Team-Based Online Instruction and Research in Machine Learning for Proton Beam Radiotherapy

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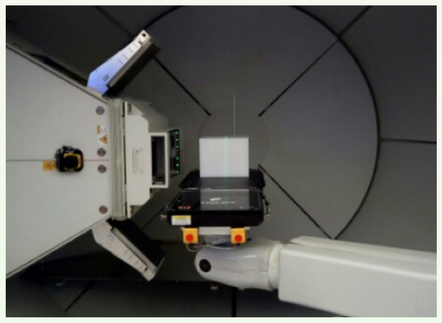
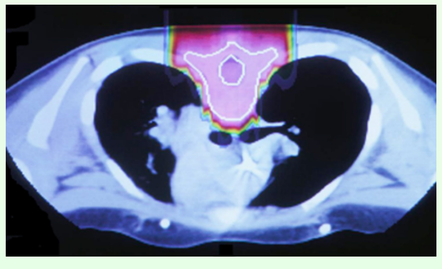
Proton Beam Radiotherapy

Proton beam radiotherapy is a cancer treatment that uses proton beams to irradiate a tumor. A Compton camera that tracks prompt gamma rays emitted along the beam's path through the patient has the potential to verify treatment delivery in real time, provided it works at clinically relevant high dose rates. We demonstrate that machine learning cleans noisy raw data rapidly and can gives more accurate images across all dose rates.

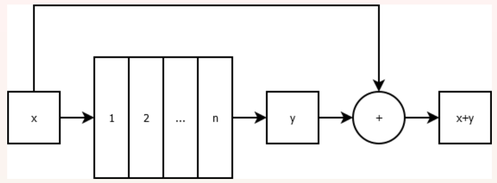


Treatment table in Maryland Proton Treatment Center.

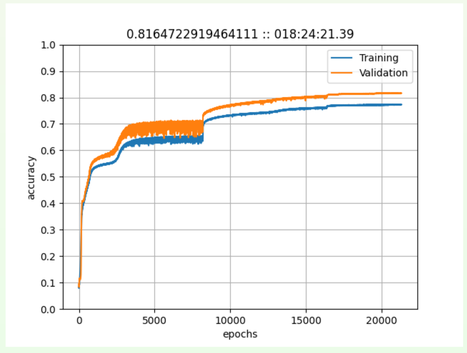


Beam penetration through tumor.

Fully Connected Neural Network



- Neural networks that are sufficiently deep typically experience a dying gradient during the weight update step. The solution to this is to use residual blocks.
- Our fully connected residual block takes an input and passes it through n layers eventually concatenating it to the output of the final layer.
- Concatenation of the pieces by addition.



Training and validation plot for a fully connected network trained on triples from a 150MeV 0kMU/min beam and double to triples from a 150MeV 100kMU/min using 21,000 epochs. The validation data is 20% of the initial data.

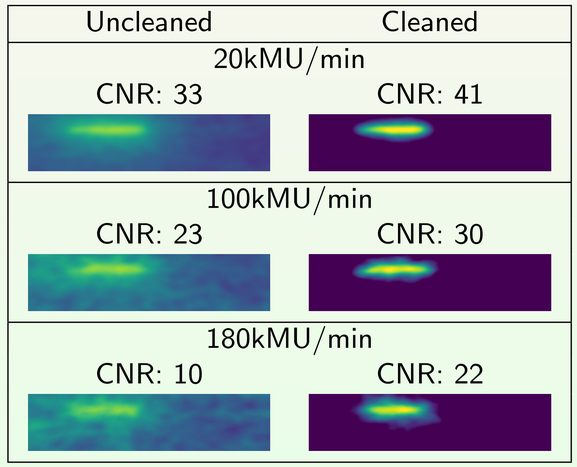
Improved Image Reconstruction

Contrast-to-Noise Ratio (CNR)

$$\text{CNR} = \frac{|\mu_{\text{BP Region}} - \mu_{\text{noise}}|}{\sigma_{\text{noise}}}$$

quantifies the improvement in the reconstructed image.

- Body of the beam is the noise free zone.
- A region after the beam is the noisy zone.



- Larger CNR is better than smaller CNR.
- All dose rates show CNR improvement after cleaning by the neural network.

UMBC HPCF

Interdisciplinary core facility for scientific computing at UMBC:

- taki: CPU cluster with over 100 nodes, 19 GPU nodes, 8 Big Data nodes
- ada GPU cluster: 13 nodes with over 100 GPUs in total

Tensorflow 2.4.0 and Keras leverage four NVLink-connected NVIDIA Tesla V100 GPUs with 16 GB onboard memory each.

Percentage of Usable Data

Dose Rate	% Usable data Before	After	Improve.
20kMU/min	7.9%	78.0%	70.1%
100kMU/min	1.8%	73.8%	72.0%
180kMU/min	0.9%	59.6%	58.7%

- When given Compton camera data, we can use the neural network's average accuracy for each event type and the theoretical event type distribution to compute the amount of data we expect to be usable for image reconstruction.
- At the highest clinically relevant dose rate of 180kMU/min, only $< 1\%$ of the noisy raw data is usable for image reconstruction. Cleaning by the neural network improves this to nearly 60% usable data for reconstruction.

Undergraduate Research

- Big Data REU Site **BigDataREU.umbc.edu**
- Michelle Ramsahoye, senior thesis, May 2022
- Opportunities: *UMBC Review*, URCAD, conference travel, NSF REU funding

Team-Based Online Learning

Synergy in pedagogy and technology from regular classes to research programs:

- All activities are team-based as preparation for the real world.
- Online delivery opens participation to students with special needs and from across the nation.
- UMBC provided tools include Webex, Blackboard, Panopto, and more.

Students gain demonstrated experience in modern professional skills!

Acknowledgments

- NSF, NIH, NSA, UMBC, Math & Stat
- NSF: CyberTraining, Big Data REU Site
- HPCF: NSF MRI program, UMBC, CIRC

Most Recent Publications

Available at **hpcf.umbc.edu/publications**.

[1] Polf, Barajas, et al., *Front. Phys.*, 2022.
[2] C. A. Barajas, PhD Thesis, May 2022.