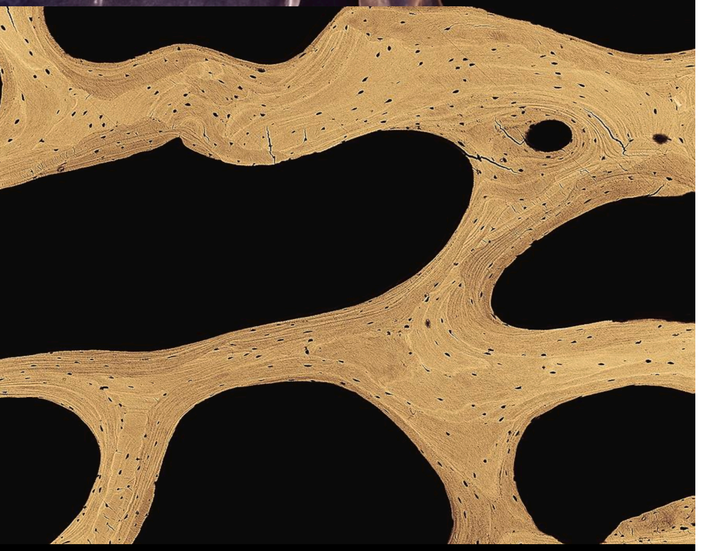
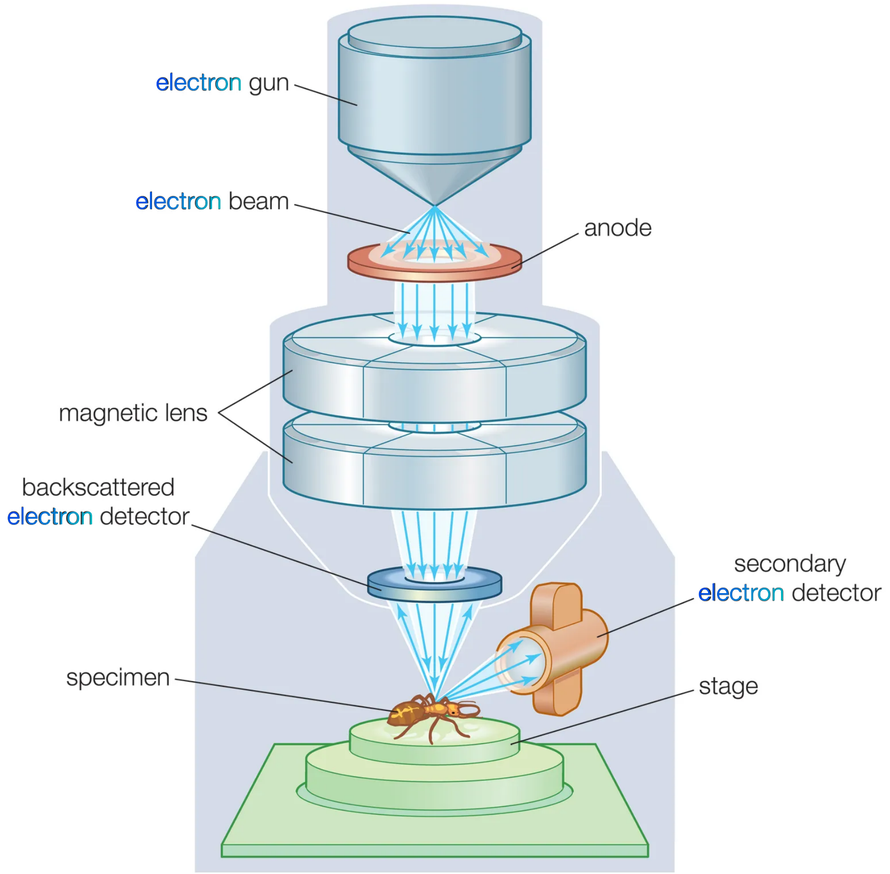


A Survey on SEM Imaging Techniques

Naveen Bharadwaj

What is SEM?



SCANNING ELECTRON MICROSCOPE

- Scanning Electron Microscopy.
- Used for micro and nanoscale analysis, surface morphology studies, elemental and chemical analysis etc.

- High Magnification
- Resolution
- Non Destructive Imaging
- Surface Imaging

Why do we need Imaging techniques?

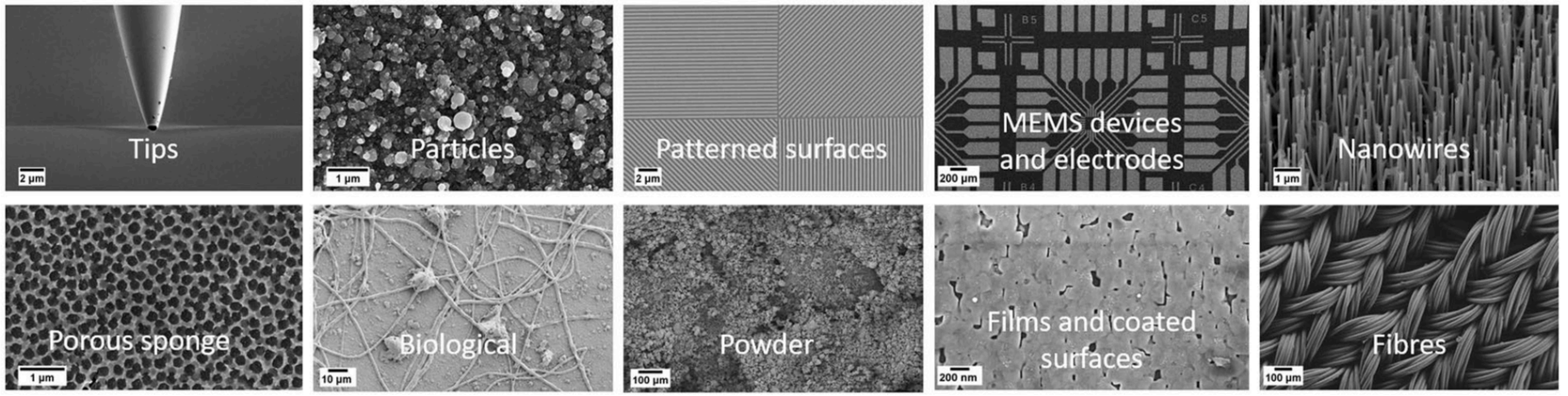


Figure: Categories chosen for SEM Imaging, source: SEM Database

- To remove noise, enhance contrast, brightness and sharpness.
- Can also be used for Image classification, object detection, segmentation, and feature extraction.
- Increasing the accuracy and reliability of the results.
- Improve the speed and efficiency of image analysis and processing.

Techniques

Image Processing

- Edge detection
- Segmentation
- Feature extraction
- Wavelet Transform

Deep Learning

- Convolutional Neural Networks (CNNs)
- Generative Adversarial Networks (GANs)
- Autoencoders
- Transfer Learning

Techniques

Pre Processing

+

Deep Learning

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Image Processing Techniques

Edge Detection
Provides information on the boundaries of different structures within the image.

Segmentation
Dividing an image into multiple segments to analyse individual features.

Feature Extraction
Identifying significant features within the image that can be used to train a DLP.

Wavelet Transform
Decomposing an image into different frequency components.

Convolutional Neural Networks

- Used for Image denoising, restoration, and segmentation.
- Can also enhance image quality, or classify defects.

PRE-PROCESSING

Edge detection/Wavelet Transform: Can help the CNN to learn the mapping between low-res and high-res SEM images.

Segmentation: Can be used to train the CNN to better recognise different features in the image.

Feature extraction: Can be used to identify significant features within the image.

Convolutional Neural Networks

Require large amounts of labeled SEM data to train effectively

⊕ **Transfer Learning,** a technique that uses pre-trained models on a large dataset.

Can overfit if the model is too complex or if the training data is too small or biased

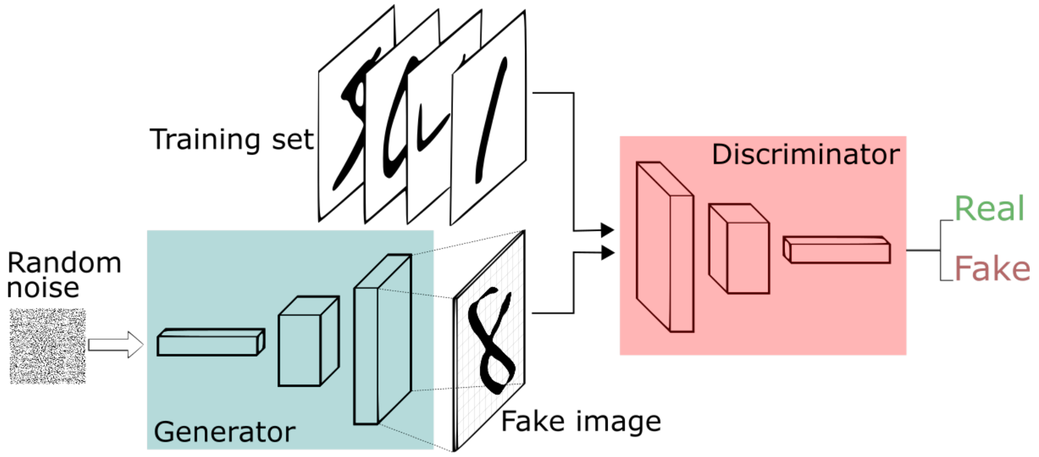
⊕ **Regularisation** and **Data Augmentation**.

Can be computationally expensive, especially for high-resolution SEM images

⊕ **GPUs, parallel processing, and distributed computing can be used.**

Generative Adversarial Networks

- Two Neural Networks, Generator and Discriminator.
- Generator creates fake data, discriminator used to distinguish fake and real data.
- Used to generate high quality images, to overcome noise, low resolution, and poor contrast.



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PRE-PROCESSING

Edge detection: Can help the GAN to generate high-quality SEM images that closely resemble real SEM images.

Segmentation/Feature extraction: Can used to train the GAN to better recognise different features in the image.

Wavelet Transform: Can improve the GAN's ability to generate high-quality SEM images.

Generative Adversarial Networks

Difficult to train and stabilise, which can lead to mode collapse.

⊕ Using **Alternative loss functions, Support Vector Machines.**

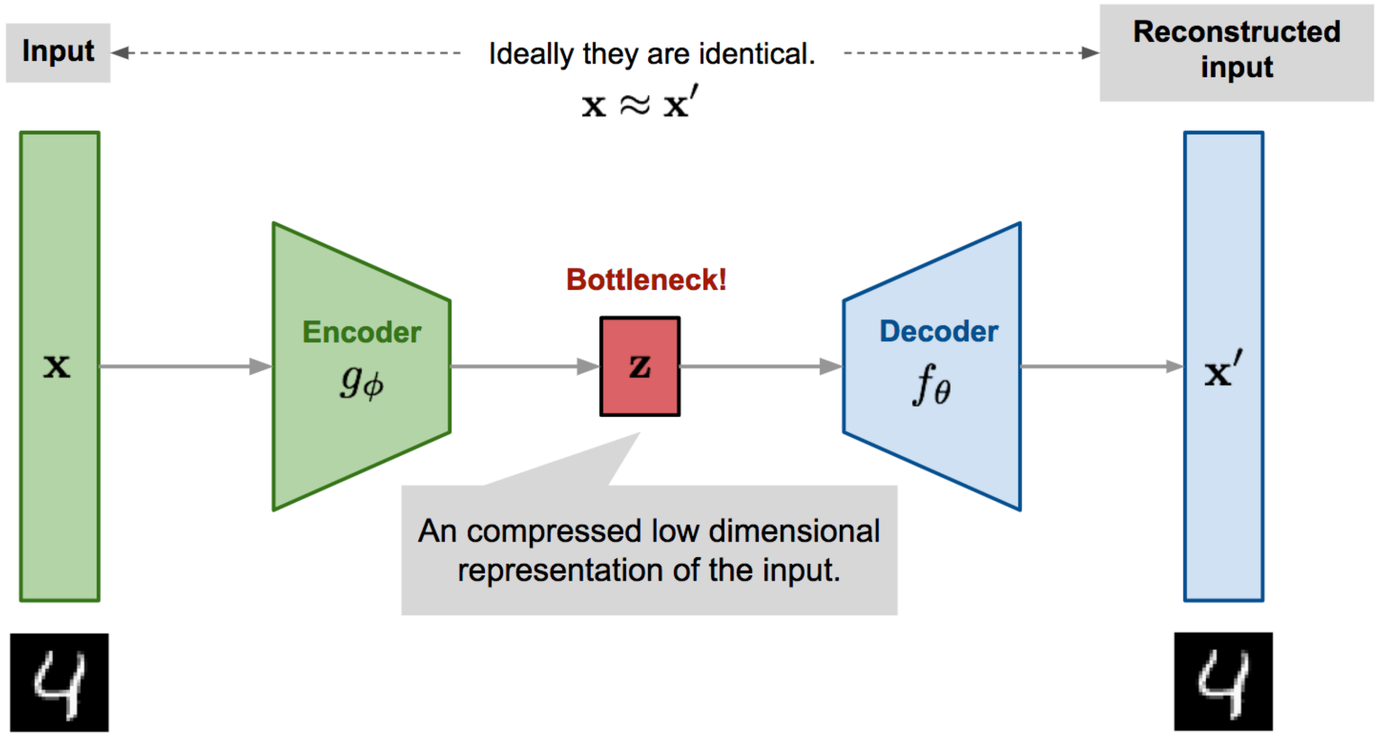
Can generate SEM images that may lack fine details present in the original data.

⊕ Techniques such as **visualisation, clustering are used.**

Require large amounts of computational resources.

⊕ **Weight initialisation, batch normalisation,** or **skip connections.**

Autoencoders



- Retains most important information for reconstruction.
- Used for image restoration, image enhancement, and segmentation.

Autoencoders

- Enhances SEM images by reconstructing high-quality images from low-quality ones.
- Used for unsupervised learning in SEM.

PRE-PROCESSING

Edge detection: Can help the autoencoder to learn a compressed representation of the input image.

Segmentation/Feature extraction: Can used to train Autoencoders to better recognise different features in the image.

Wavelet Transform: Can improve the autoencoder's ability to learn a compressed representation of the input image.

Hybrid Techniques

CNN + GAN for SEM image restoration, CNN is used for noise reduction and GAN is used for image enhancement.

CNN + Wavelet Transform for SEM image restoration, CNN is used for feature extraction and the wavelet transform is used for image decomposition.

Pre-trained CNN + Unsupervised Learning Algorithm for SEM image segmentation, CNN is used for feature extraction and the unsupervised learning algorithm is used for clustering.

CNN + Autocoders for SEM image analysis, CNN is used for feature extraction and the autoencoder is used for dimensionality reduction.

Techniques	Advantages	Disadvantages	ML/ Non-ML	Training Data Required	Throughput	Signal-to-Noise Ratio Higher is better
CNN	Provides high-quality results, superior to other traditional techniques	Computationally expensive, requires large amounts of training data, prone to overfitting	ML	Large amounts of high-quality training data required	High	High
GAN	Can produce high-quality images, can learn complex image distributions	Can be difficult to train, can suffer from mode collapse	ML	Can work well with small amounts of training data	Low	High
Autoencoders	Can capture subtle image details, can learn useful image representations	May not capture all image details, can suffer from overfitting	ML	Requires large amounts of training data, specialized architecture	High	High
Transfer Learning	Can improve performance on new and related tasks, reduces the amount of training data required	Pre-trained models may not be applicable to all tasks, may require fine-tuning	ML	Pre-existing models and large datasets required	High	High
Wavelet Transform	Can effectively reduce noise in SEM images	Can be computationally intensive	Non-ML	Not applicable	High	High
Feature Extraction	Can capture complex image features, can be used with different types of data	May not capture all relevant image features, may be sensitive to noise and lighting conditions	ML/ Non-ML	May require significant computational resources	High	Low
Hybrid Techniques	Can provide more accurate results, can address complex image processing tasks	Can be complex to implement and optimize, may require extensive computational resources	ML/ Non-ML	Large amounts of high-quality training data required	Varies	Low

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Future Work

1 Standardised Datasets
To enable the comparison of results across different studies.

2 Transfer Learning
Proven effective in improving performance.

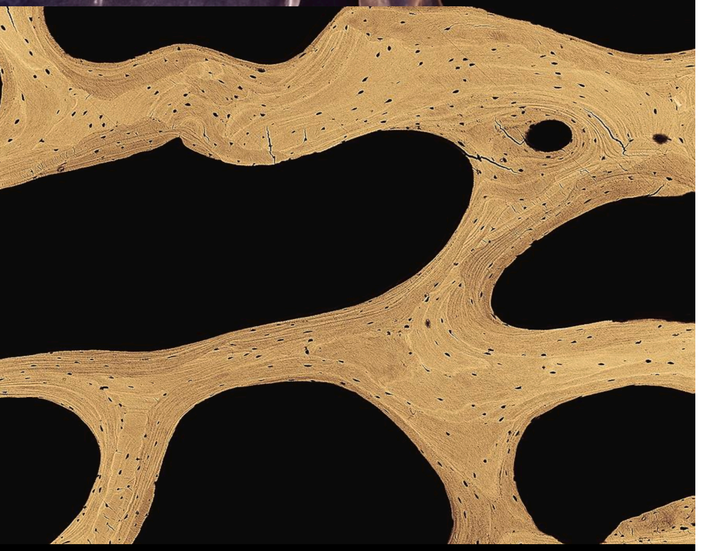
3 Explainable Deep Learning
To increase reliability and accuracy.

4 Real-time analysis of SEM

Conclusion

- Deep learning techniques have shown great potential.
- Improving the resolution, contrast, and reducing noise.
- Accuracy on availability of large amounts of labeled SEM data for training and Imaging Conditions.
- Traditional image processing techniques fare better for simpler structures.

Thank you.



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Q&A

Advanced Topics - Final Project