

# Generating Hyperrealistic Labeled Images

04/16/2026

Images were kindly provided by Dr. hab. Łucja Kowalewska and her team.

# Our Team

## Machine Learning Team:

- Anna Śliwińska<sup>2</sup>
- Marek Bukowicki<sup>2</sup>
- Szymon Nowakowski<sup>1,2</sup>

<sup>1</sup>Faculty of Mathematics,  
Informatics and Mechanics,  
University of Warsaw

<sup>2</sup>CNBCh, University of Warsaw

## Plant Anatomy and Cytology Team:

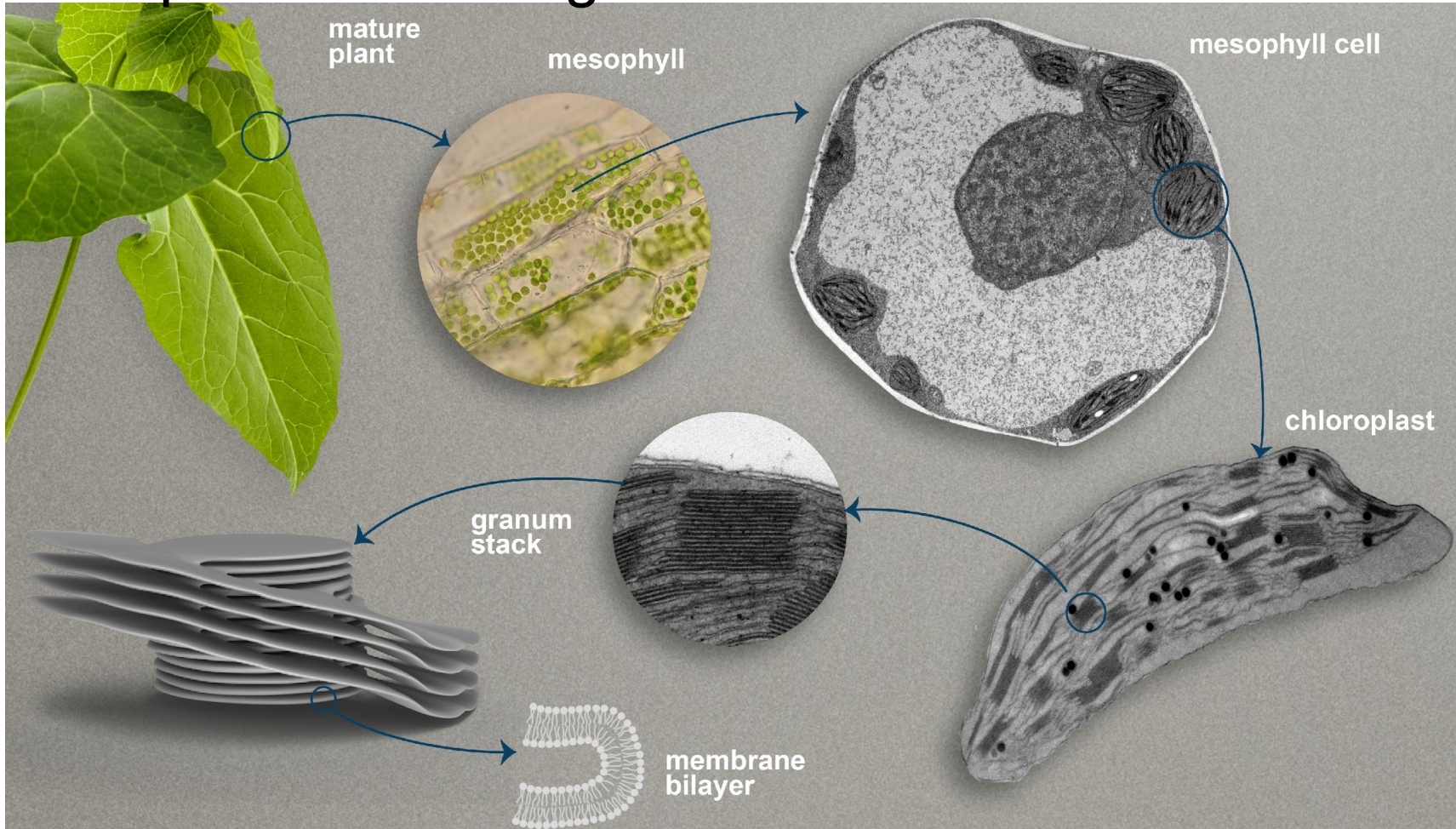
- Zuzanna Bieńko<sup>2,3</sup>
- Michał Bykowski<sup>2,3</sup>
- Łucja Kowalewska<sup>2,3</sup>

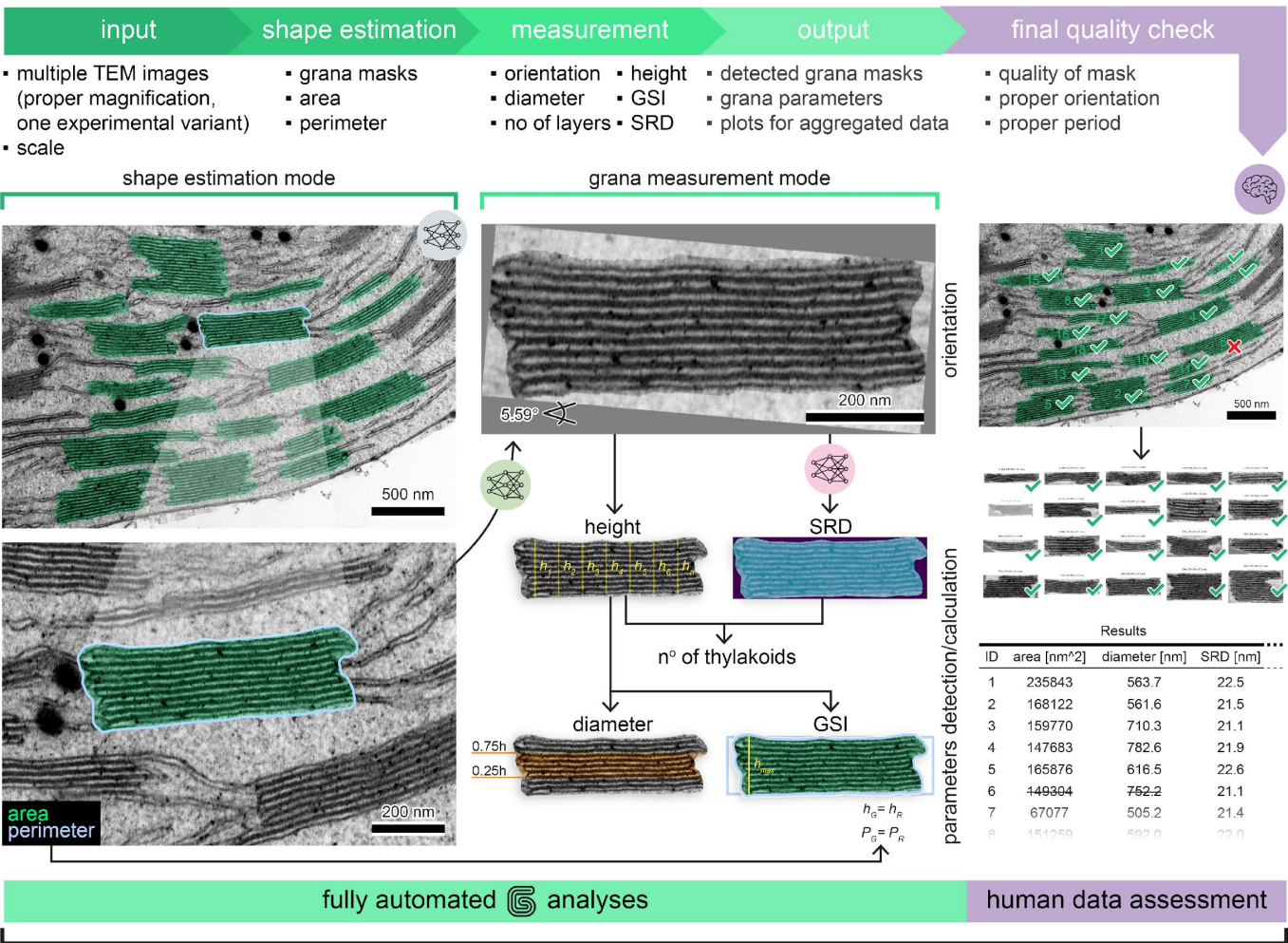
<sup>3</sup>Faculty of Biology, University of  
Warsaw

# Part I. Motivation

Bukat, Alicja, Marek Bukowicki, Michał Bykowski, Karolina Kuczkowska, Szymon Nowakowski, Anna Śliwińska, and Łucja Kowalewska. 2025. "GRANA: An AI-Based Tool for Accelerating Chloroplast Grana Nanomorphology Analysis Using Hybrid Intelligence." *Plant Physiology* 198 (2): 1–16.

# Structural parameters in grana



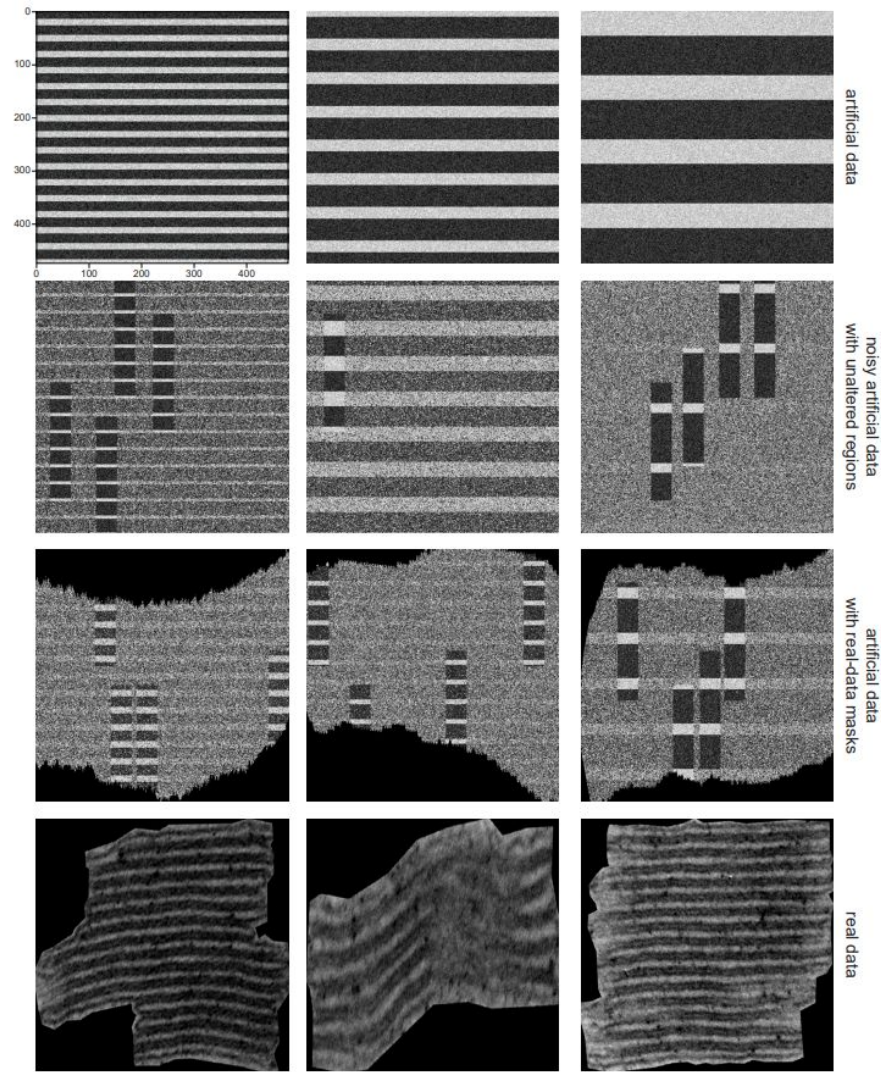


# Period (SRD) Estimation Problem Statement

- Given an image of an individual granum
  - cropped from TEM
  - aligned horizontally
- Estimate the average period length (Stacking Repeat Distance, SRD) in pixels
  
- We note considerable amount of variability even amongst humans
- Data: 339 **annotated** images
- In Machine Learning, such an amount **is considered insufficient**

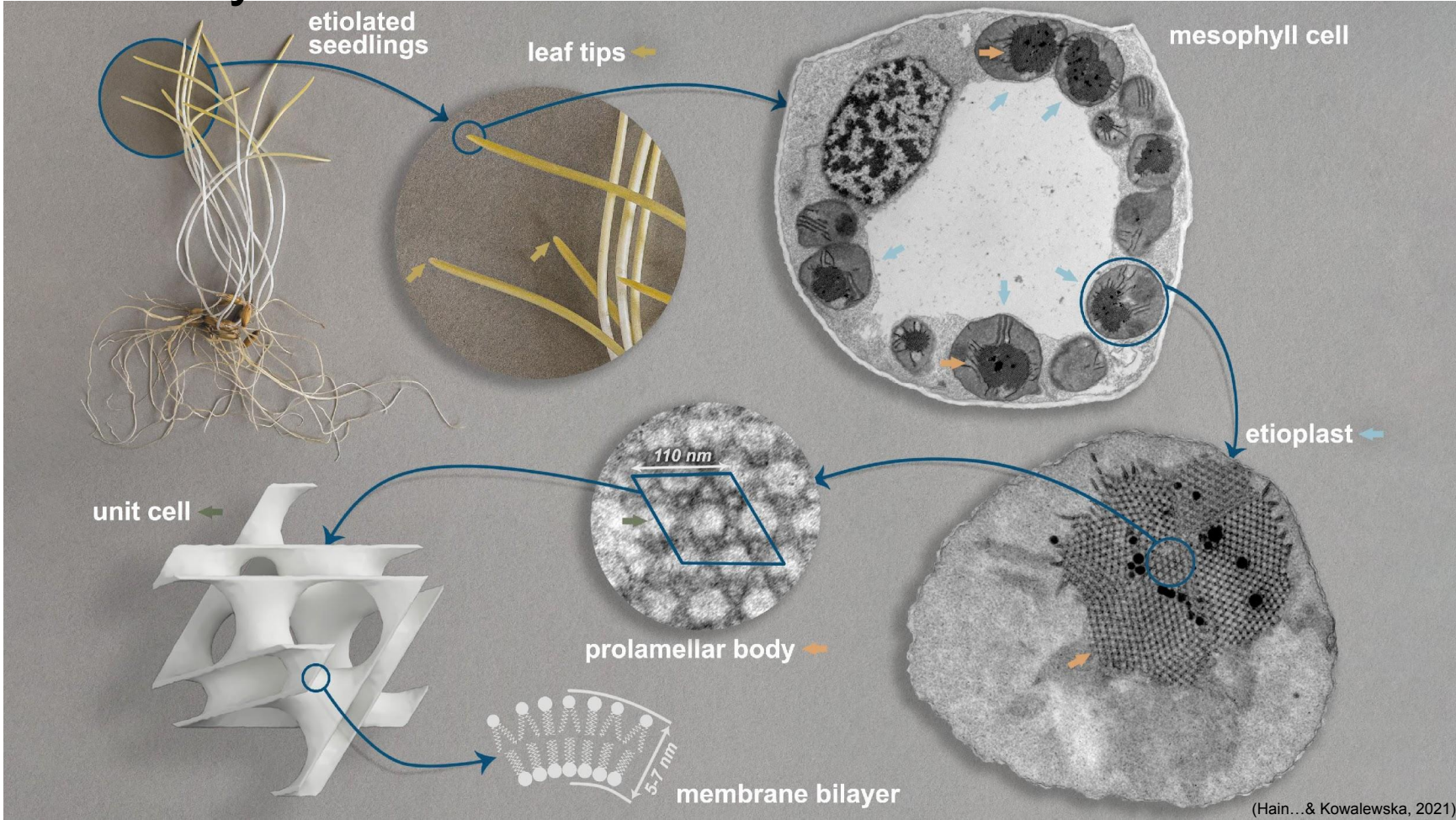
# Progressive Model Growth

- We note insufficient amount of annotated real data
- We train model in stages
  - artificial data, very simple, 200 epochs
  - noisy artificial data, 460 epochs
  - artificial data+real-data masks+image augmentation, 550 epochs
  - **real data+image augmentation, 430 epochs**
- **By using artificial data, we were able to overcome the problem of insufficient data.**



# Part II. Estimating parameters of crystals in PLBs

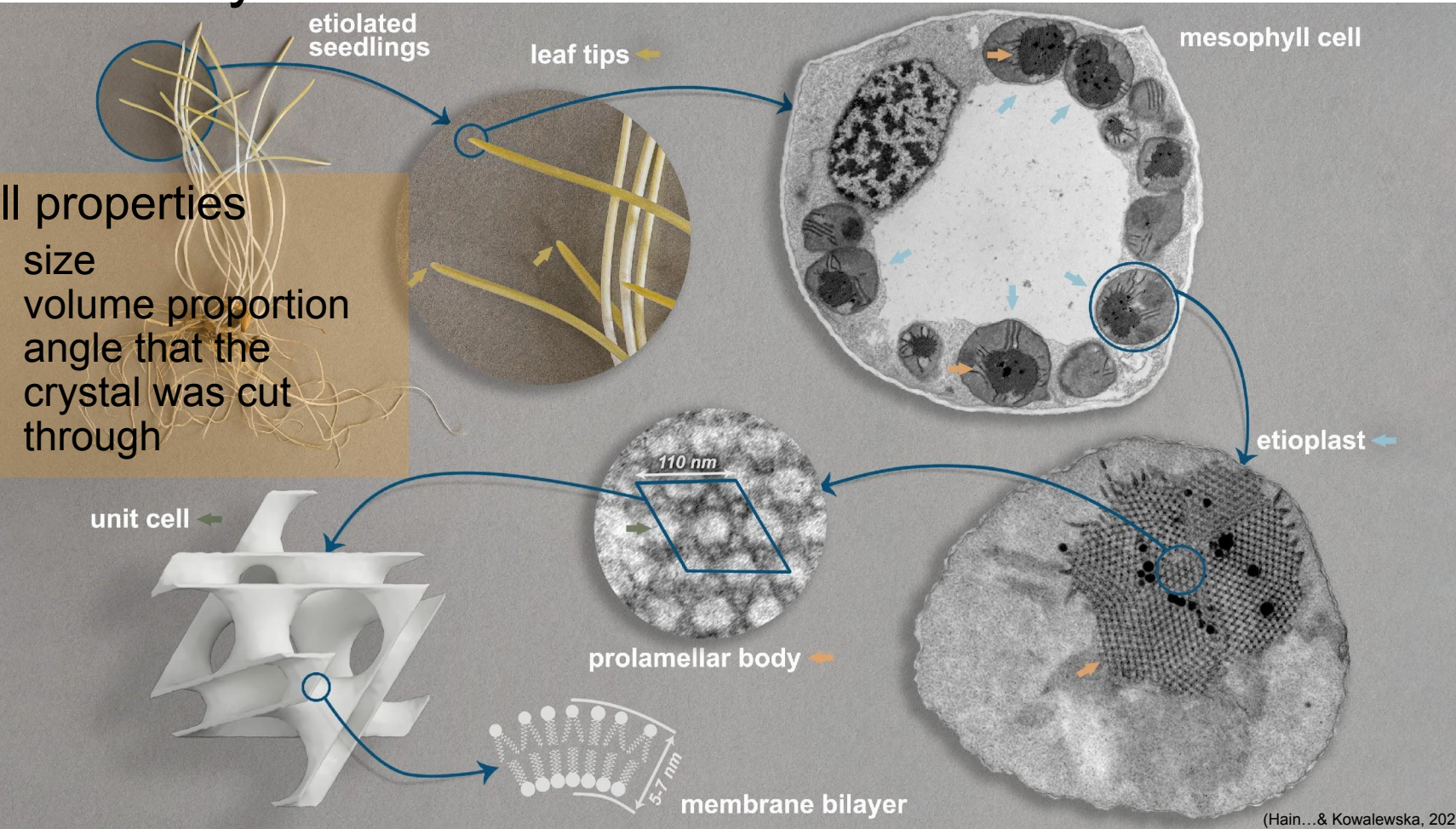
# Membrane crystals in PLB



# Membrane crystals in PLB

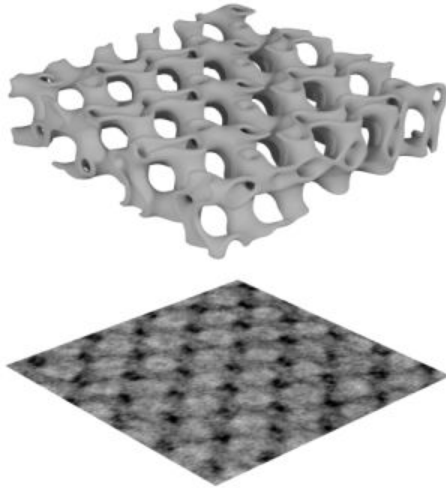
unit cell properties

- size
- volume proportion
- angle that the crystal was cut through

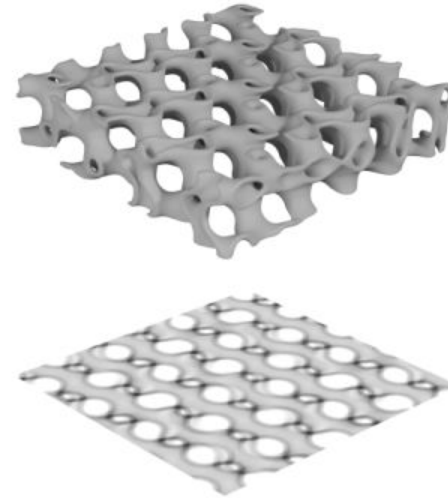


# Triply Periodic Minimal Surface Model

TEM



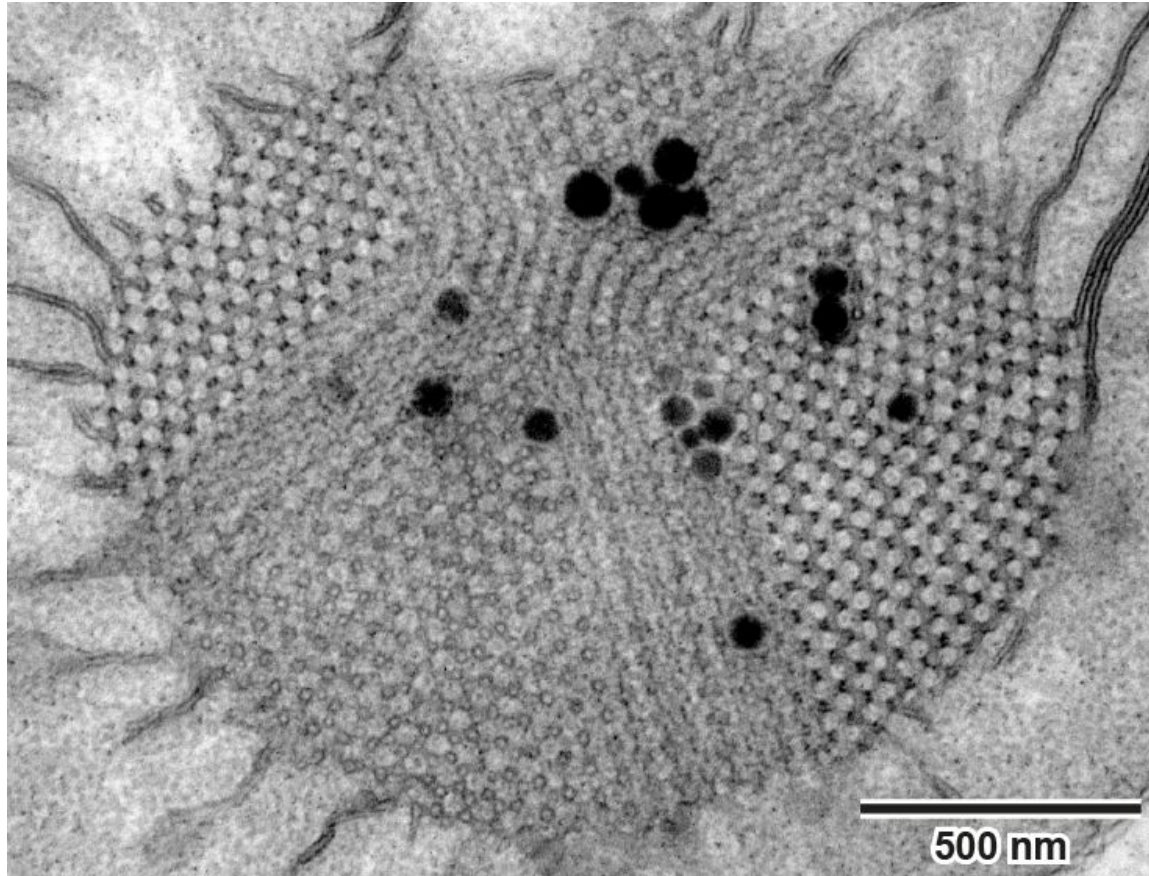
microscopy image



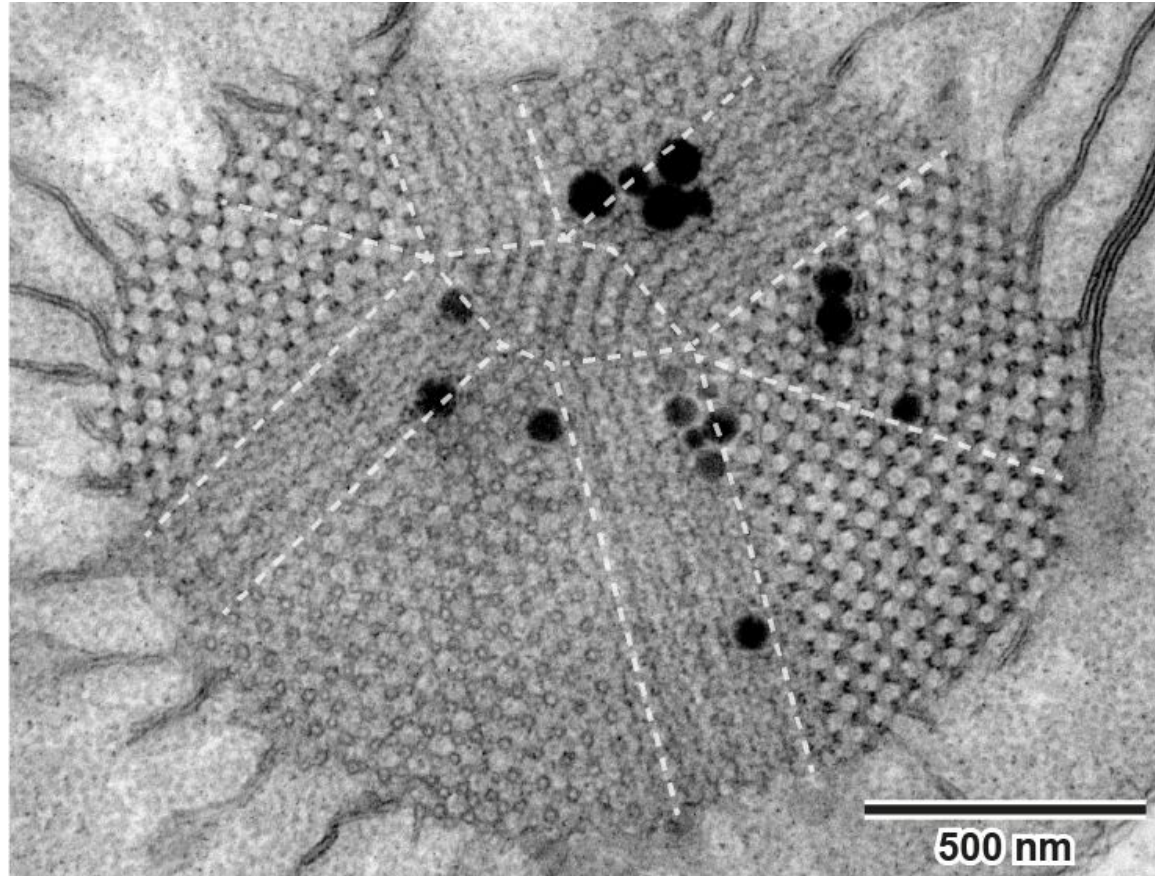
computed projection

Hain, Tobias M., Michał Bykowski, Matthias Saba, Myfanwy E. Evans, Gerd E. Schröder-Turk, and Łucja Kowalewska. 2022. "SPIRE-a Software Tool for Bicontinuous Phase Recognition: Application for Plastid Cubic Membranes." *Plant Physiology* 188 (1): 81–96.

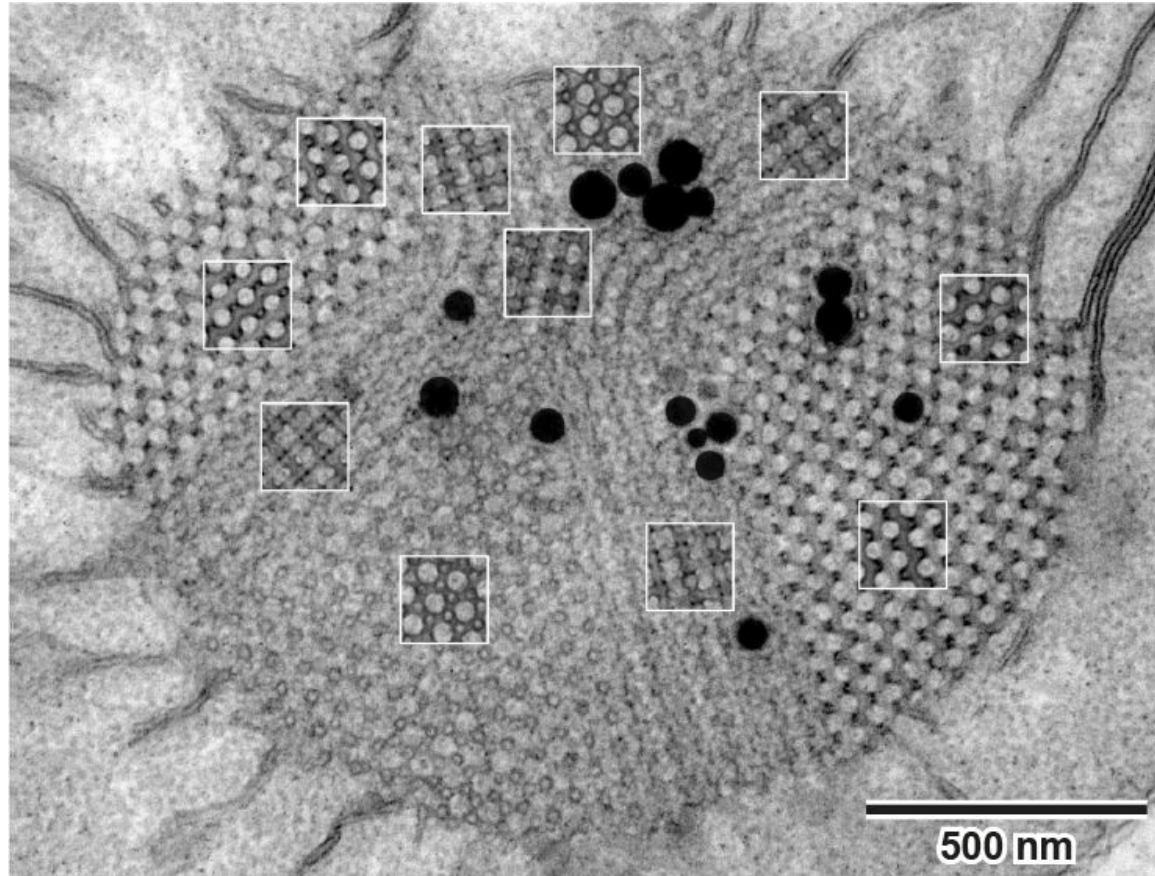
# Current manual process - real PLB



# Current manual process - sections into monocrystals

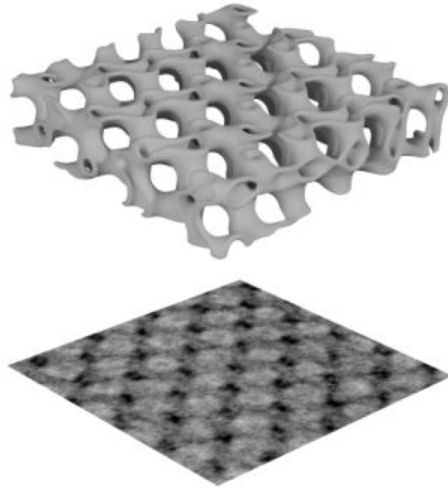


# Current manual process - overimposing SPIRE

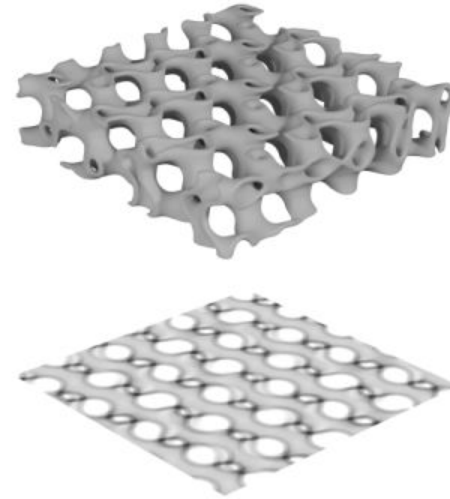


# Current manual process - bottleneck

TEM

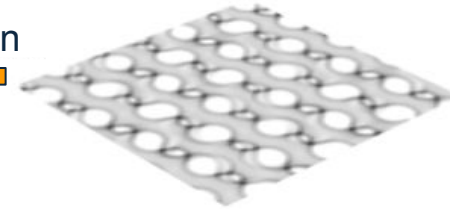
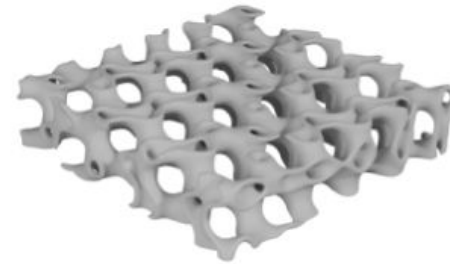


microscopy image

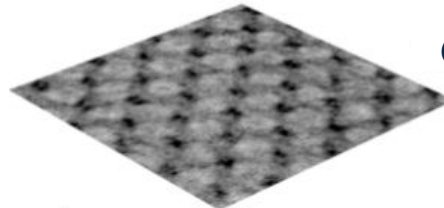


computed projection

# New automatic process - solution to too few data



Generation



hyperrealistic

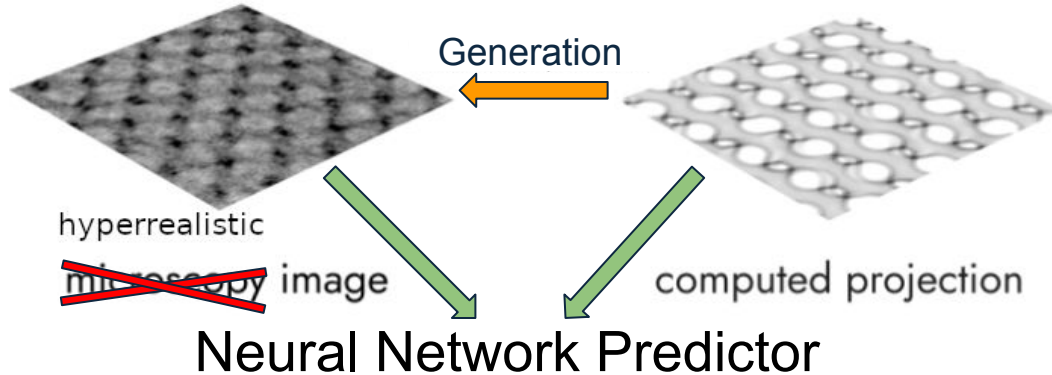
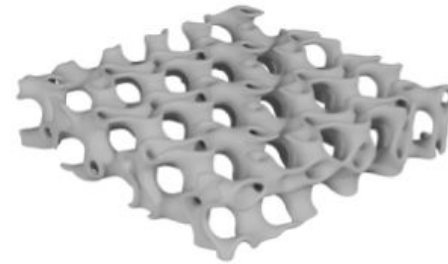
~~microscopy~~ image

computed projection

# New automatic process - solution to too few data

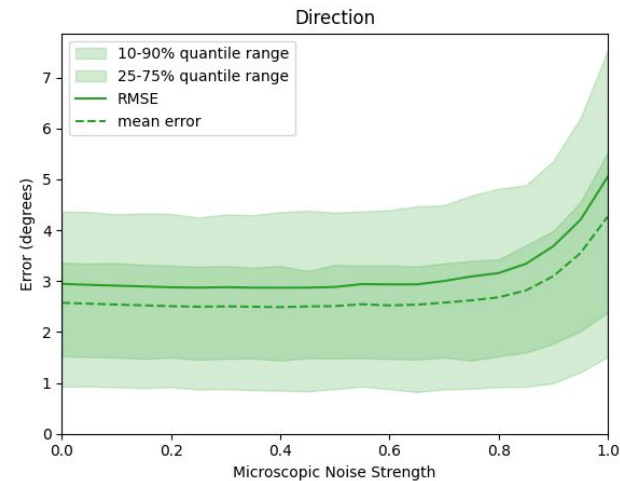
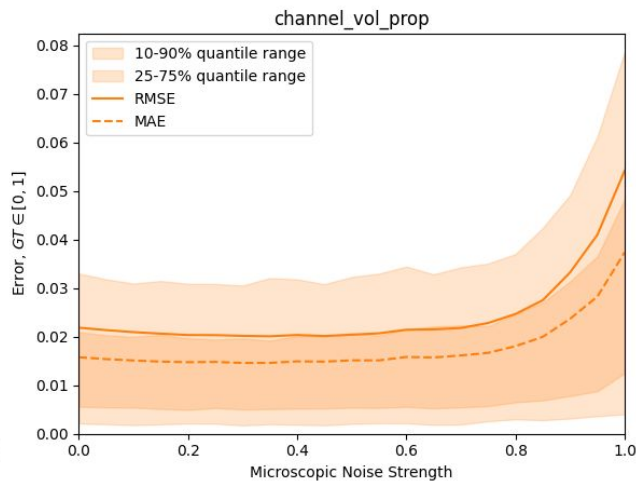
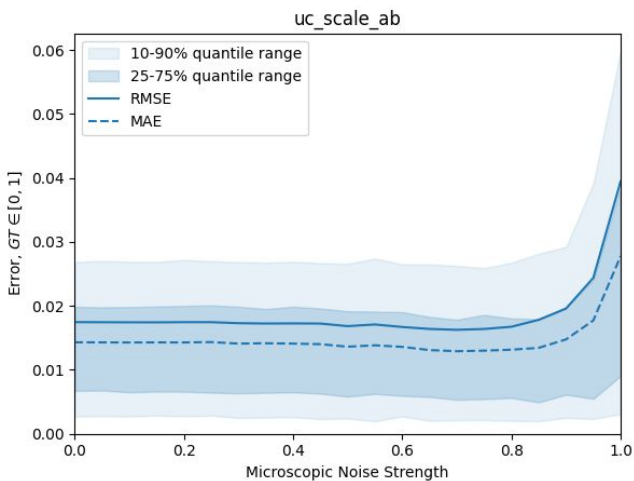
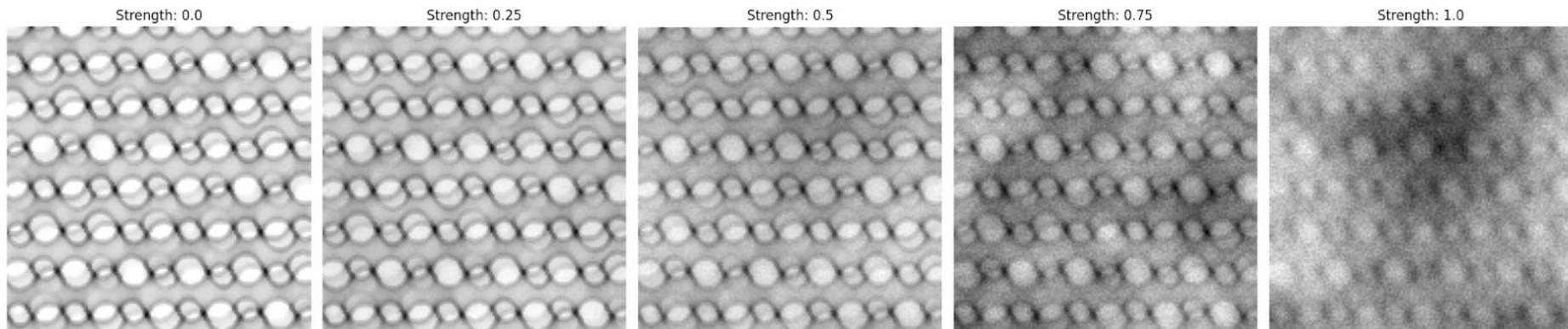
This process can generate unlimited amounts of images that are hopefully

- not distinguishable from real TEM images and
- labeled



# Neural network trained ONLY on noised synthetic data from SPIRE

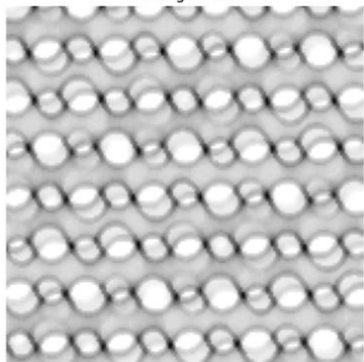
Distortion Progression (Strength 0.0 -> 1.0)



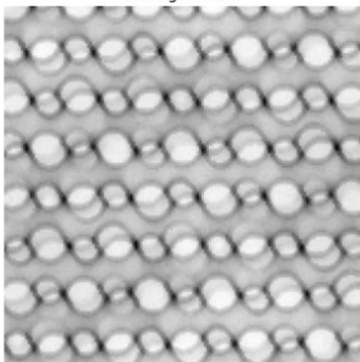
# Neural network trained ONLY on noised synthetic data from SPIRE

Distortion Progression (Strength 0.0 -> 1.0)

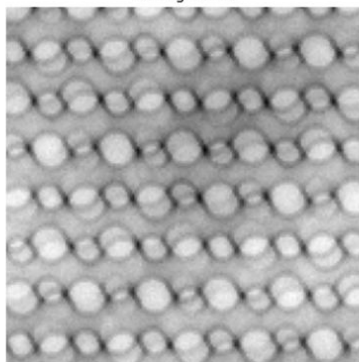
Strength: 0.0



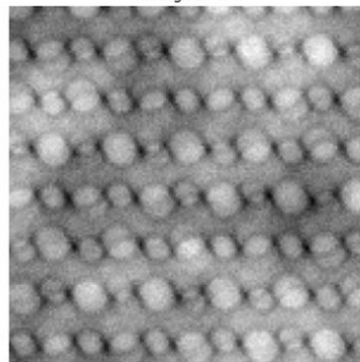
Strength: 0.25



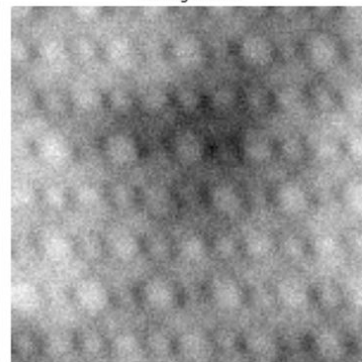
Strength: 0.5



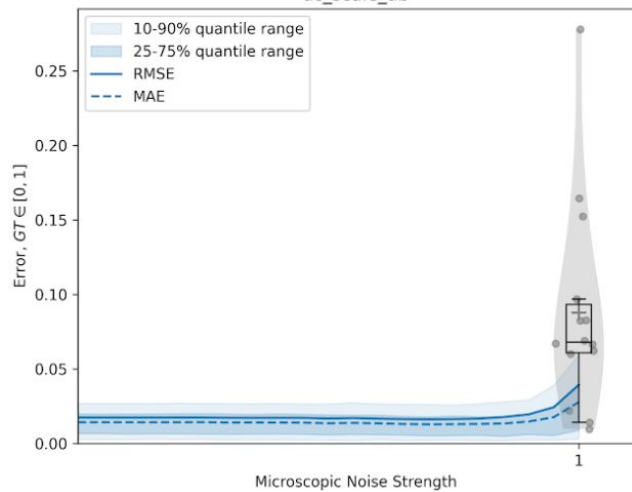
Strength: 0.75



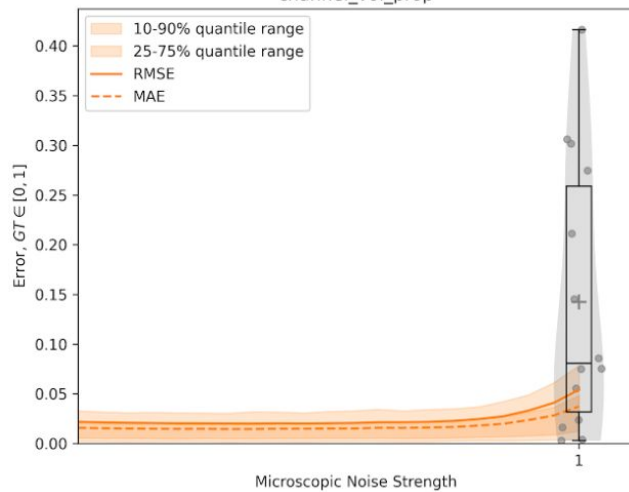
Strength: 1.0



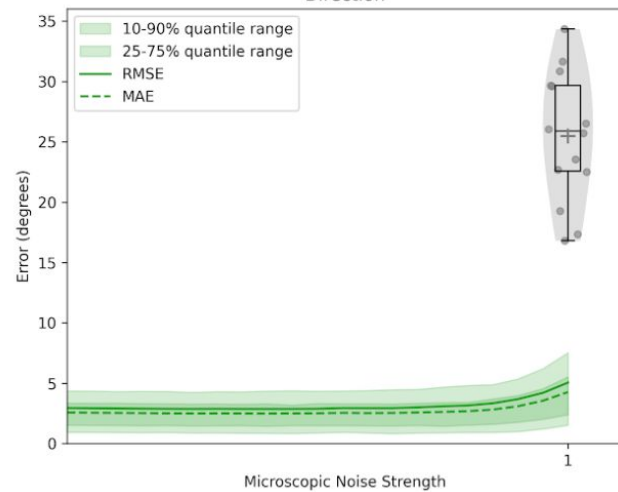
uc\_scale\_ab



channel\_vol\_prop

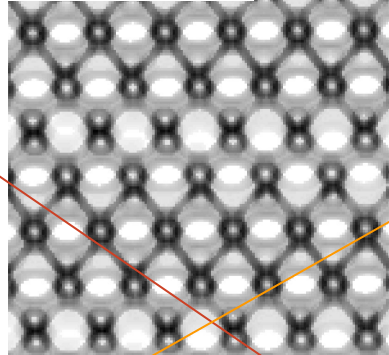
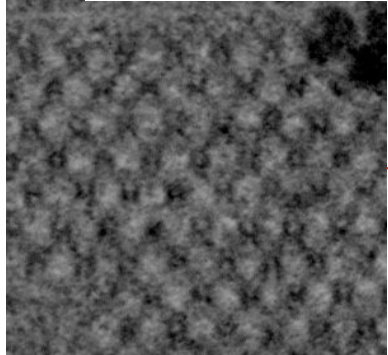


Direction

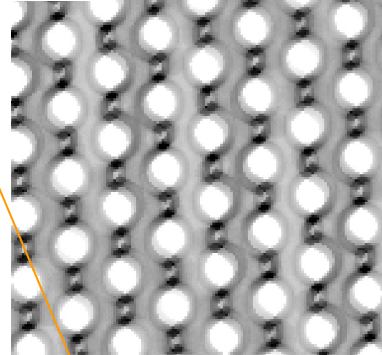
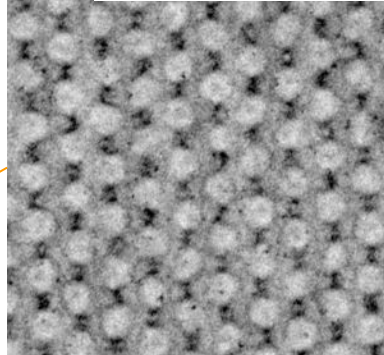


# Neural network trained ONLY on noised synthetic data from SPIRE

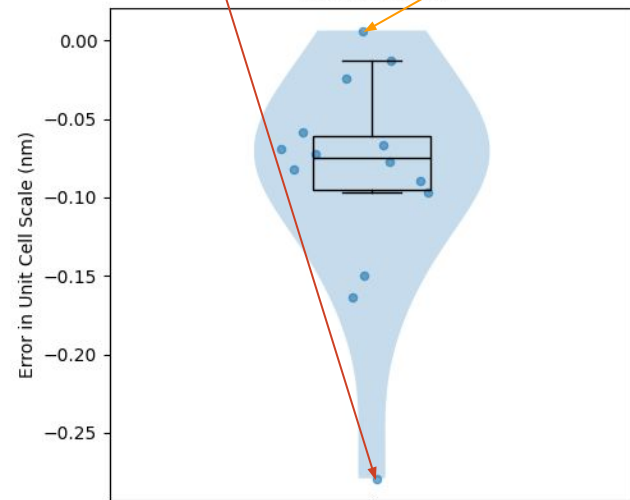
*Arabidopsis thaliana* (rzodkiewnik pospolity)



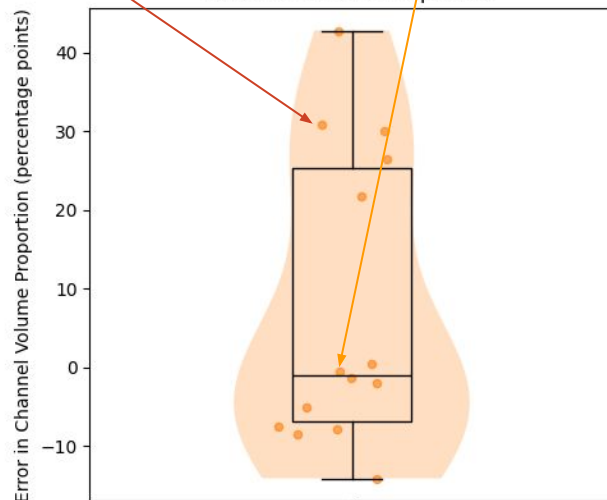
*Avena sativa* (owies zwyczajny)



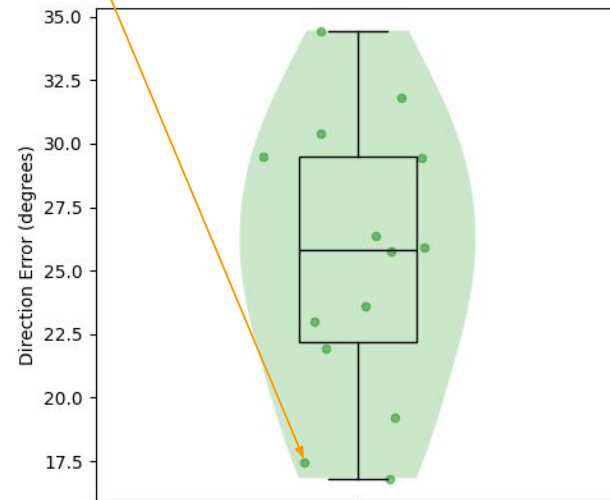
Unit Cell Scale



Channel Volume Proportion



Direction



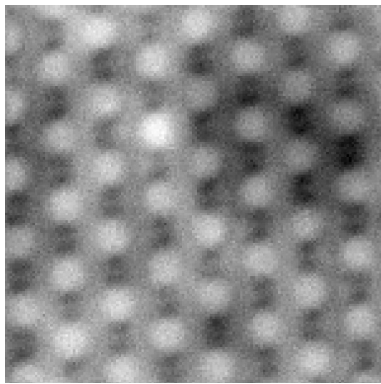
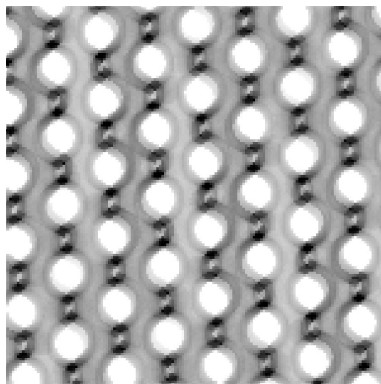
# Domain Gap Visualization

Artificial

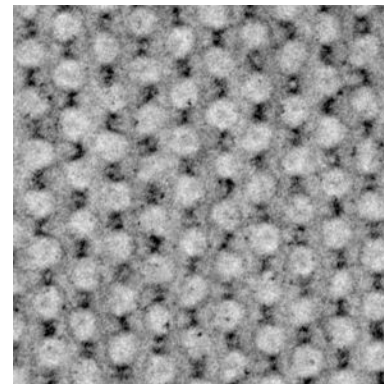
+Noised

Real

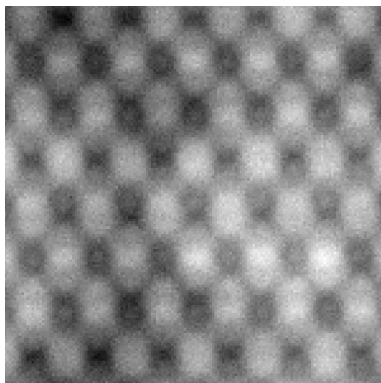
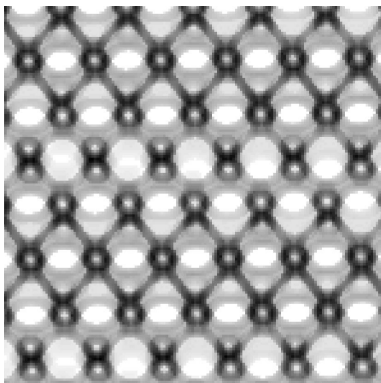
Easy



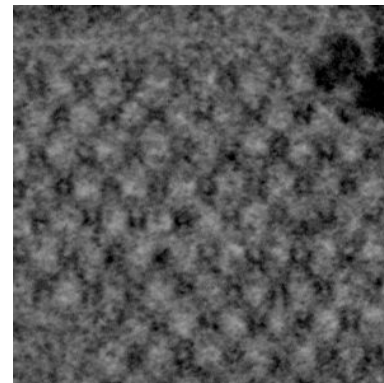
?



Hard



?



# Part III. Generation

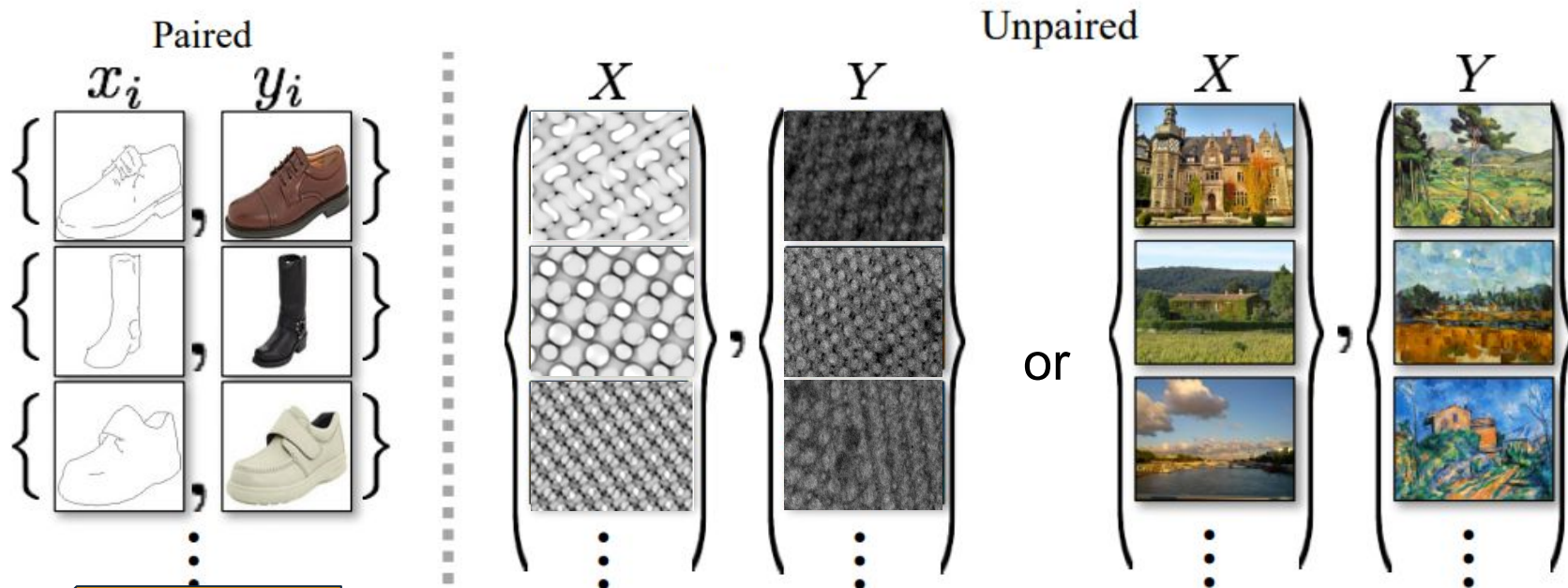
- **Data**
  - Millions of images from SPIRE
  - Object detection with YOLOv11 to isolate PLB crops in real TEM images resulted in [2957 real images](#).
- Aligning synthetic and real image distributions **without paired data.**  
**(We don't have *corruption model* needed in inverse problems)**

In inverse problems, the goal is to recover an unknown sample  $x \in \mathbb{R}^n$  from a distribution  $p_X$ , assuming access to measurements  $y \in \mathbb{R}^m$  and a corruption model

$$Y = \mathcal{A}(X) + \sigma_y Z, \quad Z \sim \mathcal{N}(\mathbf{0}, I_m).$$

# Aligning synthetic and real image distributions without paired data

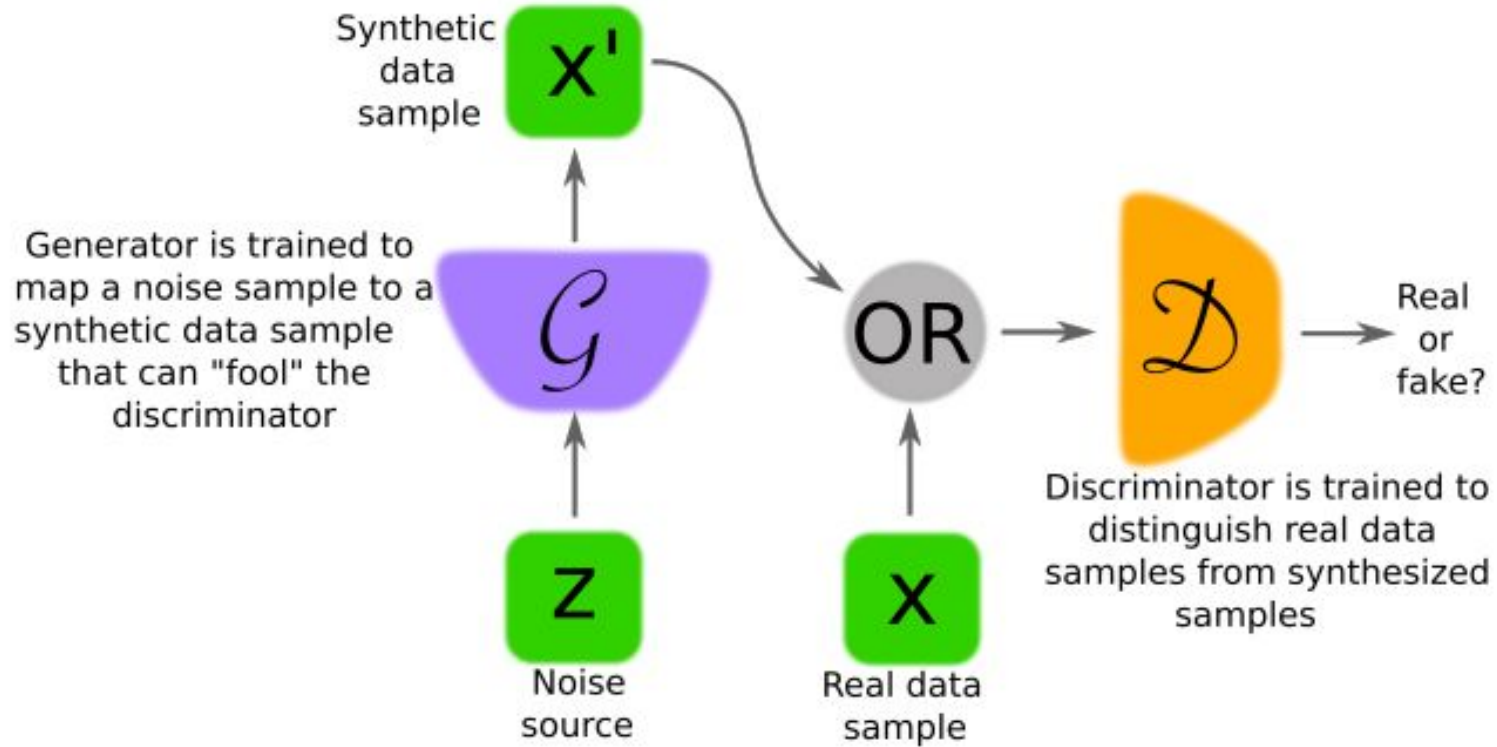
CycleGAN: a method for **unpaired** image distributions



Corruption model

image edited from Zhu, Jun-Yan, Taesung Park, Phillip Isola, and Alexei A. Efros. 2017. "Unpaired Image-to-Image Translation Using Cycle-Consistent Adversarial Networks." In *2017 IEEE International Conference on Computer Vision (ICCV)*, 2242–51. IEEE.

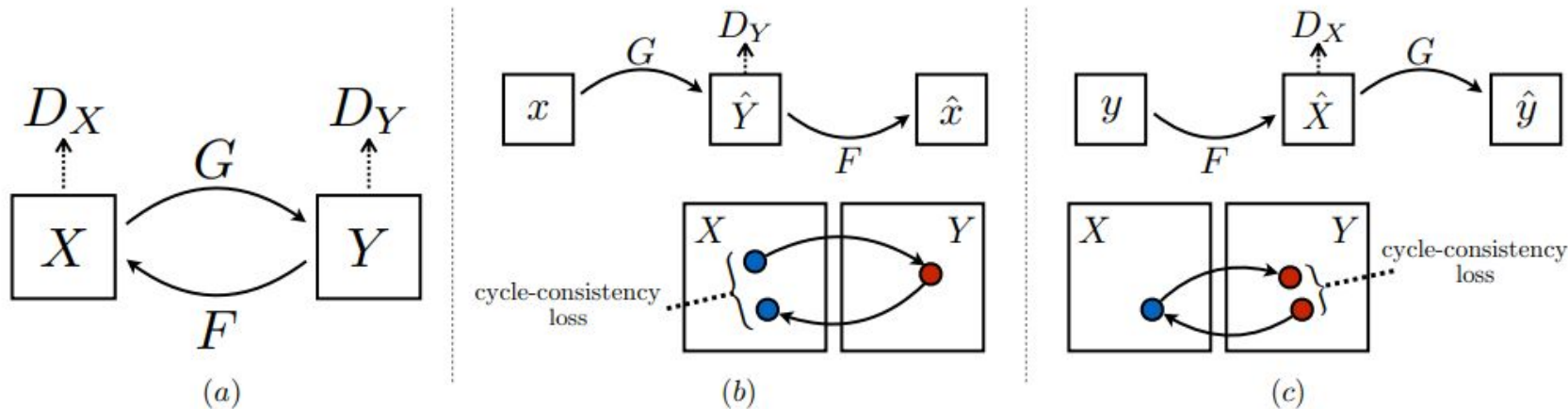
# GANs



# Aligning synthetic and real image distributions without paired data

CycleGAN has

- two GANs and
- additional cycle-consistency loss components



# Current Results - need improvement

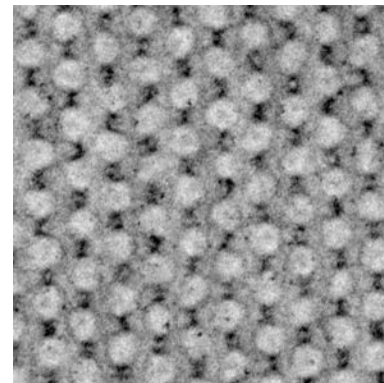
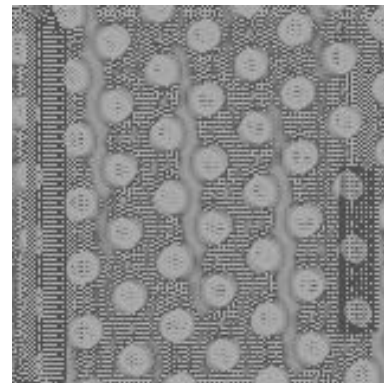
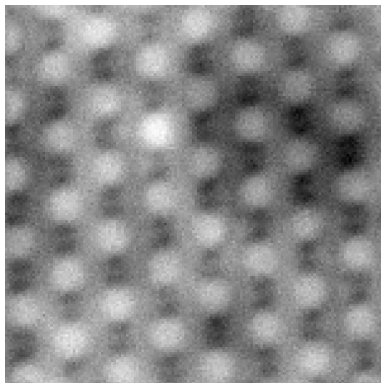
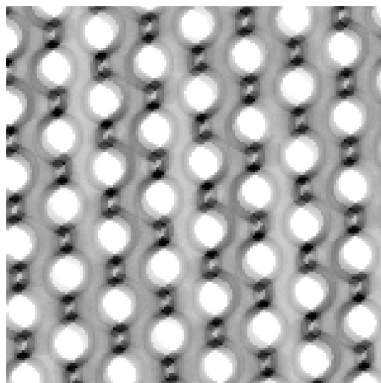
Artificial

+Noised

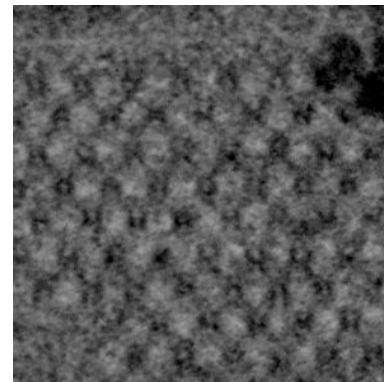
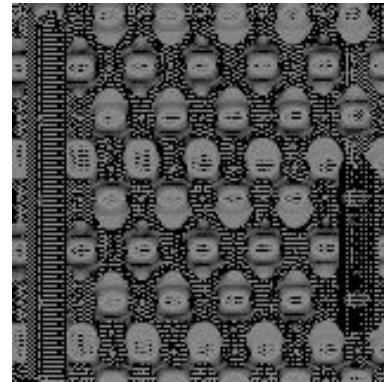
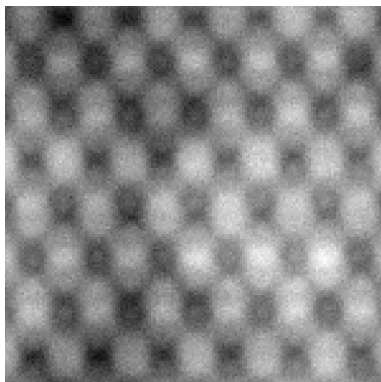
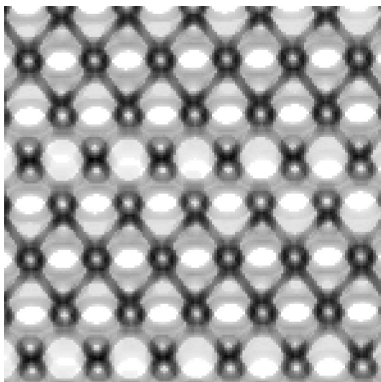
Hyperrealistic???

Real

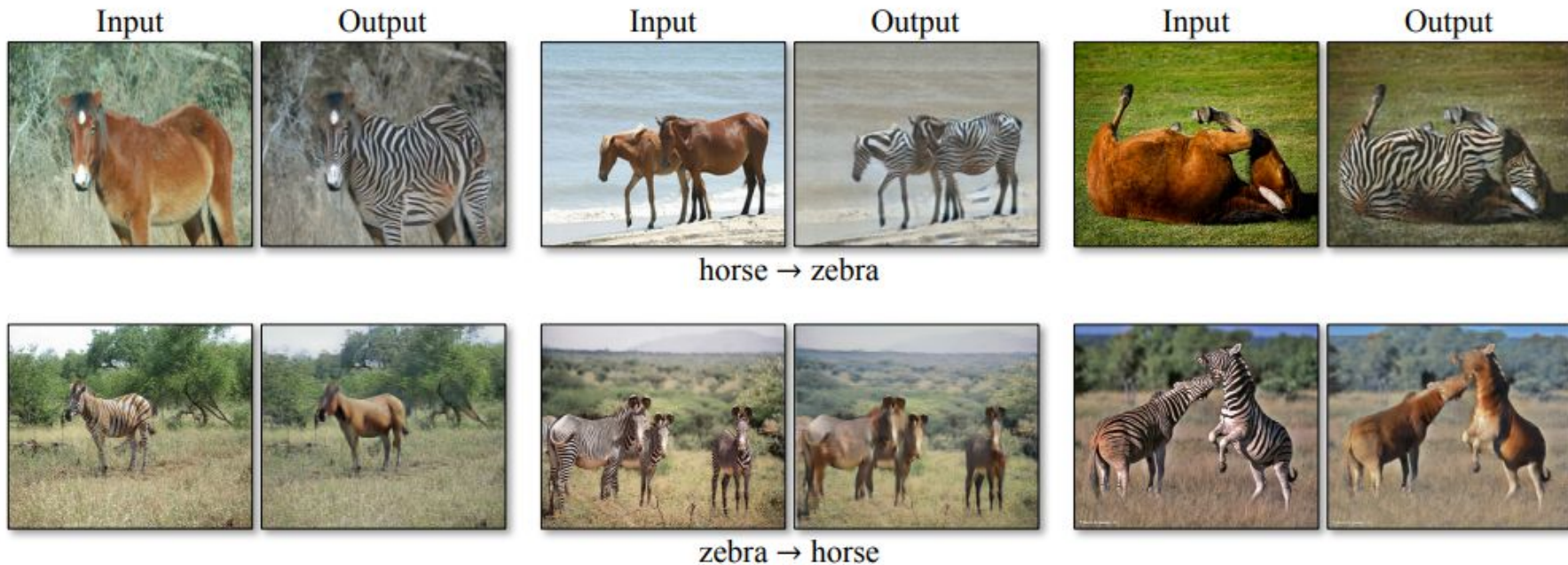
Easy



Hard



# Properly trained CycleGANs achieve impressive results



# Properly trained CycleGANs achieve impressive results



apple → orange



orange → apple

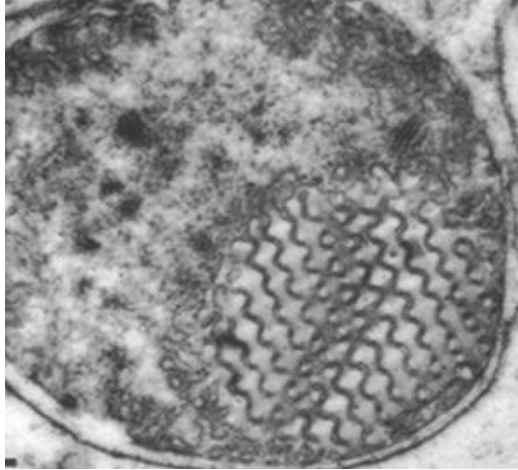


# Part IV. Future work

- This approach is universal
  - can be used to revisit period detection in GRANA tool
  - we hope to find other datasets of biological origin with few annotated samples

# Other structures amenable to analysis

Amoeba



Mitochondria inner membranes

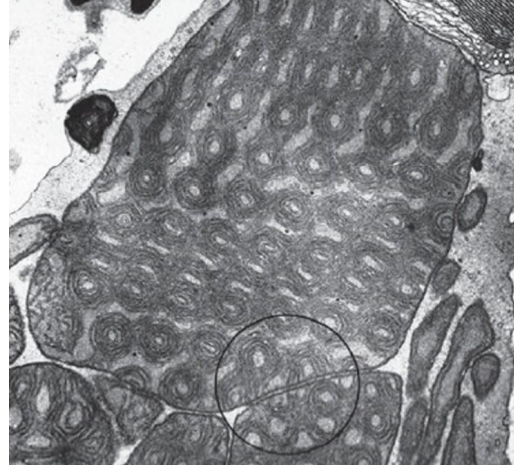


PRIMITIVE



(Deng and Mieczkowski 1998)

Tree shrew



Endoplasmic Reticulum of retina cells

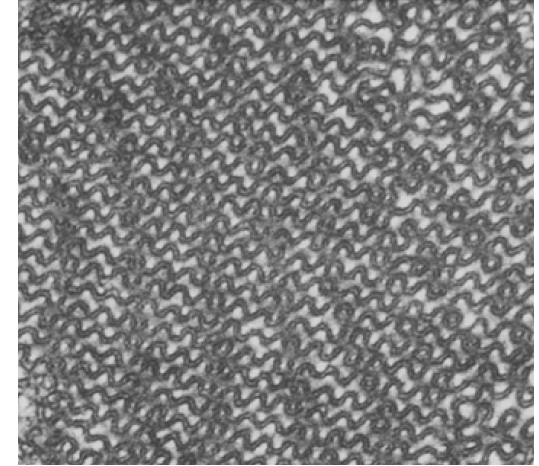


GYROID



(Almsherqi et al. 2021)

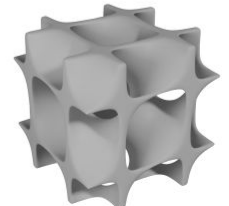
Scale-worm



Endoplasmic Reticulum of luminous epithelium



DIAMOND



(Bassot and Nicolas 1995)