Seeking Higher-Order Modes in Free Electron Lasers

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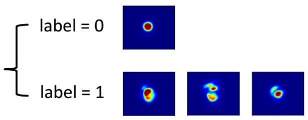
Introduction

Understanding the beam profile of X-ray free-electron lasers (FELs) and its correlation with electron bunch parameters is important to the improvement of FEL facilities. Towards this end, we use deep neural networks to classify the X-ray beam profiles obtained under various conditions. Both a supervised learning model and an unsupervised learning model are used, and the results are compared.

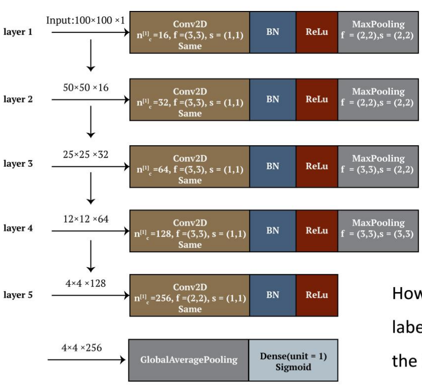
Supervised Learning

For supervised learning, we manually sort 4000+ images into two categories

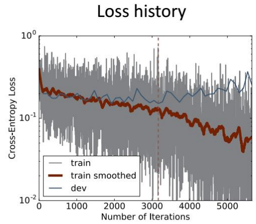


We then use a CNN to learn the classification:

Architecture



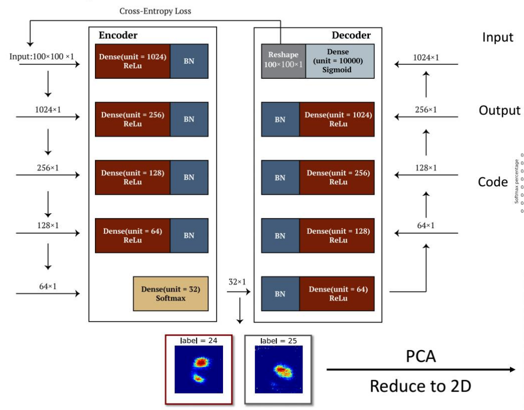
Loss history

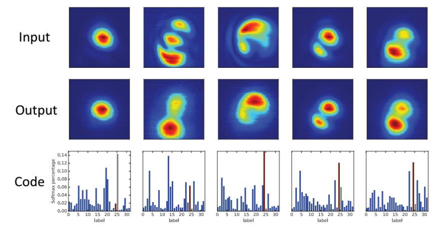


However, because of ambiguities in labelling some images, we estimate the human error to be ≈ 8%...

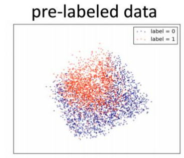
Unsupervised Learning

To utilize the large dataset available to us and address the ambiguity in human labelling, we use a 2-step unsupervised learning with an autoencoder network to reduce the 100×100 images to a 32-parameter "code" before they are further reduced to 2D information. A total of 76800 images are used as input.

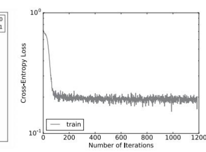




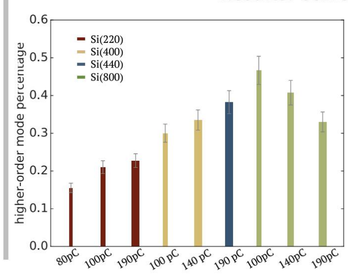
Sanity check using pre-labeled data

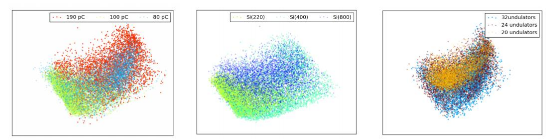


Loss history



Results: Correlation with Electron Bunch Parameters





Our results show that deep neural networks can be used to characterize FEL X-ray beam profiles and reveal their relation with tunable parameters. In general, higher bunch charge, higher-order crystal reflection and insufficient number of undulators lead to the increase of higher-order modes. This can be used to optimize FEL performance in the future.