ETH zürich

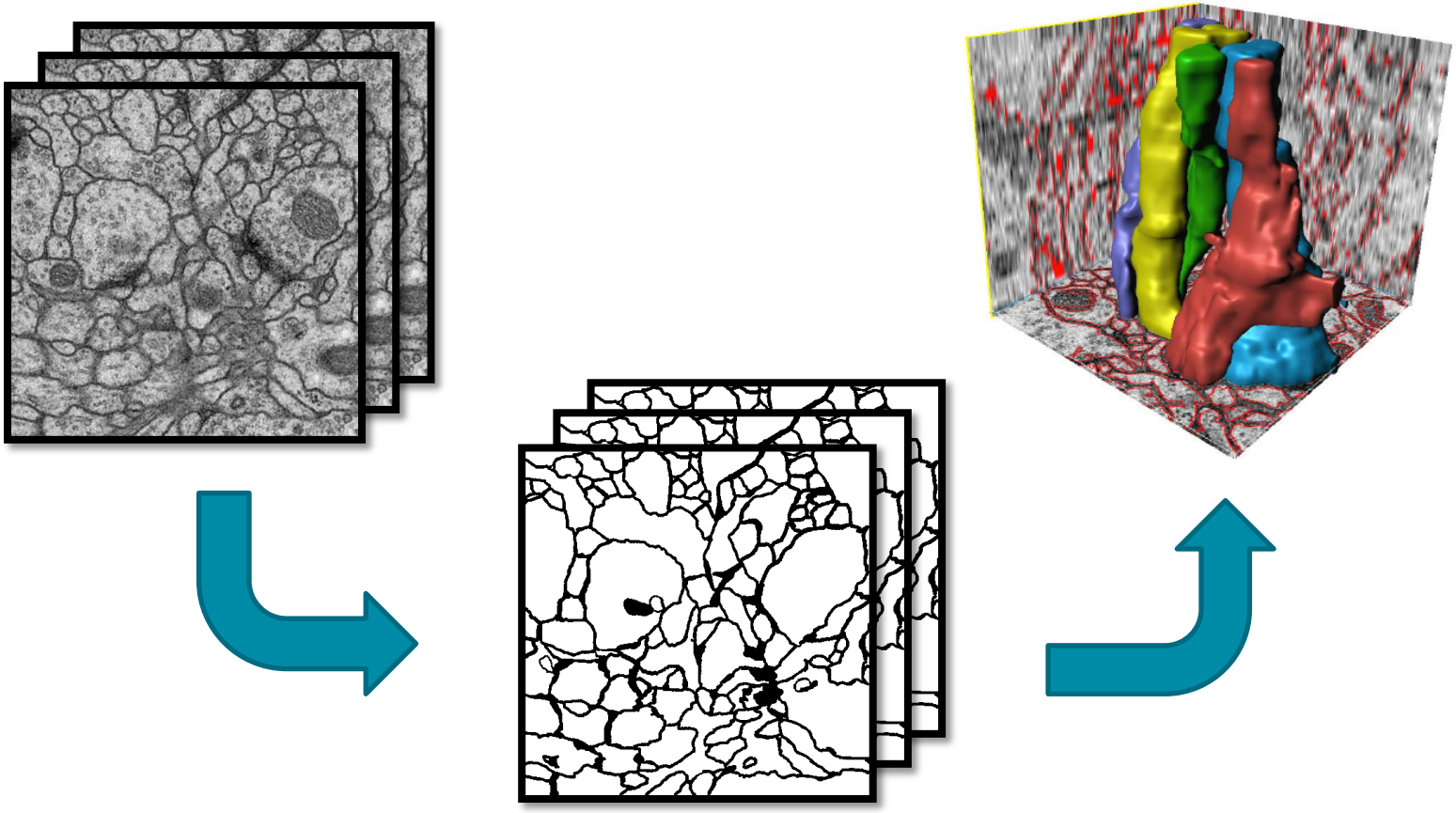
SuperSlicing Frame Restoration

for Anisotropic ssTEM and Video Data

Dmitry Laptev, Joachim M. Buhmann
Machine Learning Lab, ETH Zurich

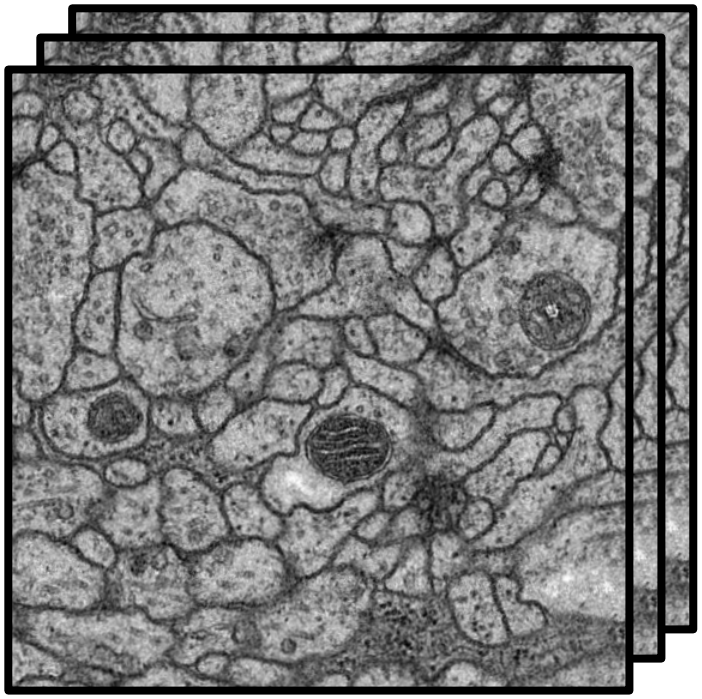
http://dlaptev.org
dlaptev@inf.ethz.ch

3d topology reconstruction from neuroimaging*



*only one of many branches in Connectomics research

Connectomics



Sections from a serial section Transmission Electron Microscopy (ssTEM) data set of the Drosophila first instar larva ventral nerve cord

Imaging

- Slices 2μm × 2μm × 50nm
- Slice projection with EM
- Resolution: 4 × 4 × 50nm

  => highly anisotropic

Problems

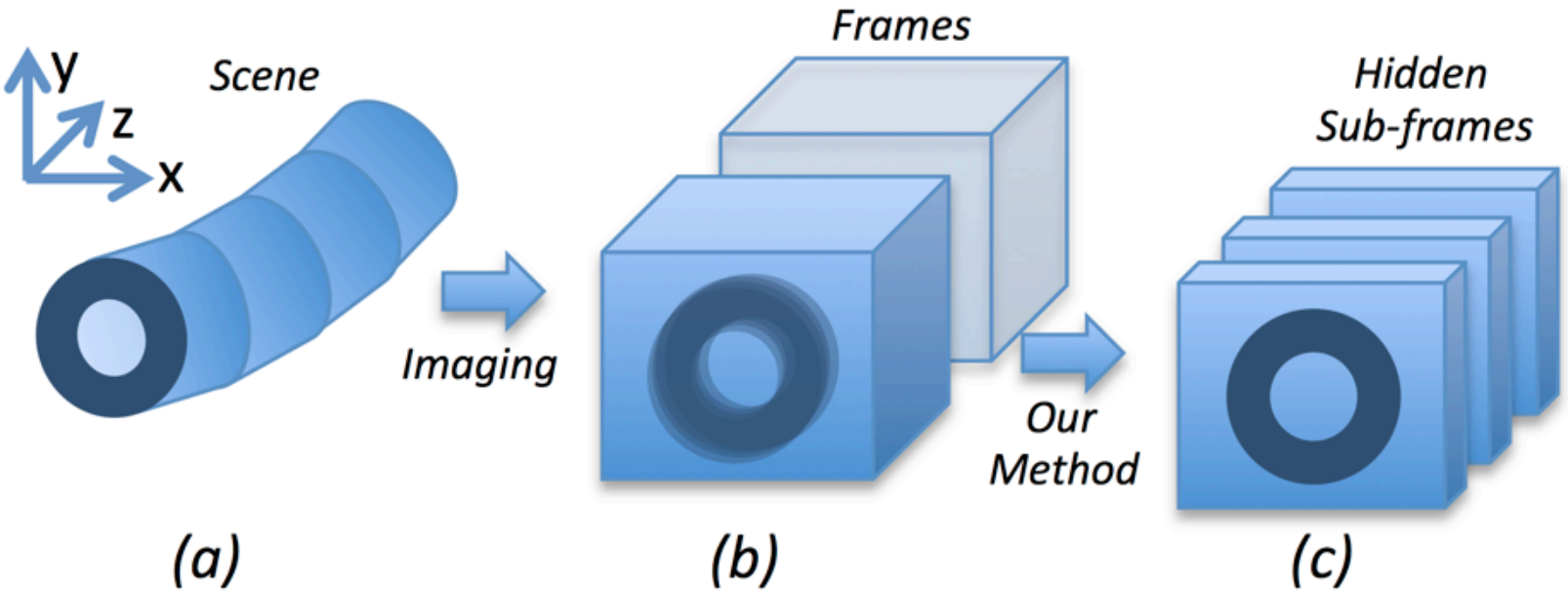
- Blurred membranes

  => It is difficult to detect
- Slices sufficiently different

  => We cannot use 3d

Idea of SuperSlicing

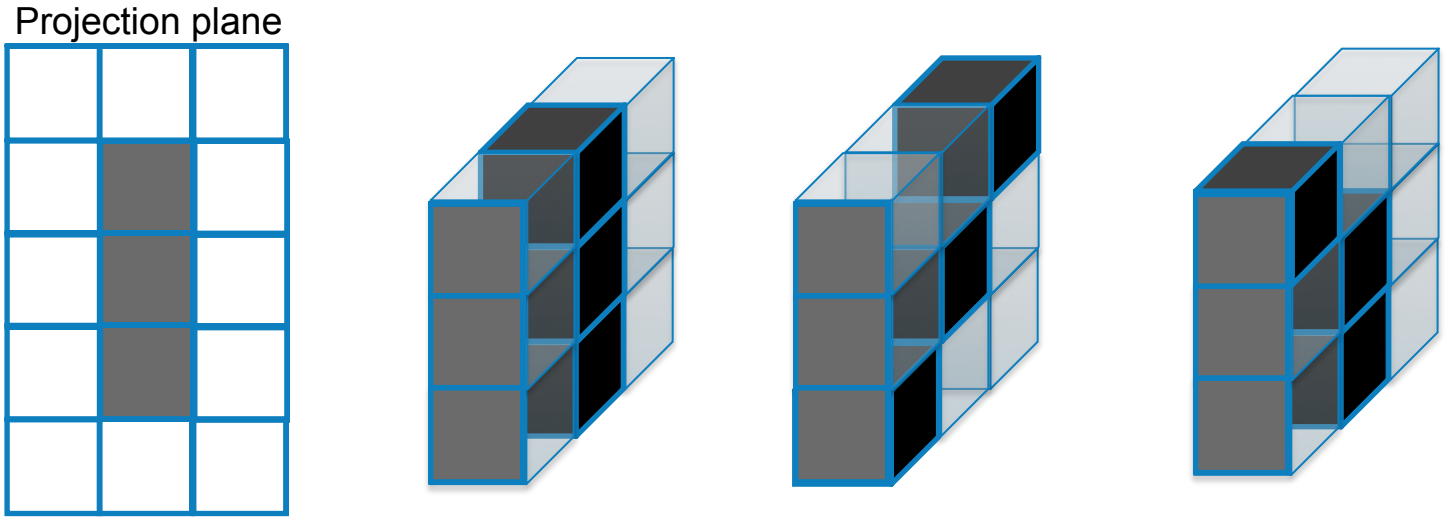
Decompose the observed frame into “hidden sub-frames”



Very ill-posed problem in general

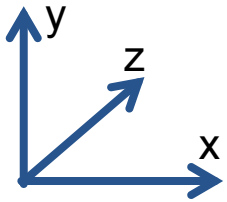
Idea of SuperSlicing

Decompose the observed frame into “hidden sub-frames”



Observed frame

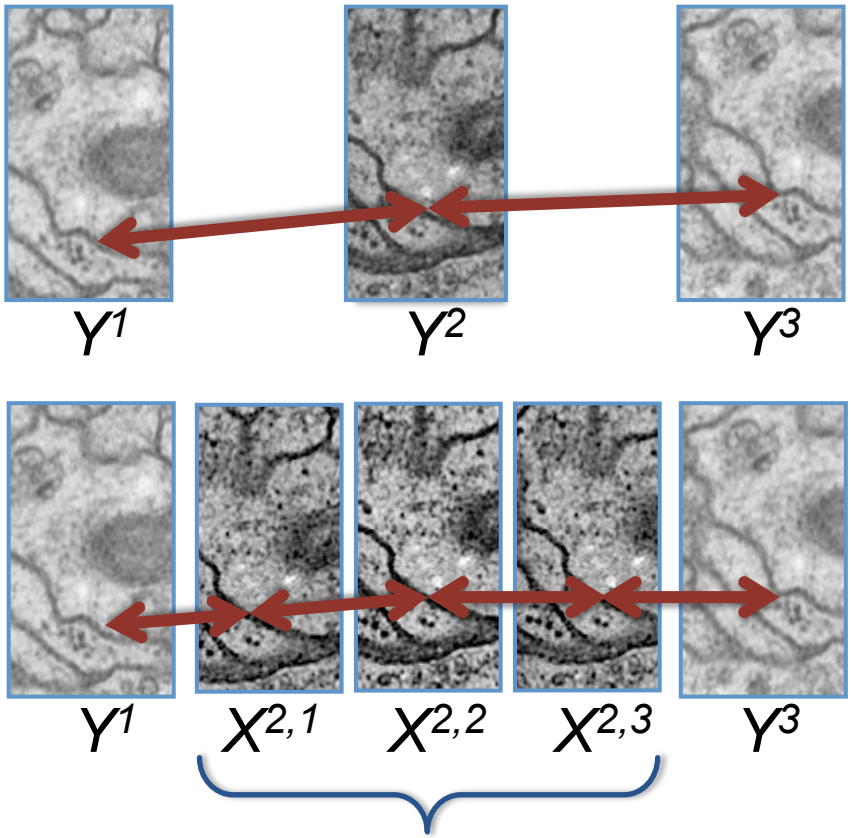
Three possible sub-frame decompositions



Need structural constraints

Idea of SuperSlicing

Y^1, Y^2, Y^3 – observed neighboring frames



Hidden sub-frame decomposition of Y^2

- Find corresponding pixels in anisotropic frames by solving **registration task**
- Interpolate correspondences between pixels in sub-frames
- Corresponding pixels should have similar intensities

SuperSlicing Algorithm

- Notation
  - Y^n — observed frames, $n \in [1, \ldots, N]$,
  - y_p^n — pixel p of the frame Y^n,
  - $i(y_p^n)$ — the intensity of pixel y_p^n,
  - $\epsilon(x_p^n)$ — a set of neighbors of pixel x_p^n,
  - Ω — a set of given correspondences,
  - $X^{n,l}$ — hidden sub-frames decomposition of Y^n, $l \in [1, \ldots, L]$.

SuperSlicing Algorithm

- Energy minimization problem

An average of the hidden frames should give observed frame

$$E(X^{n,1},\dots,X^{n,L}) = \sum_{y\in Y^n}\left(i(y) - \frac{1}{L}\sum_{l=1}^{L} i(x_p^{n,l})\right)^2$$

Smoothness across all the correspondences

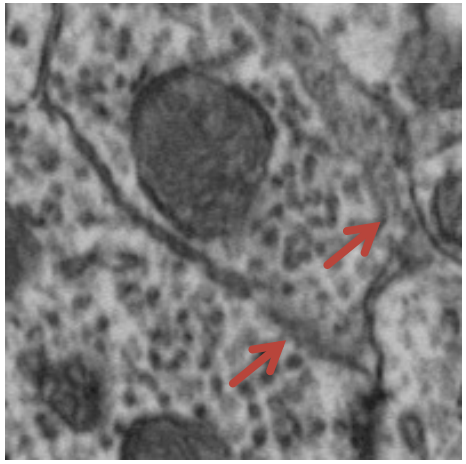
$$+\lambda \sum_{(\hat{x}_p^{n,l},\hat{x}_q^{n,l+1})\in\Omega}\left(\sum_{x\in\epsilon(\hat{x}_p^{n,l})} w(x,\hat{x}_p^{n,l})i(x) - \sum_{x\in\epsilon(\hat{x}_q^{n,l+1})} w(x,\hat{x}_q^{n,l+1})i(x)\right)^2$$

Smoothness within the frame

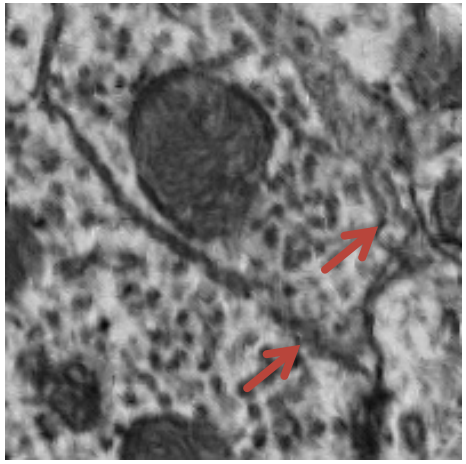
$$+\gamma \sum_{\substack{x_p^{n,l};x_q^{n,l}\in\epsilon(x_p^{n,l})\\ l=1,\dots,L}}\left(i(x_p^{n,l}) - i(x_q^{n,l})\right)^2$$

Quadratic programming: global optimum

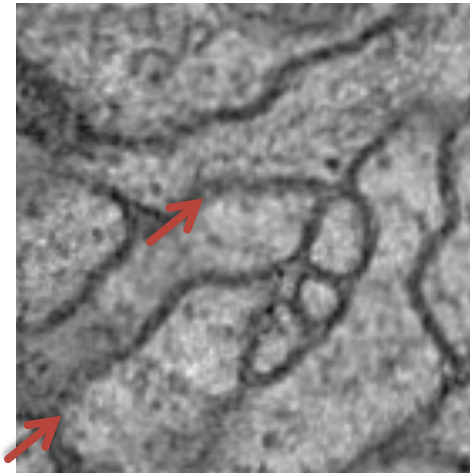
SuperSlicing experiments: ssTEM

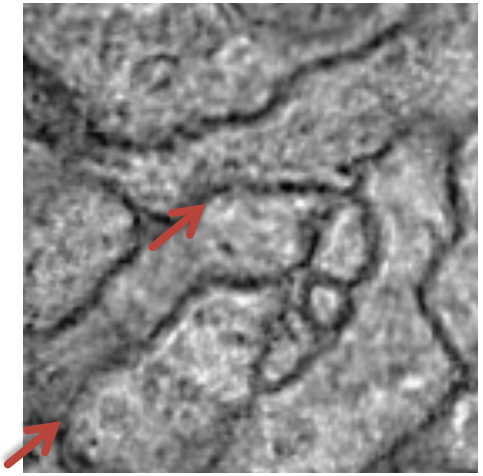


Anisotropic frames

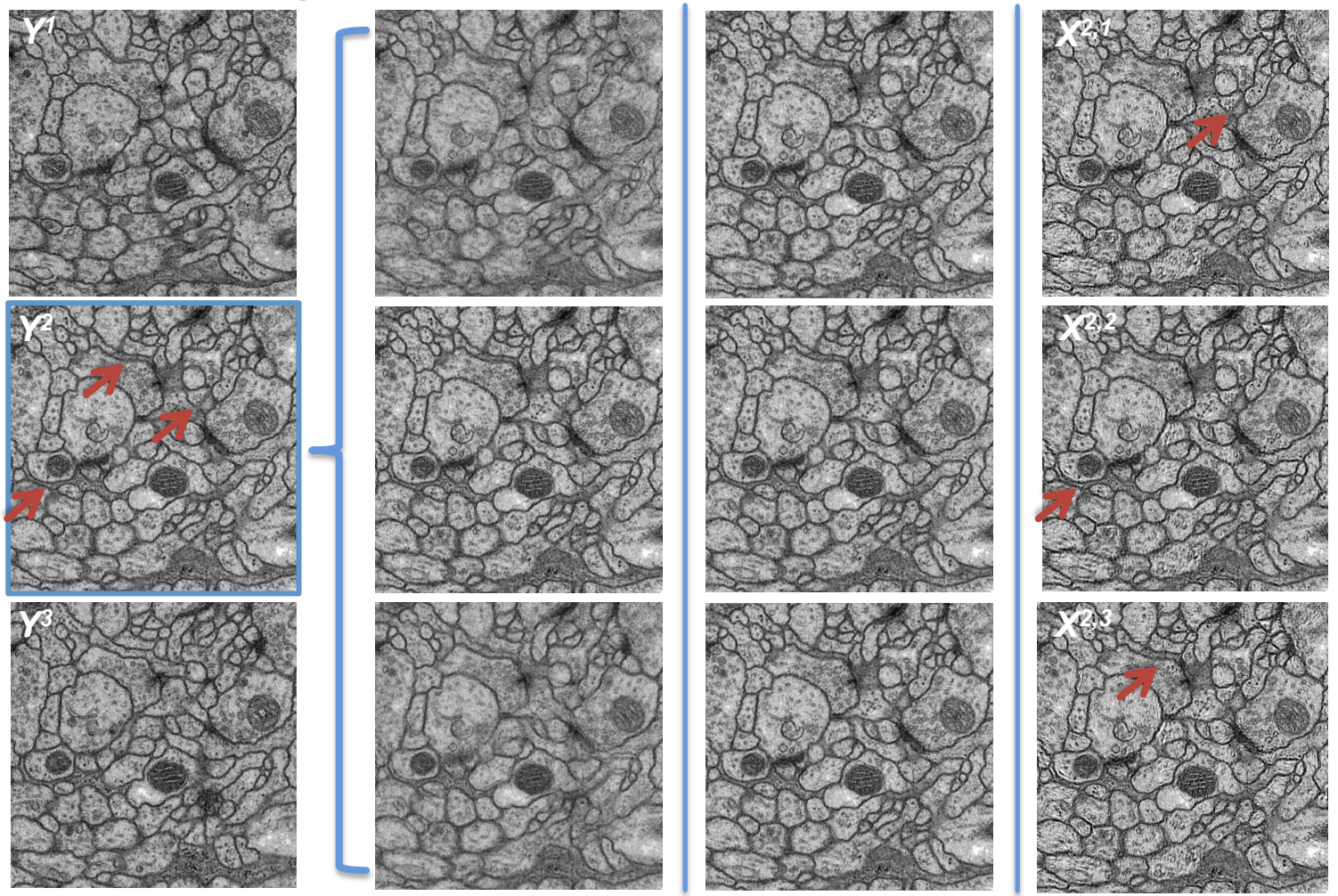


Reconstructed sub-frame

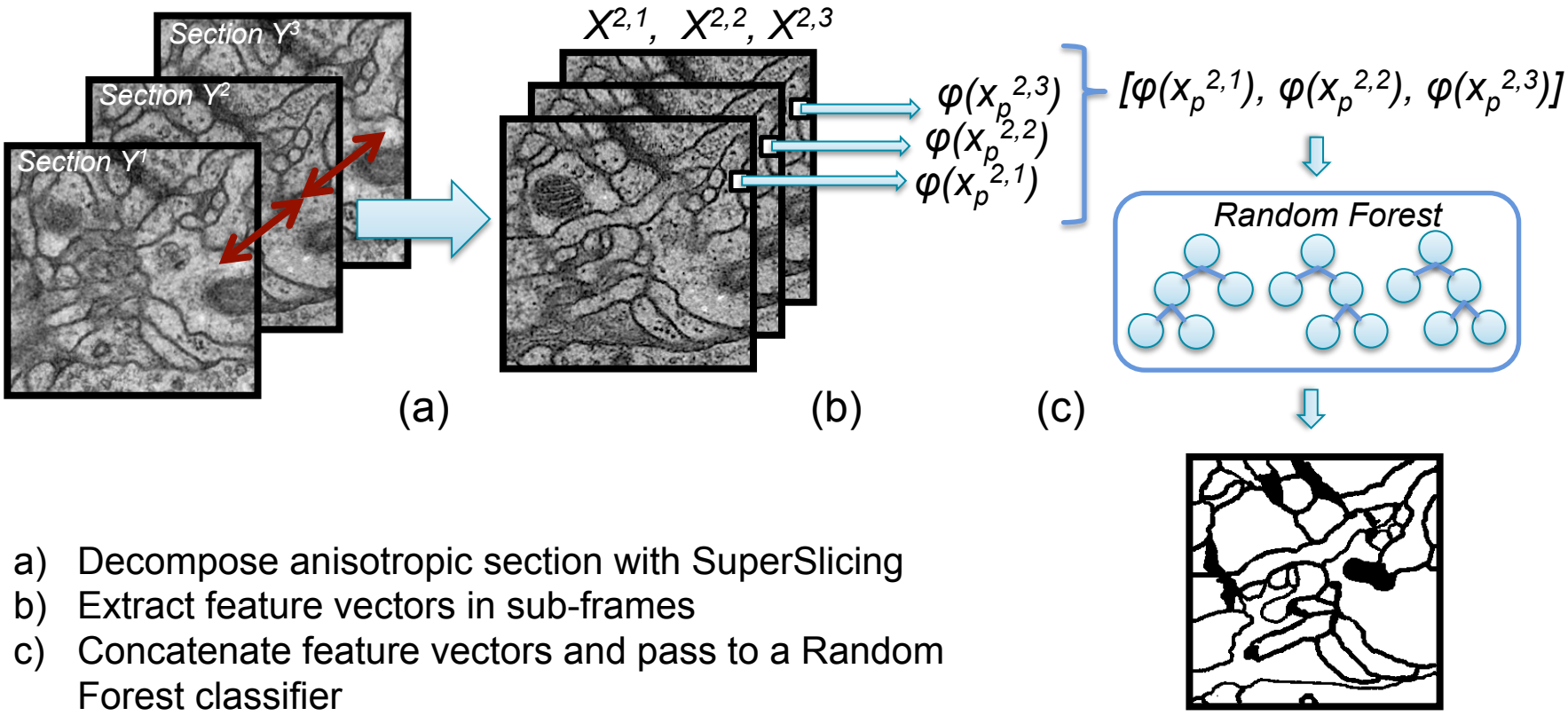




SuperSlicing experiments: ssTEM

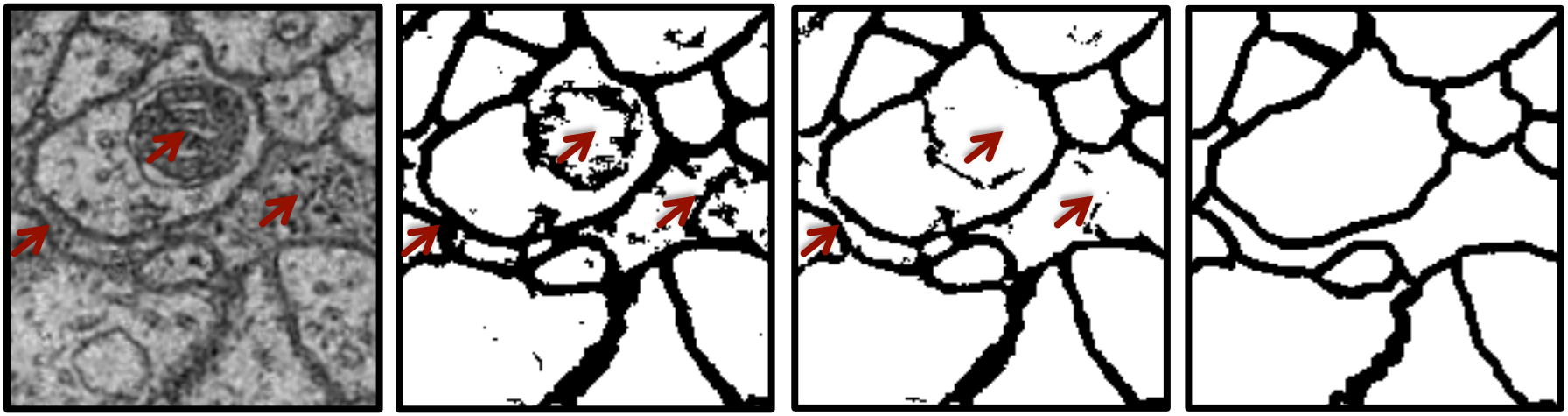


SuperSlicing segmentation



a) Decompose anisotropic section with SuperSlicing
b) Extract feature vectors in sub-frames
c) Concatenate feature vectors and pass to a Random Forest classifier

SuperSlicing segmentation

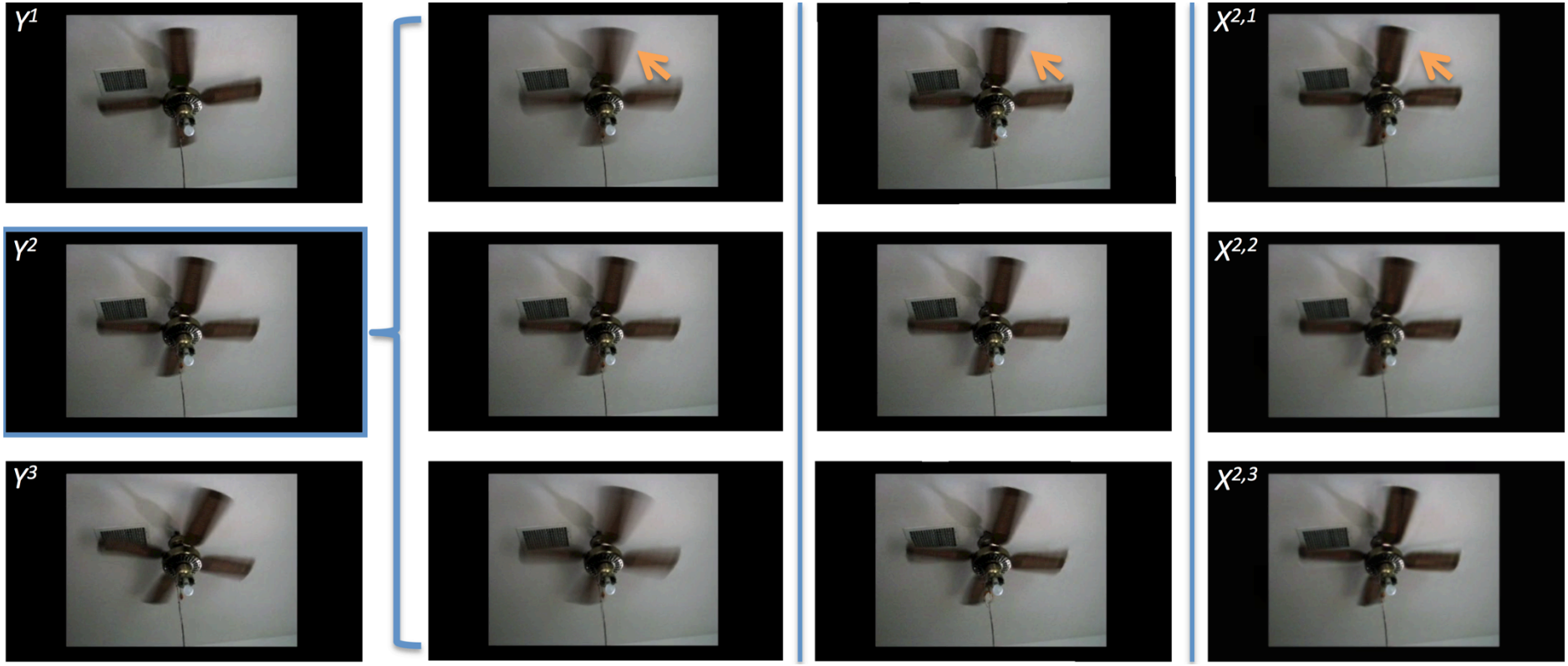


Original fragment | *One-slice segmentation* | *SuperSlicing segmentation* | *Ground Truth*

Method	Warping error*	
One section segmentation	$2.87*10^{-3}$	(17%)
Three section segmentation	$2.69*10^{-3}$	(11%)
SuperSlicing segmentation	$2.38*10^{-3}$	

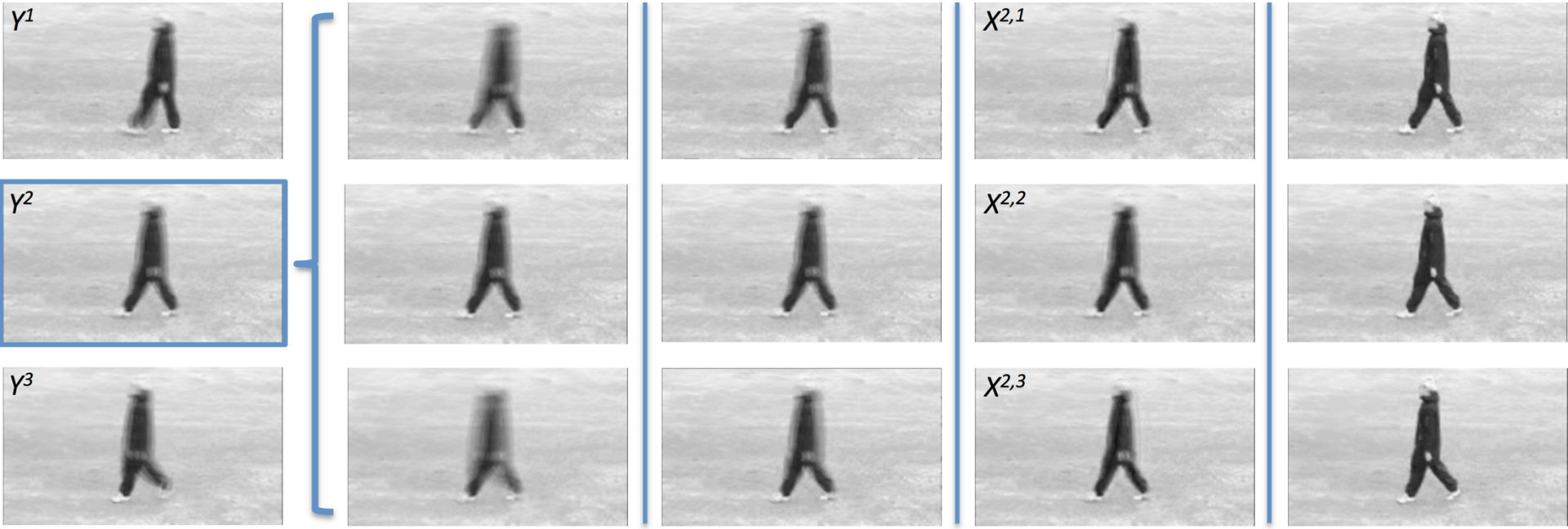
*the metric of topological inconsistency

SuperSlicing experiments: video



Three original frames | *Linear interpolation* | *Optical Flow warping* | *Ours*

SuperSlicing experiments: synthetic video

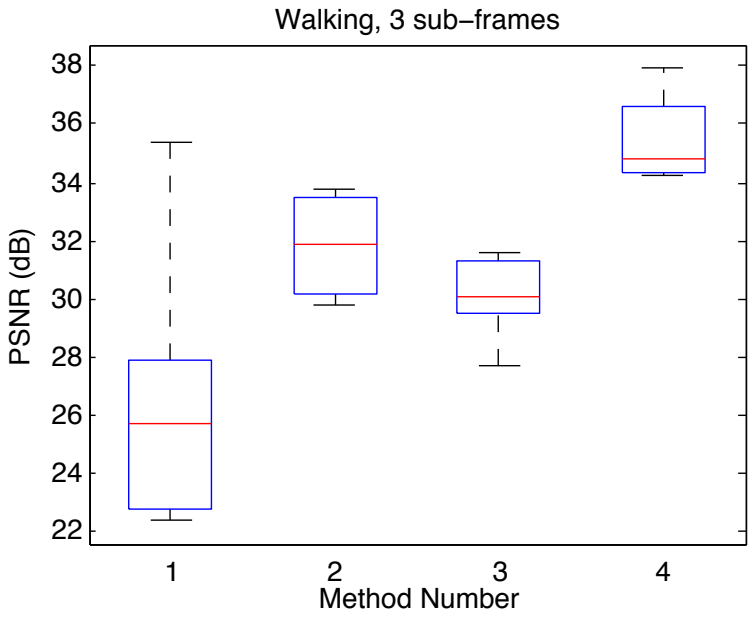


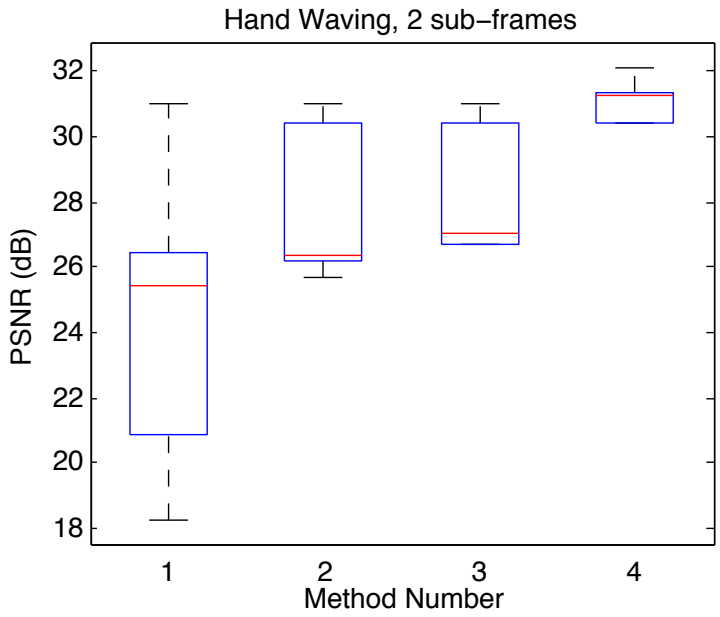
Synthetic frames | *Linear interpolation* | *Optical Flow warping* | *Ours* | *Original frames*

SuperSlicing experiments: synthetic video

Synthetic frames | *Linear interpolation* | *Optical Flow warping* | *Ours* | *Original frames*

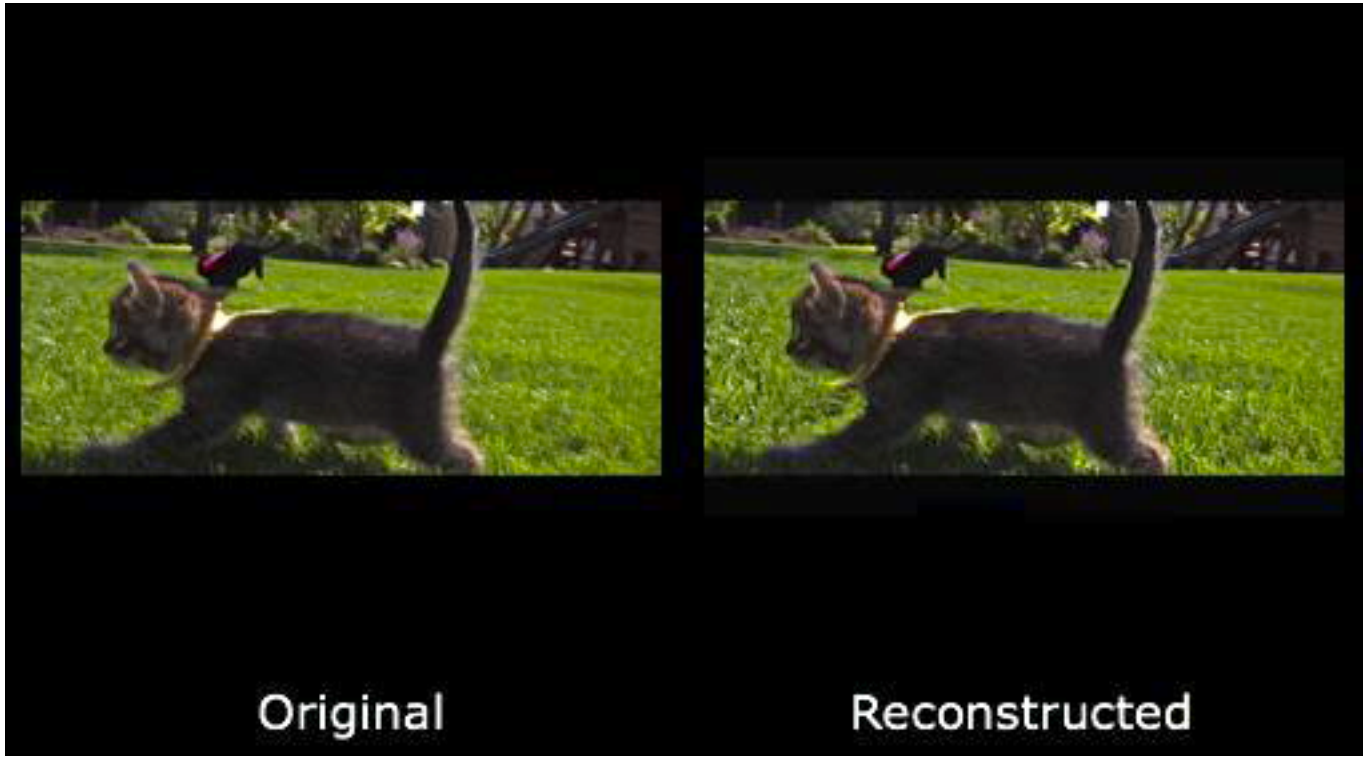
SuperSlicing experiments: synthetic video





Significantly more consistent reconstruction!

Bonus video



See http://dlaptev.org/other/SuperSlicing_demo.avi

Summary

- SuperSlicing decomposition:
  - Exploit the correspondences
  - Reconstruct, not interpolate
  - Good for visualiation and processing

- SuperSlicing segmentation:
  - Apply sub-frame decomposition
  - Use concatenated feature vectors for training

Thanks for your attention!

Questions / ideas are welcome

Based on previous works

1. Laptev, D.; Veznevets, A; Buhmann, J.M., "Superslicing frame restoration for anisotropic ssTEM"*, 2014 IEEE 11th International Symposium on Biomedical Imaging (ISBI)*, pp.1198-1201, doi: 10.1109/ISBI.2014.6868090

2. Laptev, D.; Veznevets, A; Buhmann, J.M., "Anisotropic ssTEM Image Segmentation Using Dense Correspondence across Sections", *Medical Image Computing and Computer-Assisted Intervention – MICCAI 2012*, doi: 10.1007/978-3-642-33415-3_40