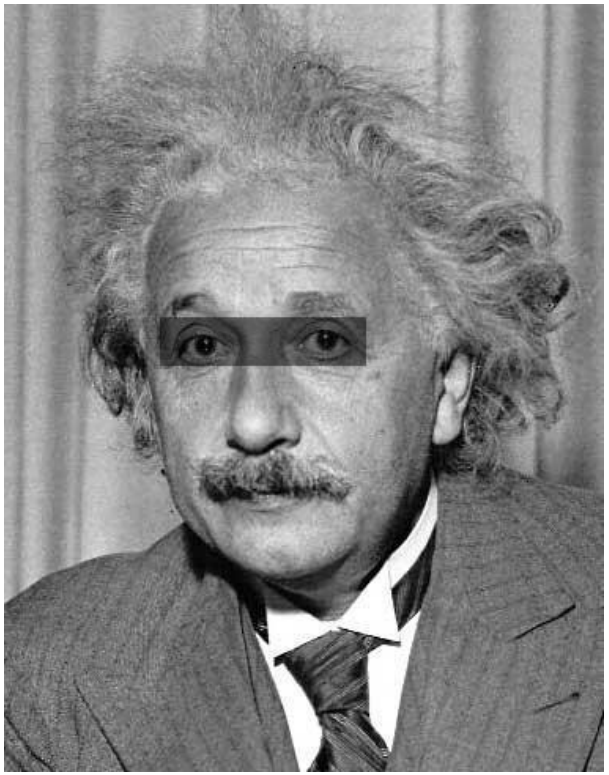


threshold = 25



Template Matching with SSD

- However, SSD is sensitive to intensity change
  - hard to define the threshold value



threshold = 36

Normalized Cross-Correlation

- Normalized cross-correlation:
  - assume P_{uv} is a local image patch at (u, v), H is the template patch

$$normcorr = \frac{\sum_{i,j}(P_{uv}(i,j) - \bar{P}_{uv})(H(i,j) - \bar{H})}{\left(\sum_{i,j}(P_{uv}(i,j) - \bar{P}_{uv})^2 \sum_{i,j}(H(i,j) - \bar{H})^2\right)^{0.5}}$$

$\bar{P}_{uv} = \text{mean}(P_{uv})$
$\bar{H} = \text{mean}(H)$

Normalized Cross-Correlation

- Let's simplify it:
  1. convert P_{uv} and H to vectors

Normalized Cross-Correlation

- Let's simplify it:
  1. convert P_{uv} and H to vectors
  2. subtract mean: $\mathrm{P}'_{uv} = P_{uv} - \bar{P}_{uv}$ and $\mathrm{h}' = H - \bar{H}$

Normalized Cross-Correlation

- Let's simplify it:
  1. convert P_{uv} and H to vectors
  2. subtract mean: $\mathrm{P}'_{uv} = P_{uv} - \bar{P}_{uv}$ and $\mathrm{h}' = H - \bar{H}$
  3. normalize length to 1: $\mathrm{P}''_{uv} = \frac{P'_{uv}}{\|P'_{uv}\|_2}$ and $\mathrm{h}'' = \frac{\mathrm{h}'}{\|\mathrm{h}'\|_2}$

$$normcorr = dot(\mathrm{P}''_{uv}, \mathrm{h}'')$$

Simple dot product of two normalized vectors

Normalized Cross-Correlation

- Let's simplify it:
  1. convert P_{uv} and H to vectors
  2. subtract mean: $\mathrm{P}'_{uv} = P_{uv} - \bar{P}_{uv}$ and $\mathrm{h}' = H - \bar{H}$
  3. normalize length to 1: $\mathrm{P}''_{uv} = \frac{P'_{uv}}{\|P'_{uv}\|_2}$ and $\mathrm{h}'' = \frac{\mathrm{h}'}{\|\mathrm{h}'\|_2}$

$$normcorr = dot(\mathrm{P}''_{uv}, \mathrm{h}'')$$

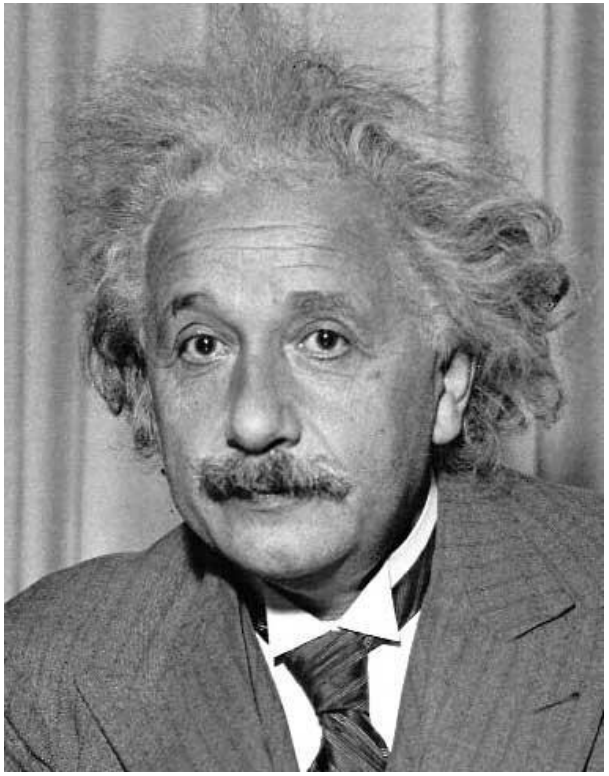
Simple dot product of two normalized vectors

- $\|x\|_2$: the norm (length) of the vector
  - $\|x\|_2 = \sqrt[2]{\sum_i x_i^2}$
  - use `norm(x)` in MATLAB (x must be a vector!)
  - norm of vector ≠ norm of matrix

Normalized Cross-Correlation

- Normalized cross-correlation:

$$normcorr = dot(\mathrm{P}'_{uv}, \mathrm{h}')$$



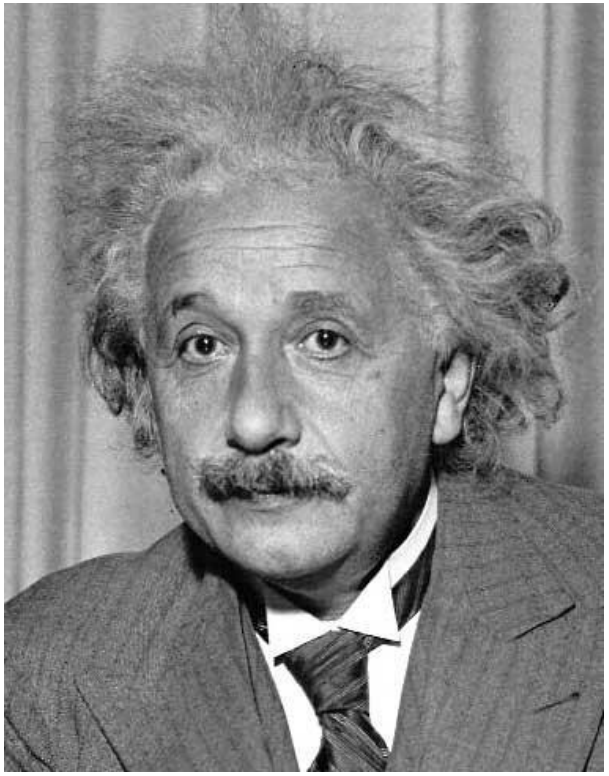
Normalized Cross-Correlation

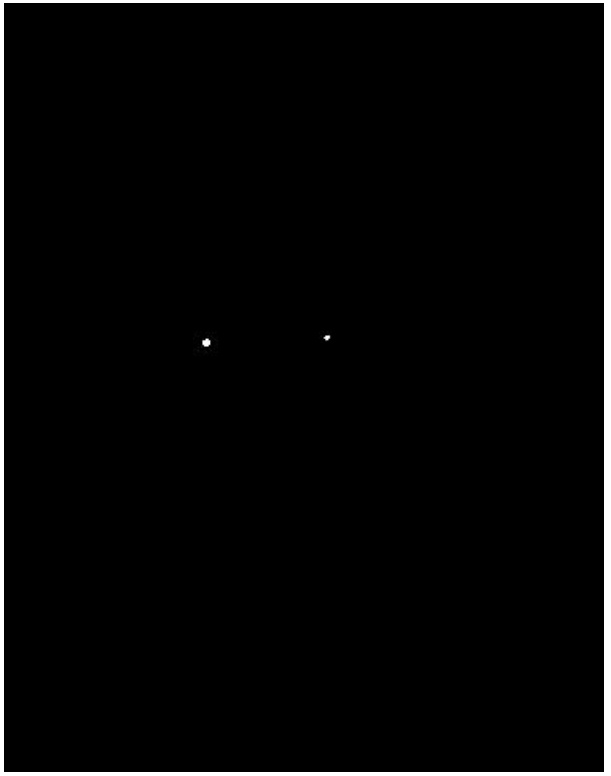
- Normalized cross-correlation:

$$normcorr = dot(\mathrm{P}'_{uv}, \mathrm{h}')$$

$$Match\ Regions = (output > threshold)$$

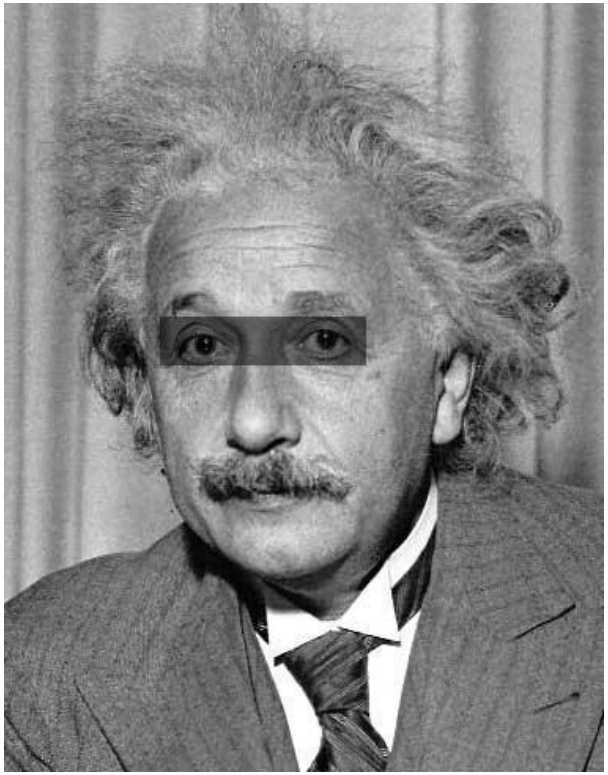
threshold = 0.5





Normalized Cross-Correlation

- Normalized cross-correlation is invariant to intensity/contrast change

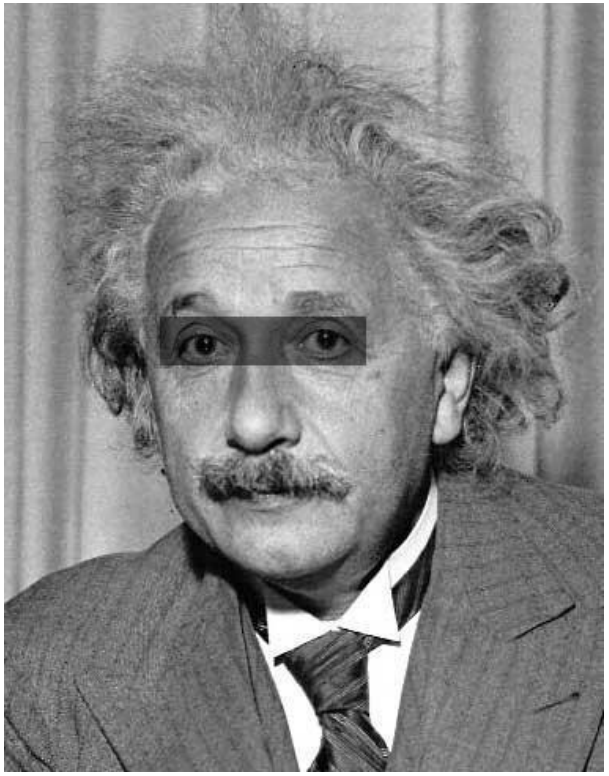


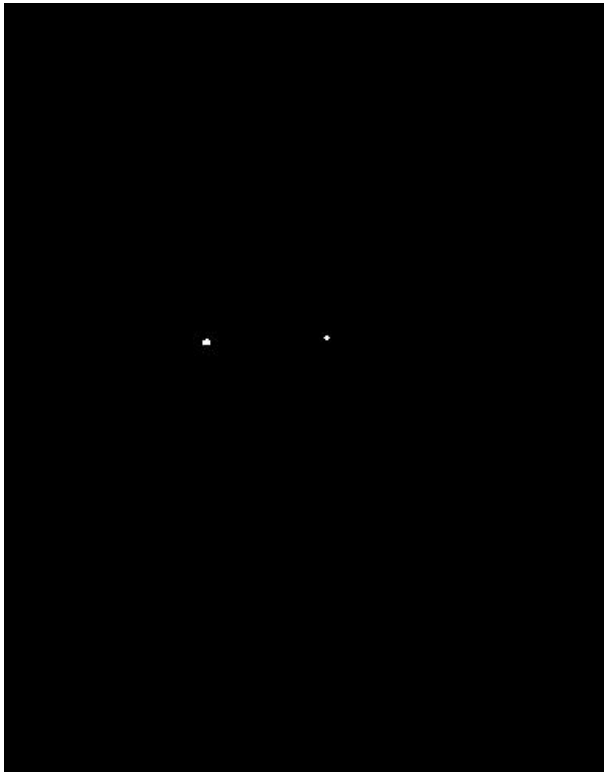
Normalized Cross-Correlation

- Normalized cross-correlation is invariant to intensity/contrast change

$$Match\ Regions = (output > threshold)$$

threshold = 0.5





Template Matching with NormCorr

- In `template_matching_normcorr.m`

```
for u = 1 + shift_u : size(I1, 2) - shift_u
    for v = 1 + shift_v : size(I1, 1) - shift_v

        x1 = ???; x2 = ???;
        y1 = ???; y2 = ???;
        patch = I1(y1:y2, x1:x2);

        % Normalized Cross-Correlation
        value = ???;
        output(v, u) = value;

    end
end

match = (output > threshold);
```

Template Matching with NormCorr

- In `lab05_task2.m`

```
%% Normalized Cross-Correlation

threshold = ???;
[output, match] = template_matching_normcorr(img,
template, threshold);

figure, imshow(output ./ max(output(:)));
title('NormCorr output');
figure, imshow(match); title('NormCorr match');

imwrite(output ./ max(output(:)),
sprintf('%s_normcorr_output.jpg', name));
imwrite(match, sprintf('%s_normcorr_match.jpg', name)
);
```

Assignment

1. Implement Gaussian Pyramid and Laplacian Pyramid in lab05_task1.m (use lena.jpg as input and save the output images as Gaussian_scale1.jpg ~ Gaussian_scale5.jpg and Laplacian_scale1.jpg ~ Laplacian_scale5.jpg)
2. Implement template_matching_SSD.m, and try to find the best threshold value for einstein1.jpg and einstein2.jpg (save the output images as einstein1_ssd_output.jpg, einstein1_ssd_match.jpg, einstein2_ssd_output.jpg, einstein2_ssd_match.jpg)
3. Implement template_matching_normcorr.m, and try to find the best threshold value for einstein1.jpg and einstein2.jpg (save the output images as einstein1_normcorr_output.jpg, einstein1_normcorr_match.jpg, einstein2_normcorr_output.jpg, einstein2_normcorr_match.jpg)
4. Upload all output images and lab05_task1.m, lab05_task2.m, template_matching_SSD.m, and template_matching_normcorr.m separately.