Deep Neural Network for Spectrum Unfolding

Haonan Zhu(1), Angela Di Fulvio(2), Alfred Hero(1), Sara Pozzi(1)
(1) University of Michigan, Ann Arbor, MI, (2) University of Illinois, Urbana, IL
Contact: Haonan Zhu (haonan@umich.edu), PIs: Prof. Alfred Hero and Prof. Sara Pozzi
Consortium for Verification Technology (CVT)

Motivation and Introduction

Knowledge of the neutron spectrum is important for nonproliferation and nuclear security applications, as it allows discriminating fission sources from other types of neutron sources. For organic scintillators, neutron spectrum unfolding is the process of obtaining the energy spectrum of neutrons from the detected light response spectrum, which is an ill-posed inverse problem.

Mission Relevance

- **Neutron spectrometry without time-of-flight** can be extremely useful in safeguards and nonproliferation applications, e.g. neutron imaging for material accountancy and verification (Fig. 1), to discriminate between fissile material and other neutron emitting sources.

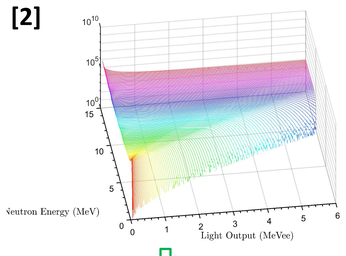
Fig. 1 Radiation Inspection System [1].

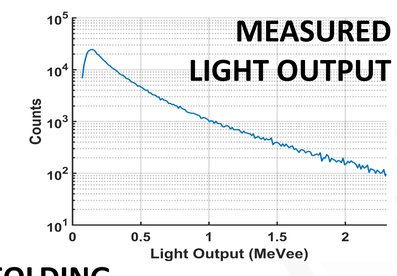
Neutron spectra unfolding

$$z_i = \sum_j R_{ij}\Phi_j + e_i \quad (i = 1 \dots M)$$

z_i light output spectrum
M is the number of detection channels
$R_i(E)$ is the detector response
$\Phi(E)$ is the Neutron spectrum flux cm^{-2}
e_i accounts for the observation noise and modelling error

RESPONSE MATRIX (Simulated) [2]





UNFOLDING ALGORITHM

NEUTRON SPECTRUM

Deep Neural Network Approach

Inspired by [3], we proposed the following architecture that mimics project gradient descent method from optimization theory [4]:

$$a^k = \rho\left(W^{1k}\begin{bmatrix} R^T z \\ \widehat{\Phi}^k \\ R^T R\widehat{\Phi}^k \\ v^k \end{bmatrix} + b^{1k}\right)$$

$$\widehat{\Phi}^{k+1} = \rho\left(W^{2k}a^k + b^{2k}\right)$$

$$\widehat{\Phi}^{k+1} = (1-\epsilon)\widehat{\Phi}^{k+1} + \epsilon\widehat{\Phi}^k$$

$$v^{k+1} = W^{3k}a^k + b^{3k}$$

where $k = 1, \cdots, L$ denotes the layer number (analogous to number of iteration of projected gradient descent), ρ is the standard ReLU nonlinearity and $\widehat{\Phi}^k$ is the output at layer k.

The loss function used to train the neural network is defined below:

$$\ell(\Phi, \widehat{\Phi}) = \sum_{k=1}^{L} \log(k) \frac{\|\Phi - \widehat{\Phi}^k\|^2}{\|\Phi - \tilde{\Phi}\|^2}$$

Where $\tilde{\Phi}$ is the least square solution to the inverse problem

Simulation Results

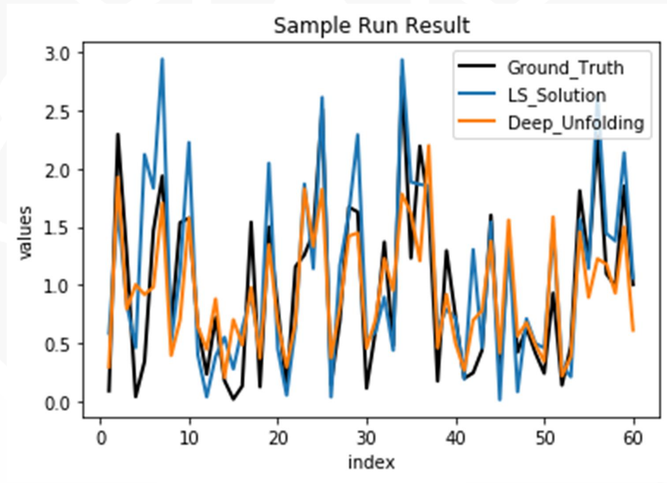


Fig. 3 Simulated truncated i.i.d data with noise

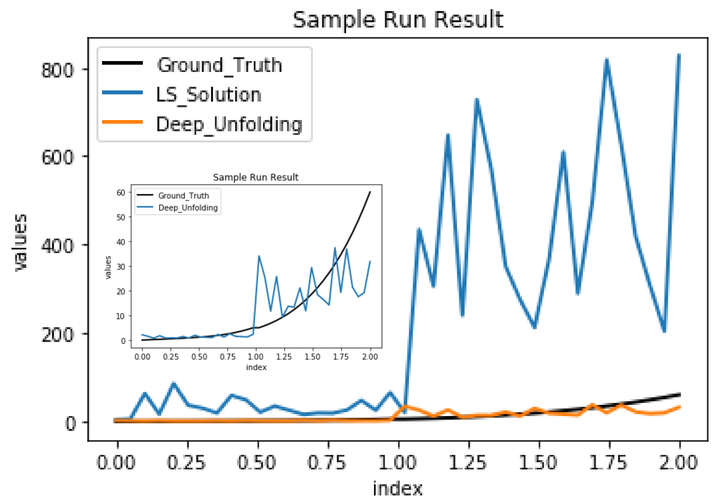


Fig. 4 Simulated truncated polynomial data, it is worth noting that the neural network is only trained on Truncated Gaussian i.i.d data with noise

Conclusions and Future Work

- A neural network architecture particularly designed for spectrum unfolding is proposed in this work
- Demonstrated by our simulation, the proposed neural network once trained outperforms basic least square solution significantly in simulation, and has a linear run time
- Even though the network is only trained on i.i.d generated data, our simulation shows that it can generalize to generated polynomial data

CVT Impact

- I attended INMM 2018 Workshop and presented a poster on related work.
- This is promising results that can be an improvement from my previous work based on Bayesian formulation
- I will look forward to potential collaboration with national laboratories to extend my preliminary results through summer internship

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