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Scientific Discovery from Ordered Information Decomposition

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How can we gain physical intuition in real-world datasets using 'black-box' machine learning? In this talk, I will discuss how ordered component analyses can be used to seperate, identify, and understand physical signals in astronomical datasets. We introduce Information Ordered Bottlenecks (IOBs), a neural layer designed to adaptively compress data into latent variables organized by likelihood maximization. As an nonlinear extension of Principal Component Analysis, IOB autoencoders are designed to be truncated at any bottleneck width, controlling information flow through only the most crucial latent variables. With this architecture, we show how classical neural networks can be easily extended to dynamically order latent information, revealing learned structure in multisignal datasets. We demonstrate how this methodology can be extended to structure and classify physical phenomena, discover low-dimensional symbolic expressions in high-dimensional data, and regularize implicit inference. Along the way, we present several astronomical applications including emulation of CMB power spectrum, analysis of binary black hole systems, and dimensionality reduction of galaxy properties in large cosmological simulations.

Primary author: HO, Matthew (Institut d'Astrophysique de Paris)

Presenter: HO, Matthew (Institut d'Astrophysique de Paris)

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