# EE 604
# Digital Image Processing

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# Lecture outline

- **Lossless compression**
- Image quality measurement

# Lossless compression

- **Lossless** —> full recovery of data after de-compression
- Important for:
    - medical data (due to the requirement of accuracy of diagnosis)
    - satellite images (already expensive acquisition)
- Already discussed on lossless scheme: **Huffman coding**

# LZW Coding

- Introduced by Lempel, Ziv, Welch in 1984
- Lossless data compression scheme
- Forms the basis of GIF, TIFF, PNG, ZIP, PDF
- Relies on creating data-based dictionary, which is created at both encoder and decoder
- Uses fixed length coding
- Widely used to compress text also

# LZW Encoding

- Initialize: **P** = [ ], **D** = initial_dictionary
- Loop until (end_of_data)
    - **S** = nextsymbol(**data_string**)
    - Is **[P S]** in **D?**
        - **Yes: P = [ P S ]**
        - **No**
            - Transmit codeword for the symbol in **P**
            - Add **[P S]** in **D**
            - **P <— S**

# LZW Decoding

- Initialize: **P** = [ ], **D** = initial_dictionary
- Loop
    - **C** = received_codeword
    - Output symbol **S** for **C**
    - Add **[P first_part(S)]** in **D** (if not already there)
    - **P <— C**

# LZW example

$$I = \begin{bmatrix} 39 & 39 & 126 & 126 \\ 39 & 39 & 126 & 126 \\ 39 & 39 & 126 & 126 \\ 39 & 39 & 126 & 126 \end{bmatrix}$$

# LZW example

| Currently Recognized Sequence | Pixel Being Processed | Encoded Output | Dictionary Location (Code Word) | Dictionary Entry |
|---|---|---|---|---|
| | 39 | | | |
| 39 | 39 | 39 | 256 | 39-39 |
| 39 | 126 | 39 | 257 | 39-126 |
| 126 | 126 | 126 | 258 | 126-126 |
| 126 | 39 | 126 | 259 | 126-39 |
| 39 | 39 | | | |
| 39-39 | 126 | 256 | 260 | 39-39-126 |
| 126 | 126 | | | |
| 126-126 | 39 | 258 | 261 | 126-126-39 |
| 39 | 39 | | | |
| 39-39 | 126 | | | |
| 39-39-126 | 126 | 260 | 262 | 39-39-126-126 |
| 126 | 39 | | | |
| 126-39 | 39 | 259 | 263 | 126-39-39 |
| 39 | 126 | | | |
| 39-126 | 126 | 257 | 264 | 39-126-126 |
| 126 | | 126 | | |

# Remarks

- A large number of image compression algorithms exist, not all of them are adopted as standards.
- Standards are widely available for natural images, not for medical images.
- JPEG2000 is another important lossy compression, uses Wavelet transform for transform mapping.
- Video compression will require image compression (spatial coding) and temporal coding. MPEG uses JPEG-like compression per frame.
- Autoencoder-based image compression algorithms are also being explored

# Lecture outline

- Lossless compression
- **Image fidelity measurement**
  - [Wang and Bovik 2009], [Wang et al. 2004]

# Image quality

- **Image fidelity:** measure of (dis)similarity between two images or amount of error/distortion

- **Image quality:** measure of preference of one image over another

- If one of the images is a clean original, and the other is distorted, then **fidelity = quality**

- Most popular image fidelity (quality) measure: **Mean Squared Error (MSE)**

# MSE

$$\mathbf{x} = \{x_i | i = 1, 2, ...N\} \qquad \mathbf{y} = \{y_i | i = 1, 2, ...N\}$$

$$\mathrm{MSE}(\mathbf{x}, \mathbf{y}) = \frac{1}{N} \sum_{i=1}^{N} (x_i - y_i)^2$$

- A more generic form of MSE

$$d_p(\mathbf{x}, \mathbf{y}) = \left( \sum_{i=1}^{N} |e_i|^p \right)^{1/p} \quad \text{where} \quad e_i = x_i - y_i$$

- PSNR

$$\mathrm{PSNR} = 10 \log_{10} \frac{L^2}{\mathrm{MSE}} \quad \text{where L is the dynamic range}$$

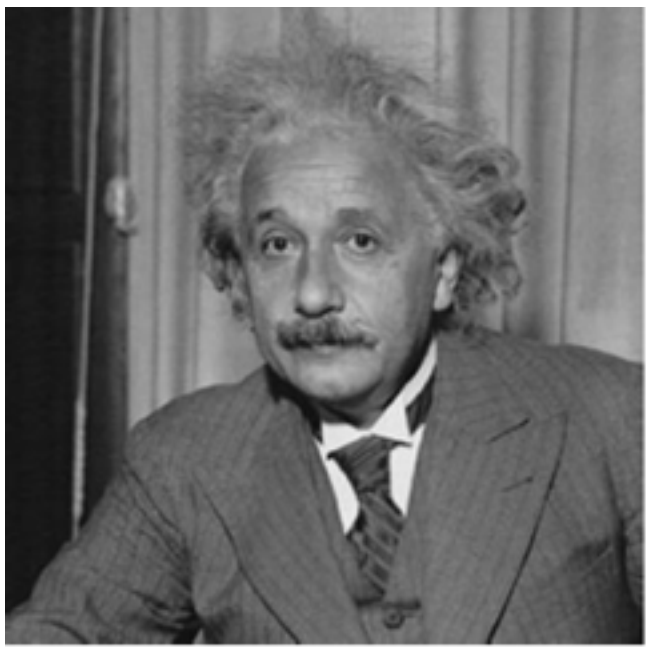
# Why is MSE popular?

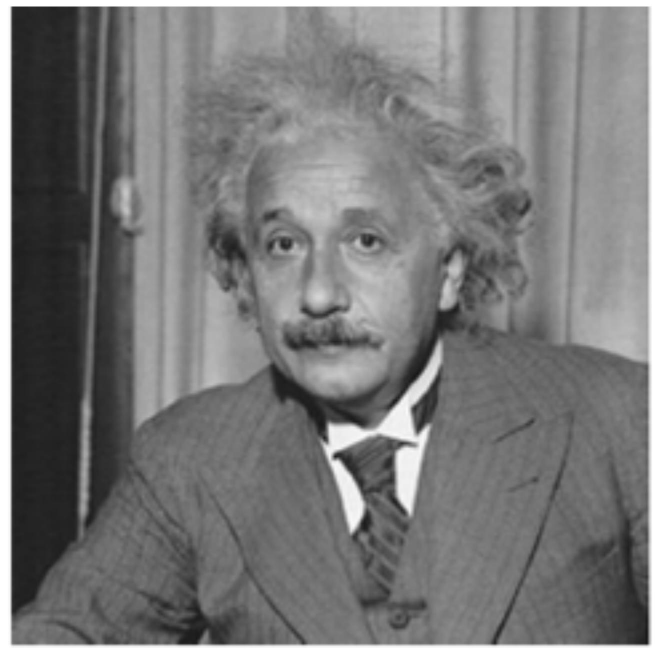
- Simple, parameter-free, non-expensive, memoryless
- Norm-based distance metric

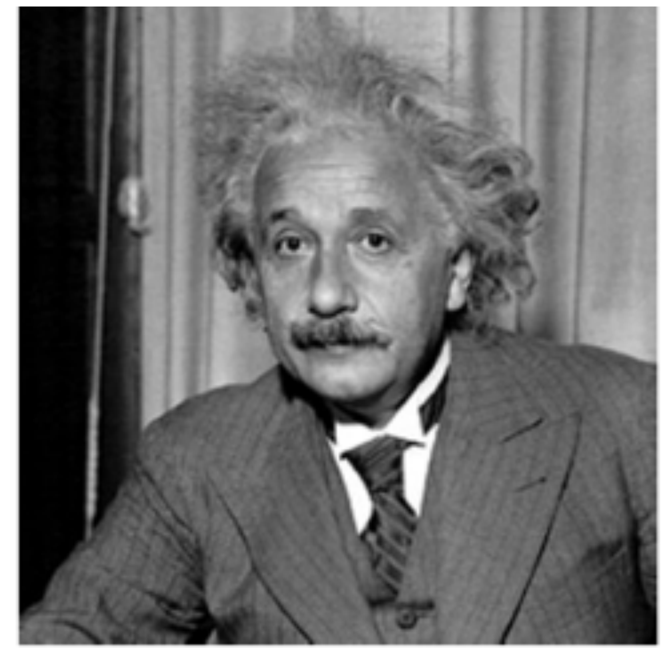
  — nonnegativity: $d_p(\mathbf{x}, \mathbf{y}) \geq 0$
  — identity: $d_p(\mathbf{x}, \mathbf{y}) = 0$ if and only if $\mathbf{x} = \mathbf{y}$
  — symmetry: $d_p(\mathbf{x}, \mathbf{y}) = d_p(\mathbf{y}, \mathbf{x})$
  — triangular inequality: $d_p(\mathbf{x}, \mathbf{z}) \leq d_p(\mathbf{x}, \mathbf{y}) + d_p(\mathbf{y}, \mathbf{z})$

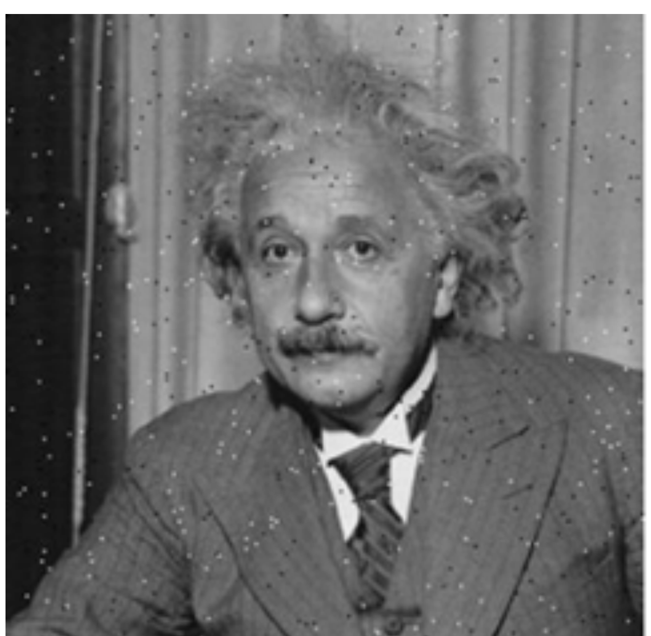
- Natural relation to energy
- Excellent for optimization: convex, symmetric, differentiable

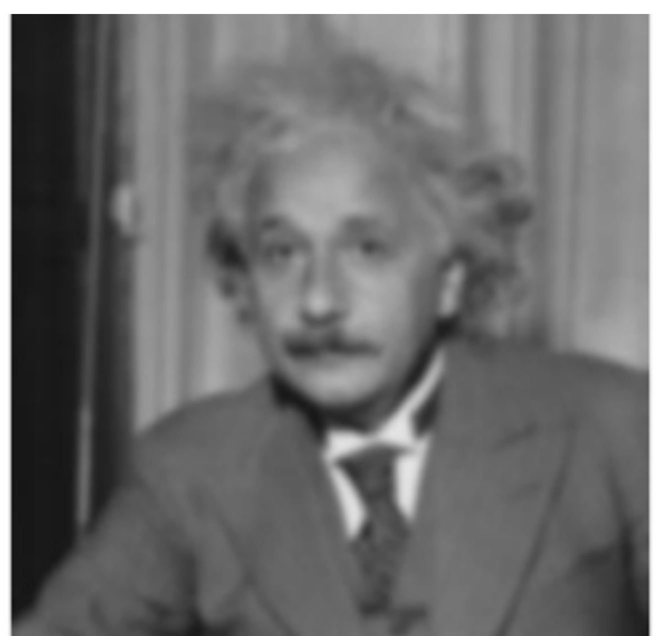
# What's wrong with MSE?

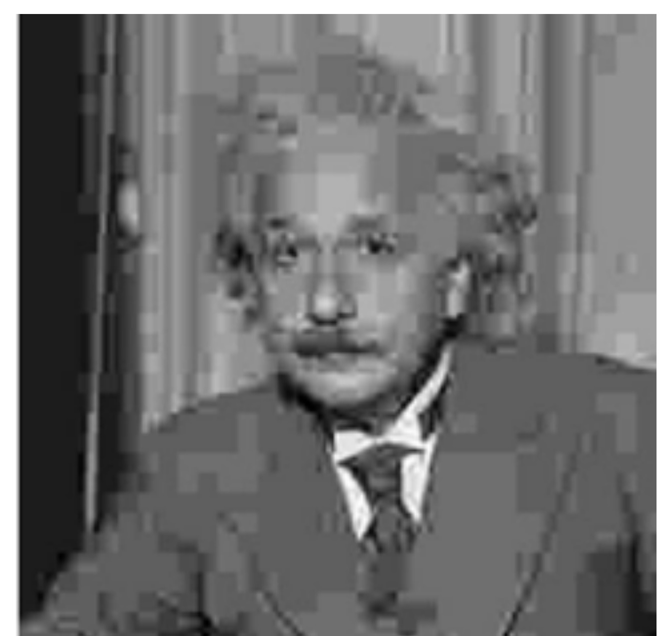

Original


MSE = 144


MSE = 144


MSE = 144


MSE = 144


MSE = 142

# Why does MSE fail?

- Several strong assumptions
  - Fidelity measure is spatially independent
  - All points are equally important for fidelity
  - Sign of change does not matter
  - The error and original image has no relationship.

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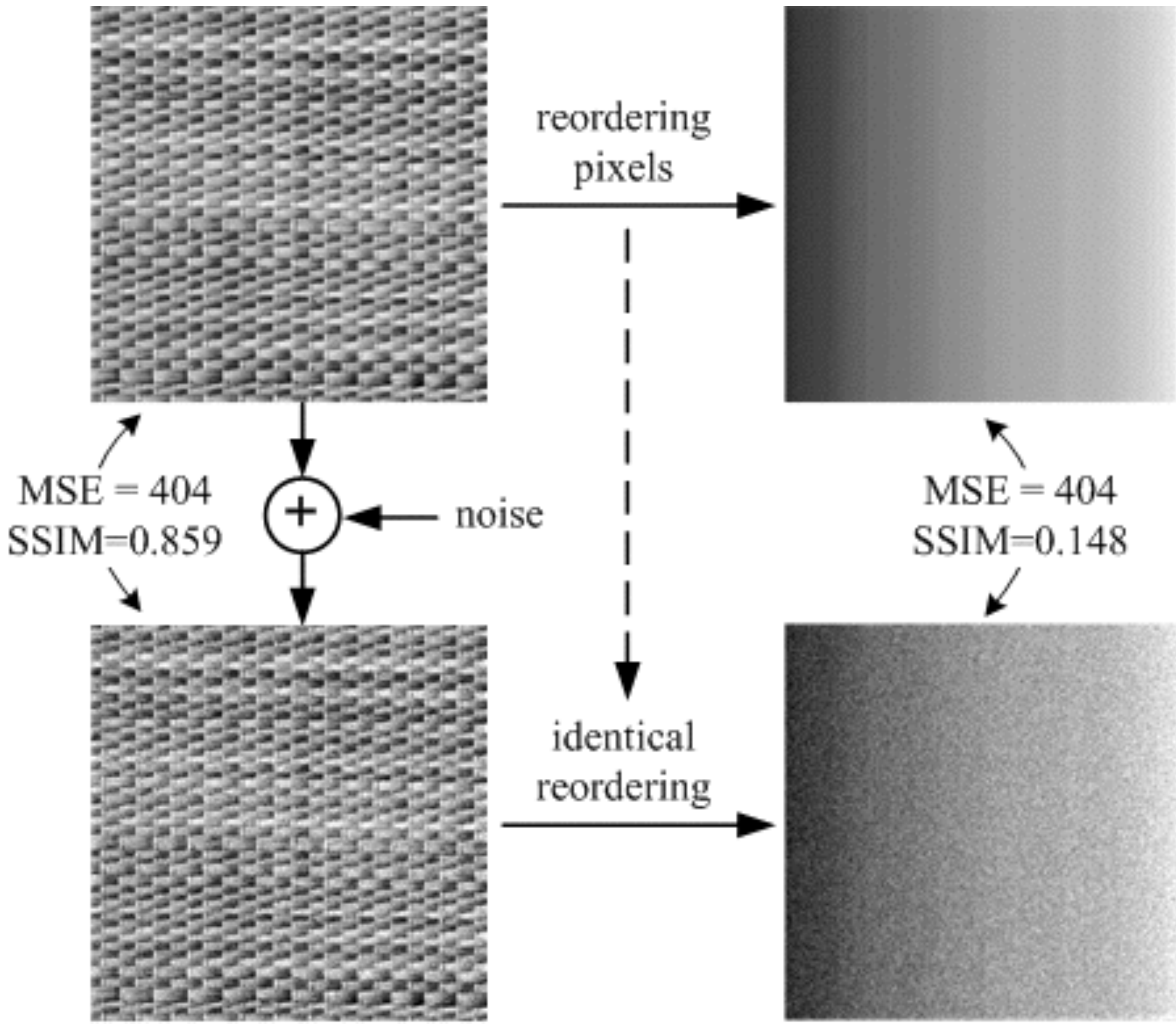


[Wang and Bovik 2009]

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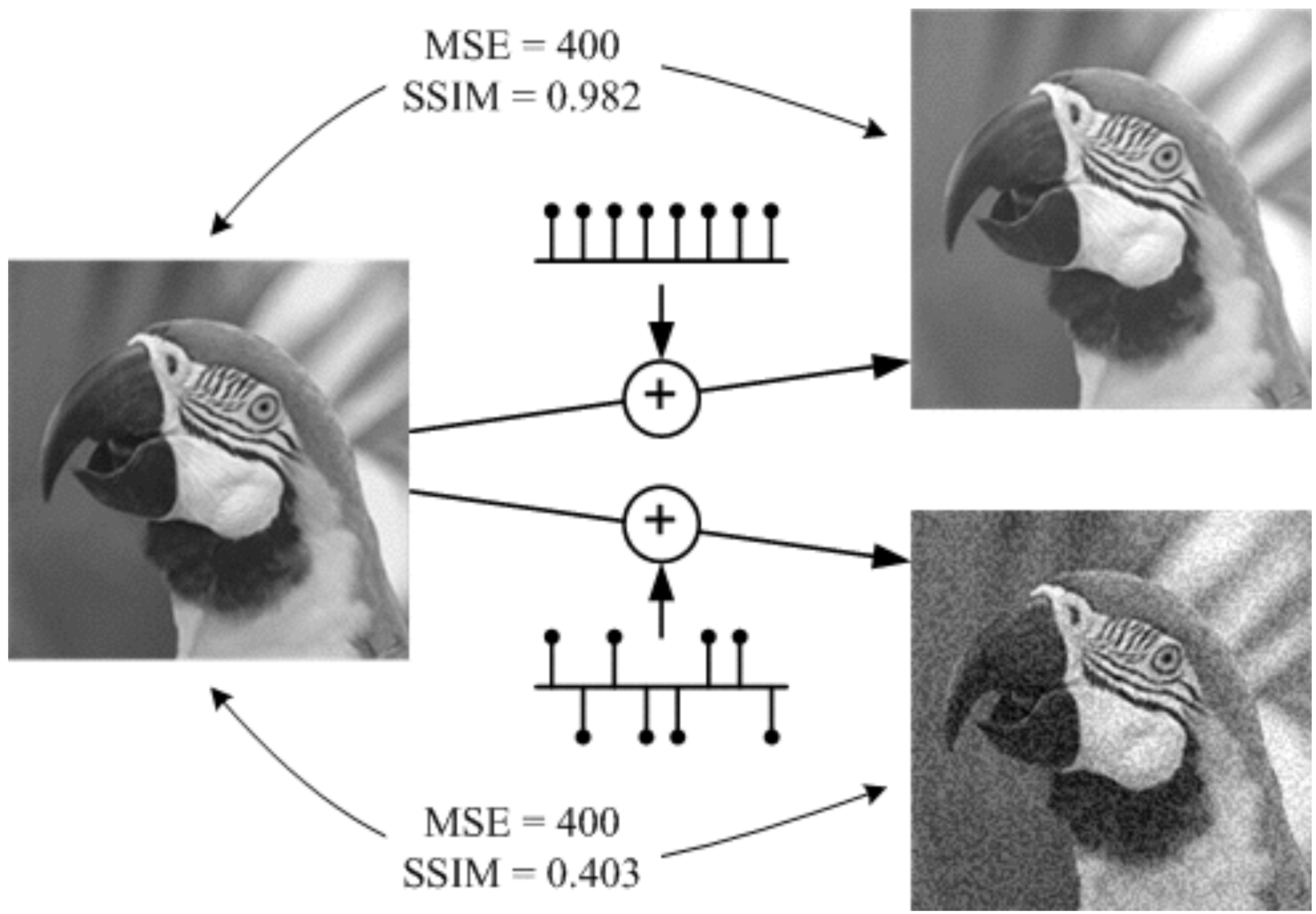


[Wang and Bovik 2009]

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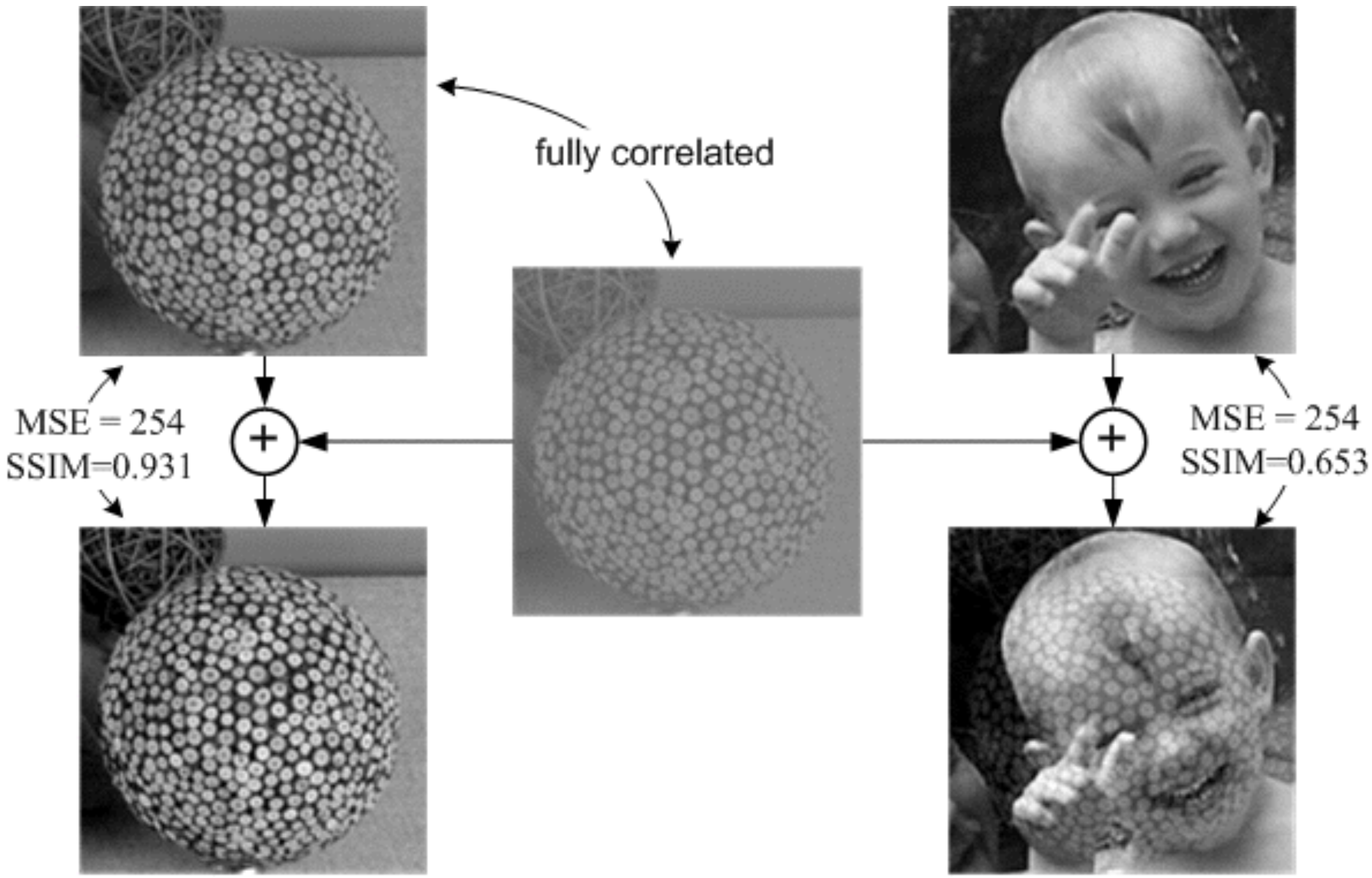


[Wang and Bovik 2009]

# Perceptual Image quality

- Image processing systems need to measure how good the output image is.
- Images are often viewed by humans. It's important that they look good to human eyes.
- MSE does not correlate well with visual perception of quality.
- **Solution?**
    - Try to model HVS!
    - Develop metrics **based on HVS properties** to measure image quality that correlate better with human perception. These metrics are often called **perceptual image quality metrics**.