Medical Image Processing for Interventional Applications

Super-Resolution: Computational Methods

Online Course – Unit 21

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Topics

Single-Frame Super-Resolution

Principles of single-frame super-resolution:

- Single-frame methods estimate a high-resolution image from one single low-resolution image by incorporation of prior knowledge.
- Methods:
  - **Learning-based methods**: Estimate high-resolution image by learning the image degradation process using training data.
  - **Frequency interpolation methods**: Represent images in frequency domain (e. g., with wavelet coefficients) to estimate high-frequency information not present in low-resolution images.

Multi-Frame Super-Resolution

Principles of (motion-based) multi-frame super-resolution:

- Capture sequence of **warped and degraded** images of ideal scene
- More precise sampling due to **non-integer pixel** shifts caused by
  - moving cameras
  - object motion

Goal: Reconstruct high-resolution (ideal) image from low-resolution frames.

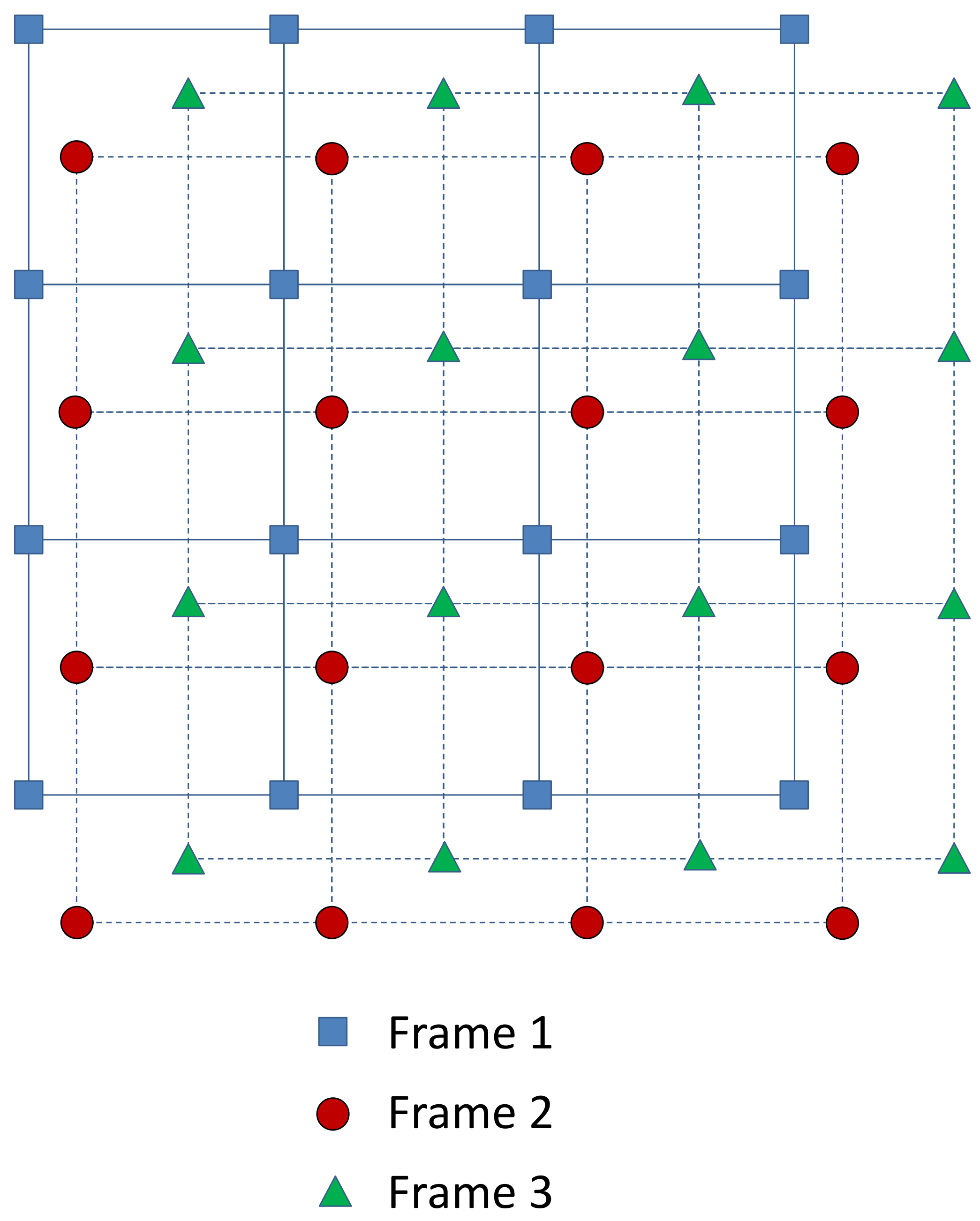

Figure 1: Relative motion shifts between frames

Super-Resolution via Non-Uniform Interpolation

Properties and assumptions:

- Direct approach (in contrast to a formulation as an inverse problem)
- Given: motion estimate for low-resolution frames

Algorithm: super-resolution performed in three stages

1. **Motion compensation**: Warp all low-resolution frames to the desired high-resolution grid according to the motion estimate.
2. **Interpolation**: Interpolate the high-resolution image from the warped low-resolution samples.
3. **Restoration** (optional): Deblur the interpolated image.

Super-Resolution via Non-Uniform Interpolation

Overview of the algorithm:

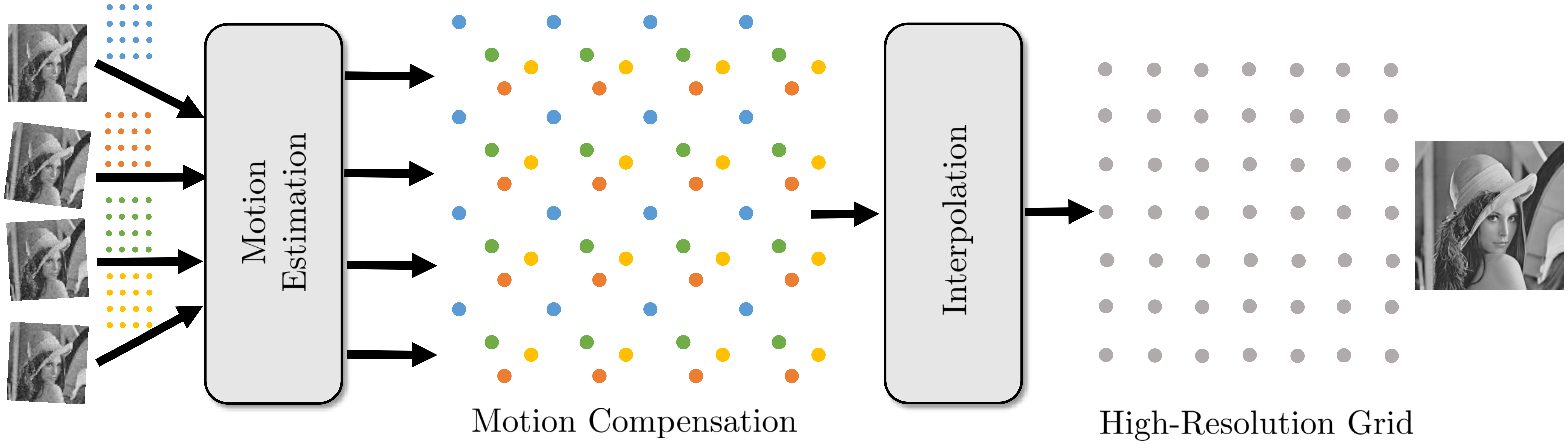

Figure 2: Schematic of the algorithm

Motion Models for Multi-Frame Super-Resolution

Description of image warping by motion model:

- **Parametric motion model** $\longrightarrow$ image-to-image homography $\boldsymbol{M}$ consisting of:
  - Rigid motion: rotation matrix $\boldsymbol{R}$ and translation $\boldsymbol{t}$ (3 degrees of freedom)

$$\boldsymbol{M} = \begin{pmatrix} \boldsymbol{R} & \boldsymbol{t} \\ \mathbf{0}^\mathsf{T} & 1 \end{pmatrix}$$

  - Affine motion: rotation, translation, scaling and shearing (6 degrees of freedom)

$$\boldsymbol{M} = \begin{pmatrix} \boldsymbol{A} & \boldsymbol{t} \\ \mathbf{0}^\mathsf{T} & 1 \end{pmatrix}$$

- **Non-parametric model** $\longrightarrow$ displacement vector fields via optical flow

Non-Uniform Interpolation: Example

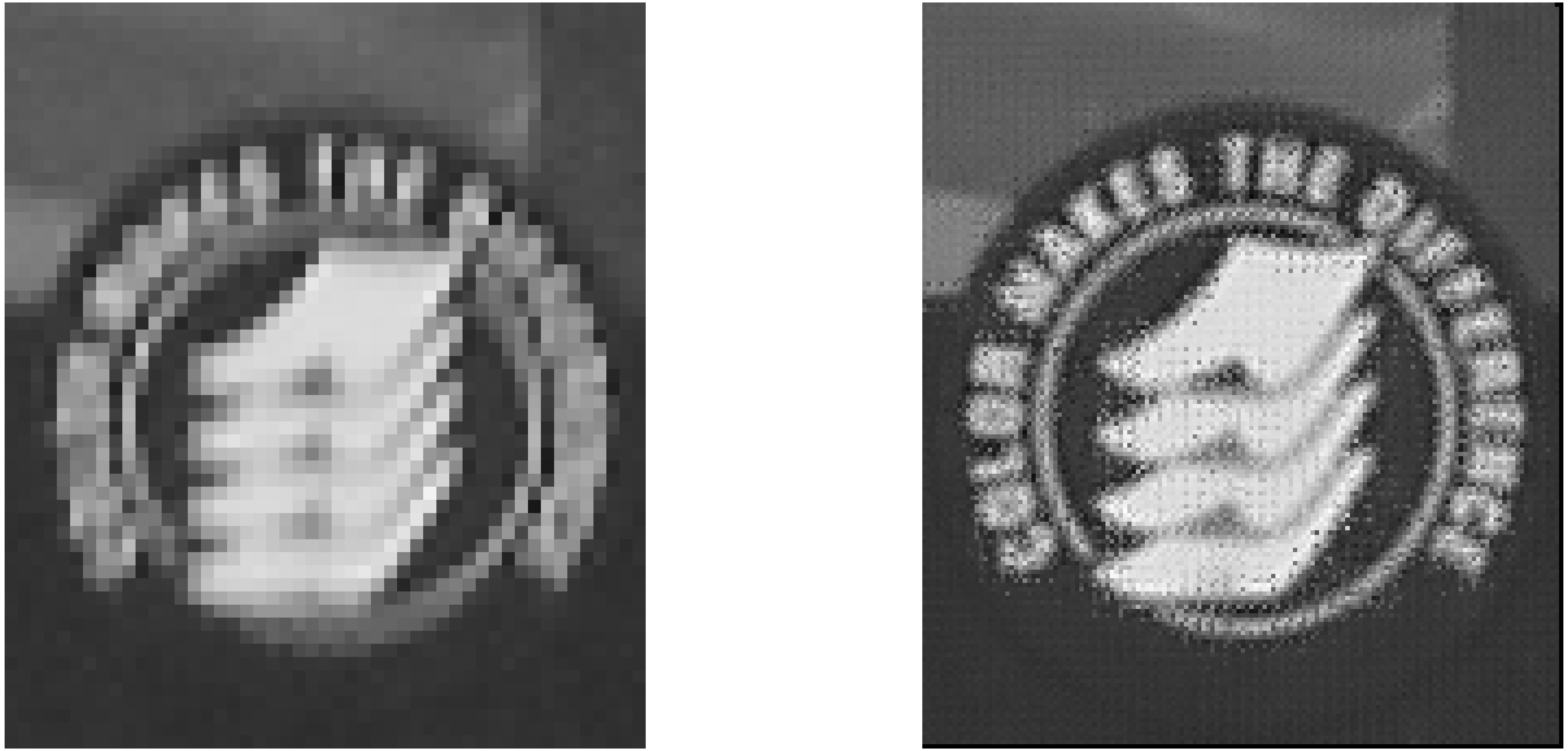

Figure 3: Single low-resolution frame (left) and result of non-uniform interpolation (right) using bicubic interpolation with $K = 26$ frames and $3\times$ magnification

Non-Uniform Interpolation: Discussion

Properties of the non-uniform interpolation approach:

- Easy to implement
- Computationally efficient (direct approach)
- Flexible in terms of motion models
- Prone to artifacts in case of misregistrations (error propagation)
- Difficult to model a priori knowledge regarding high-resolution images

Topics

Computational Methods for Image Super-Resolution

Summary

- Take Home Messages
- Further Readings

Take Home Messages

- Super-resolution algorithms can be subdivided into single and multiframe methods.
- The direct approach involves warping the frames to a high-resolution grid and subsequent interpolation.

Further Readings

Theory of image super-resolution (books and review articles):

- Hayit Greenspan. "Super-Resolution in Medical Imaging". In: *The Computer Journal* 52.1 (Feb. 2008), pp. 43–63. DOI: 10.1093/comjnl/bxm075
- Peyman Milanfar, ed. *Super-Resolution Imaging*. Digital Imaging and Computer Vision. CRC Press, 2011
- Sina Farsiu et al. "Advances and Challenges in Super-Resolution". In: *International Journal of Imaging Systems and Technology* 14.2 (Aug. 2004), pp. 47–57. DOI: 10.1002/ima.20007
- Sung Cheol Park, Min Kyu Park, and Moon Gi Kang. "Super-Resolution Image Reconstruction: A Technical Overview". In: *IEEE Signal Processing Magazine* 20.3 (May 2003), pp. 21–36. DOI: 10.1109/MSP.2003.1203207