Machine Learning for Noise Removal in Time-Resolved Data-Sparse Charged Particle Detection

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Introduction

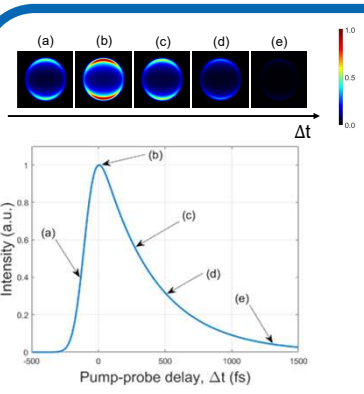

Figure 1

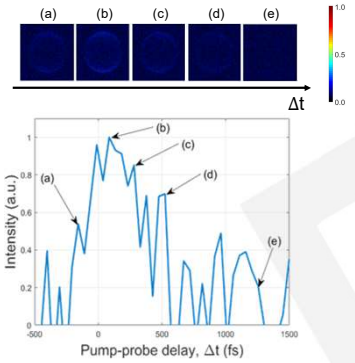

Figure 2

- Electrons/atomic molecular fragments are produced *via* interactions between molecules and laser pulses[1]
- **Velocity map imaging** (VMI) allows full 3D recoil distribution to be projected onto a 2D detection plane[2]
- Integrate images over all **energies**, results in **transient decay** (Fig. 1)
- Mathematical description of transient is convolution between Gaussian function and **exponential decay**
- Decay **lifetime** gives information regarding **dynamics** of atomic/molecular sample probed
- Event counting nature of experiments gives rise to **Poissonian noise**[3] (Fig. 2)
- Need to implement **noise removal** techniques to extract information
- Traditionally, these experience **slow runtimes** and **high computational expense**[4,5]

Artificial Neural Networks (ANNs)

- Can **machine learning** provide a **faster** and **less expensive** alternative to **statistical denoising...**?
- **Autoencoder** network architecture manipulates dimensions using convolutional filters, max-pooling and concatenations (Fig. 3)
- Results in ~500,000 **trainable** parameters

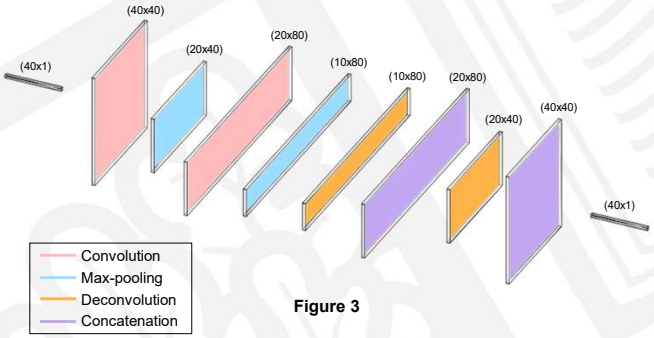

Figure 3

- **Simulate** many (1,000) pairs of **1D transient decays** with varying lifetime, noisy version and corresponding true nature
- **Train** ANN to find model reconstructing original noise-free function, by **minimising difference** between network output and truth
- Once converged over many iterations, **previously unseen** noisy data can be processed and **denoised instantaneously**
- All computational expense focussed instead on training ANN, **time savings compound with continued usage**

Results

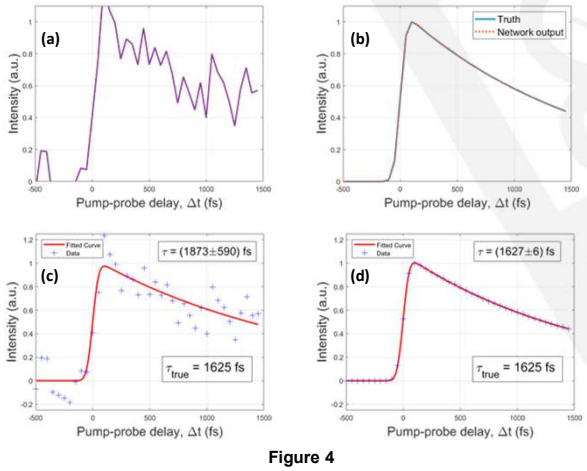

Figure 4

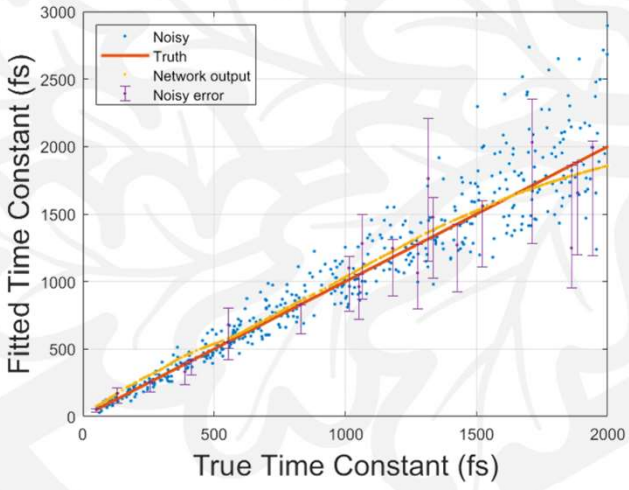

Figure 5

- ANN capable of restoring **original shape** of noisy data (Fig. 4a,b)
- Extraction of time constant **far more accurate** when performed on network processed data (Fig. 4c,d, Fig. 5)

Conclusions & Future Directions

- **ANN's** can perform **near-perfect denoising** in 1D, and can allow for subsequent extraction of information **much more reliably**
- **Multi-step transient behaviour** can be denoised successfully, issues arise when extracting time constants – **ill-posed problem**
- Next steps: **Combine** with previously worked on **2D spatial denoising**[6], to denoise a series of charged particle images over time

Acknowledgements

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References

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