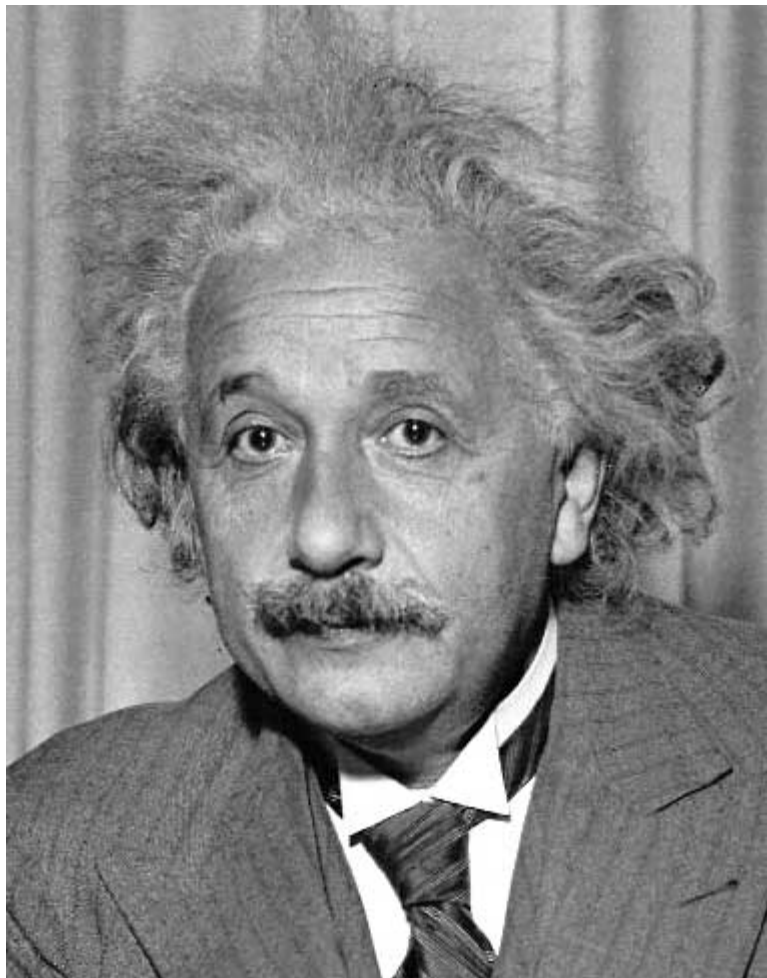


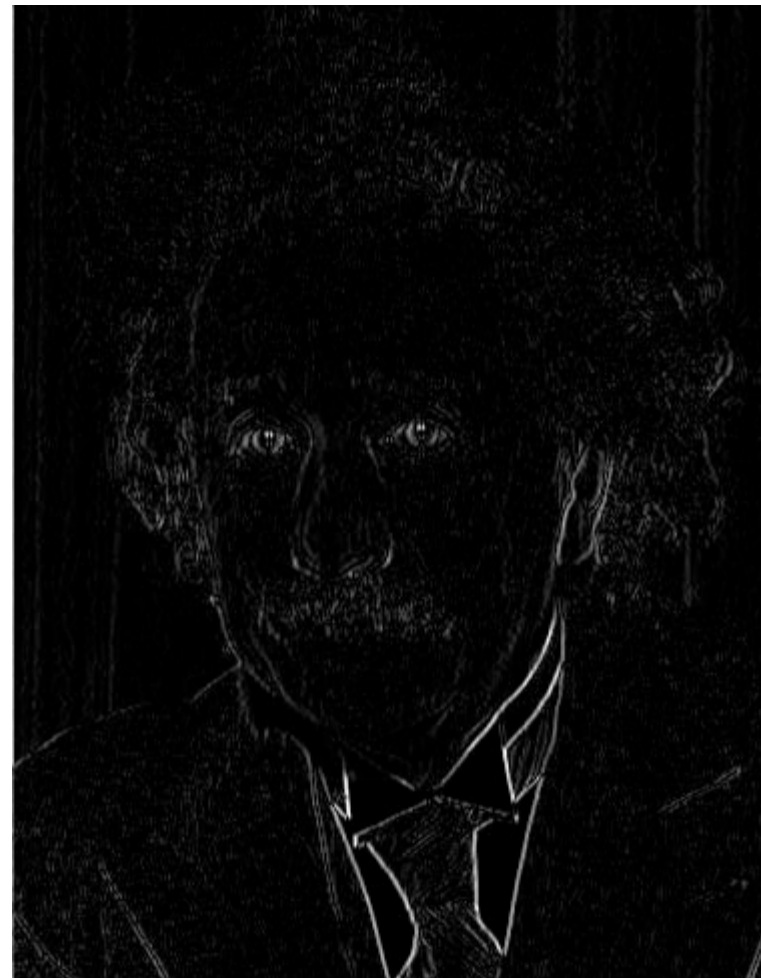
# Image Enhancement using Filters

# Other filters



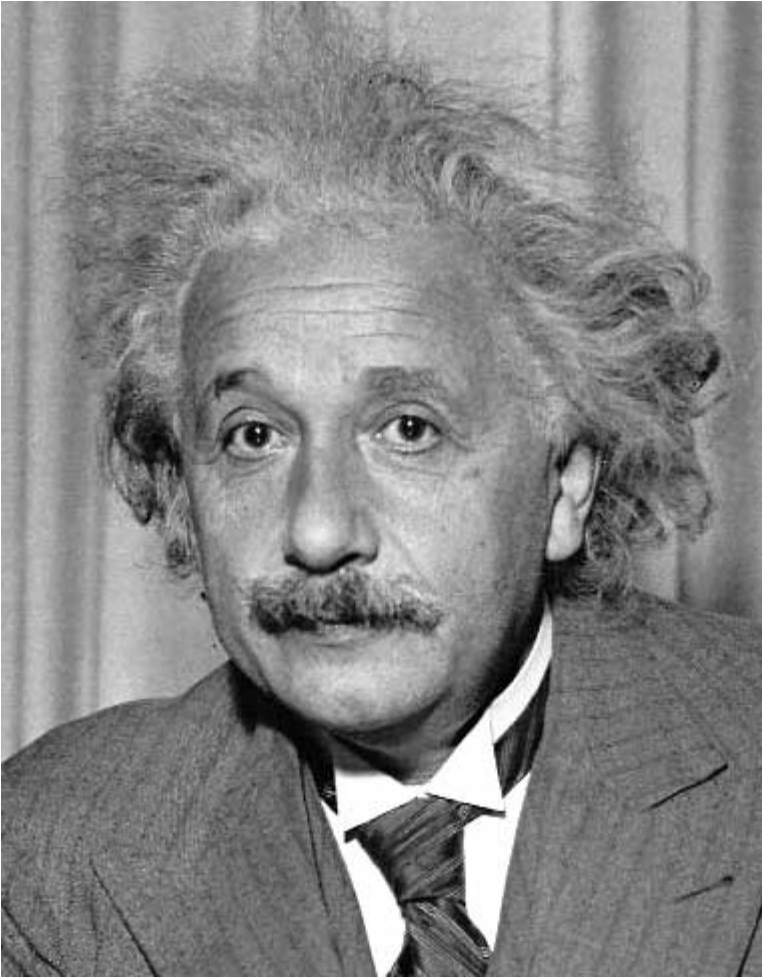
1	0	-1
2	0	-2
1	0	-1

Sobel



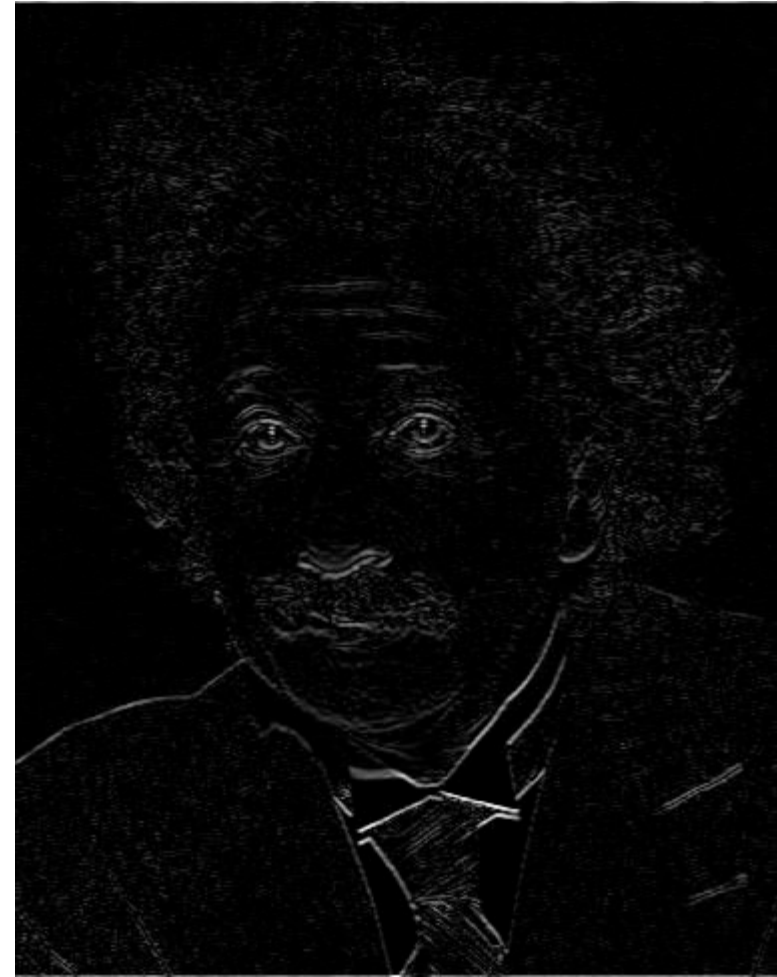
Vertical Edge  
(absolute value)

# Other filters



1	2	1
0	0	0
-1	-2	-1

Sobel



Horizontal Edge  
(absolute value)

# Key properties of linear filters

## **Linearity:**

$$\text{filter}(f_1 + f_2) = \text{filter}(f_1) + \text{filter}(f_2)$$

**Shift invariance:** same behavior regardless of pixel location

$$\text{filter}(\text{shift}(f)) = \text{shift}(\text{filter}(f))$$

Any linear, shift-invariant operator can be represented as a convolution

# Separability example

2D convolution  
(center location only)

$$\begin{array}{|c|c|c|} \hline 1 & 2 & 1 \\ \hline 2 & 4 & 2 \\ \hline 1 & 2 & 1 \\ \hline \end{array} * \begin{array}{|c|c|c|} \hline 2 & 3 & 3 \\ \hline 3 & 5 & 5 \\ \hline 4 & 4 & 6 \\ \hline \end{array}$$

The filter factors  
into a product of 1D  
filters:

$$\begin{array}{|c|c|c|} \hline 1 & 2 & 1 \\ \hline 2 & 4 & 2 \\ \hline 1 & 2 & 1 \\ \hline \end{array} = \begin{array}{|c|} \hline 1 \\ \hline 2 \\ \hline 1 \\ \hline \end{array} \times \begin{array}{|c|c|c|} \hline 1 & 2 & 1 \\ \hline \end{array}$$

Perform convolution  
along rows:

$$\begin{array}{|c|c|c|} \hline 1 & 2 & 1 \\ \hline \end{array} * \begin{array}{|c|c|c|} \hline 2 & 3 & 3 \\ \hline 3 & 5 & 5 \\ \hline 4 & 4 & 6 \\ \hline \end{array} = \begin{array}{|c|c|c|} \hline & 11 & \\ \hline & 18 & \\ \hline & 18 & \\ \hline \end{array}$$

Followed by convolution  
along the remaining column:

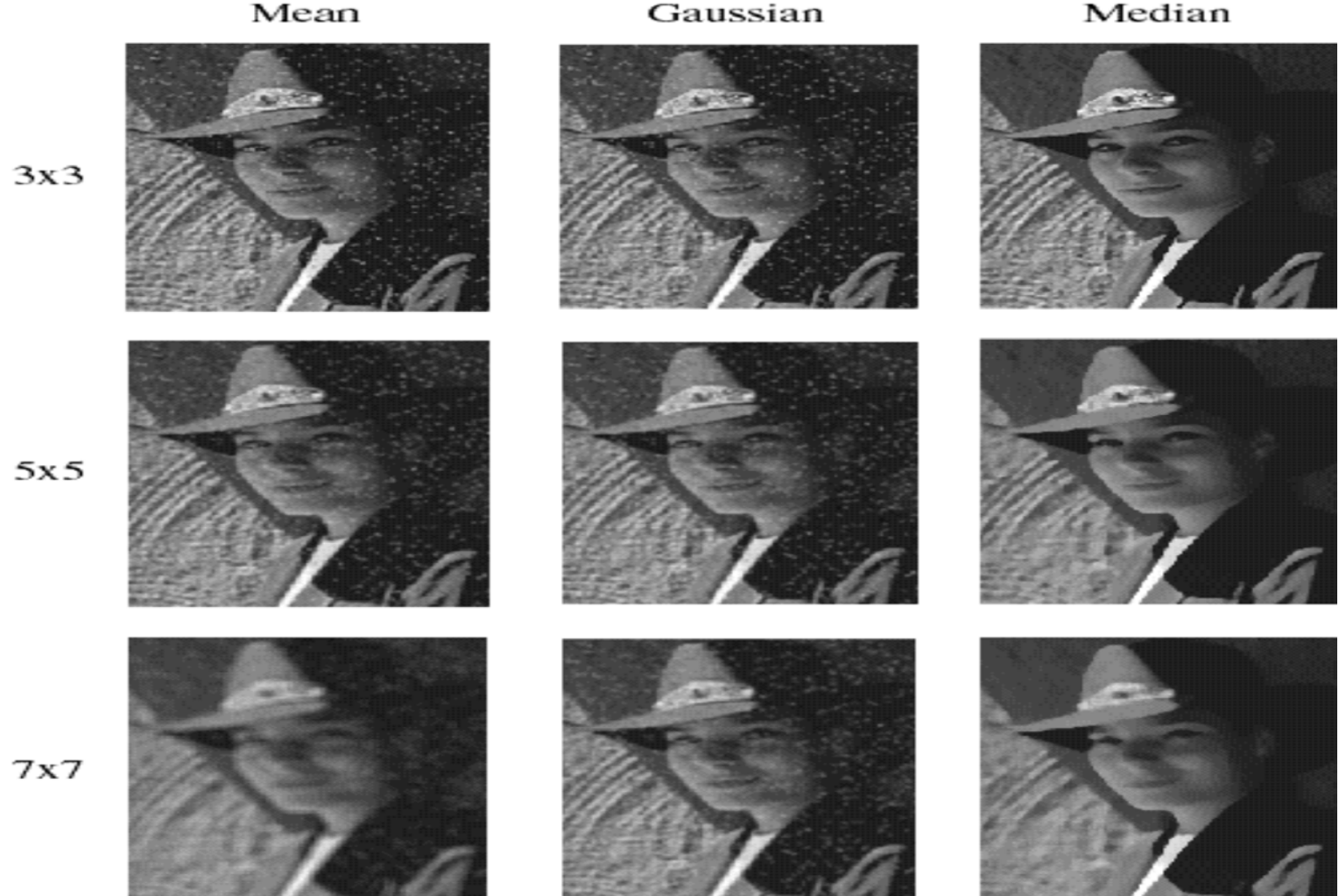
# Separability

- Why is separability useful in practice?
  - What is the complexity of filtering an  $n \times n$  image with an  $m \times m$  kernel?
    - $O(n^2 m^2)$
  - What if the kernel is separable?
    - $O(n^2 m)$

# Median filters

- A **Median Filter** operates over a window by selecting the median intensity in the window.
- What advantage does a median filter have over a mean filter?
- Is a median filter a kind of convolution?

# Comparison: salt and pepper noise





# Project 1: Hybrid Images

A. Oliva, A. Torralba, P.G. Schyns,  
["Hybrid Images,"](#) SIGGRAPH 2006

