**Optical Fingerprints of Single Nanoparticles for Deep Learning Aided Super-Capacity Optical Multiplexing**

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Introduction.



Figure. Deep learning aided super-capacity optical multiplexing of UCNPs. **a** SEM photo of 5 µm polystyrene beads tagged with UCNPs and TEM characterization of a kind of typical morphology uniform nanocrystals. **b** Lifetime curves of a UCNPs-stained bead(up) and a single UCNPs(down). **c** Illustration of the neural network used for the classification task. **d** Mean classification accuracy obtained through cross validation.

Super-capacity optical multiplexing challenges our abilities in creating multiplexed codes in orthogonal dimensions1, and also will advance the ongoing development of next-generation enabling technologies, spanning from high-capacity data storage2. Pushing the size of material that carries the optical barcodes from microscopic to the nanoscopic range is limited due to the sacrifice of detectable code numbers or weaken brightness3.

Aims.

Here we show an alternate method named deep learning algorithm by the combination of encoding single upconversion nanoparticles (UCNPs) within time-domain optical fingerprints to conquer the deadlock to super-capacity optical multiplexing in nanoscale. It poses grand challenges for material sciences to precise control in producing uniform nanoscopic carriers and explores the diversity of optical information that can be produced in multiple orthogonal dimensions. We collect the time-resolved upconversion images under a wide-field microscope to achieve the high throughput in the decoding process. Compared to the conventional micron-sized carriers4, optical codes created on nanoscopic sized UCNPs can significantly increase the capacity of coding information, which takes optical super capacity multiplexing into the region of optical diffraction limit.

Methods.

To improve multichannel recognition rates, deep learning are used to aid super-capacity optical multiplexing. The deep learning algorithm is based on an architecture of convolutional neural networks (CNN) which contains a convolutional network and a fully connected networks with two layers. We first apply the image series of ten types of single nanoparticles contains the lifetime fingerprints (τ2-dots) of 50 to 200 single nanoparticles for training. The artificial neural network could extract the fingerprint features of each type of τ2-dots and provide the optimized CNN and classification boundaries by having the feedback from accuracies. As long as the trained network is optimized, we then randomly select a set of untrained image series for each type of dots to test and obtain their classification accuracies. To eliminate the random effect, experiment is repeated 50 times of validation experiment, in which τ2-dots for each type are randomly selected for testing and the other are used for training and achieve the mean classification accuracies for each type of dots.

Results.

The accuracies of all ten types of single τ2-dots are higher than 60%, with a value between 63% and 91%, as shown in Figure. showing the better performance of deep learning algorithm. To further check the similarity interference and the classification capability of our deep learning algorithms, we perform pairwise classification and the classification capability will significantly increase with more neurons to be invoked in the fully connected networks.

Discussion.

The controlled synthesis of bright and optically uniform single nanoparticles provides an opportunity in super capacity optical multiplexing. The large amount of optical data from different batches of τ2-dots allow deep learning to classify each single τ2-dot for an untapped opportunity in decoding these nanoscale lifetime barcodes.

Conclusion.

This work further suggests future synthesis of other types of uniform nanoparticles with diverse and tunable optical signatures in multiple optical dimensions, e.g. spectrum, lifetime, and intensity, can expand super-capacity optical multiplexing. Assignments of these highly uniform and bright luminescent carriers with unique and distinguishable optical signatures will enable high throughput biomolecular discoveries and data storage.

References

1. Lin, G., Baker, M. A. B., Hong, M. & Jin, D. The Quest for Optical Multiplexing in Bio-discoveries. *Chem* **4**, 997–1021 (2018).

2. Lu, Y. *et al.* Tunable lifetime multiplexing using luminescent nanocrystals. *Nat. Photonics* **8**, 32–36 (2014).

3. Zhao, J. *et al.* Single-nanocrystal sensitivity achieved by enhanced upconversion luminescence. *Nat. Nanotechnol.* **8**, 729–734 (2013).

4. Fan, Y. *et al.* Lifetime-engineered NIR-II nanoparticles unlock multiplexed in vivo imaging. *Nature Nanotechnology* **13**, 941–946 (2018).