LinacNet

A new architecture for Linear Accelerator Surrogate Model

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ThomX: A Compact Compton Source

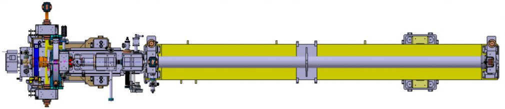


Figure: Linac of ThomX.

ThomX

- X-ray source by Compton backscattering
- Compact Accelerator $(70\mathrm{m}^2)$
- In commissioning at the IJCLab since May 2021

Linac

- Accelerate the electron beam up to 50 MeV

PhD's goal

Use machine learning to tackle the problem of adjusting the Linac parameters to fulfill the beam requirements for the transfer line.

Accelerator Tuning

$\mathcal{A}$: Controllable Parameters

- 15 controllable parameters
  - Laser position and size
  - Gun and Cavity phase and field
  - Solenoid Fields
  - Steerer Fields
  - Quadrupoles Fields

$\mathcal{B}$: Hidden Parameters

- Mechanical Misalignment
- Unknown initial particle distribution
- Slow drift of electromagnetic elements

$\mathcal{O}$: Observables

- 17 Observables
  - Position and Charge at BPMs
  - Charge at ICTs
  - Position and Size at Screen
  - Charge at Faraday Cup

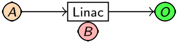
F: Objective function

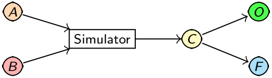
- Quality of the beam
- Function of (A, B)

Goal

- Optimize A depending on B to get minimal F with the aid of $\mathcal{O}$
- Currently : manual tuning, heavy load on expert

Context: Machine and Simulation Tools





On the Machine

1. B unknown
2. Only partial information with O
3. F not directly measurable

On the Simulator

1. B can be specified (90 parameters)
2. Output of the simulator $C \in \mathbb{R}^{6\times 17}$
3. F is a function of C

Computation time on the machine

1. Set A and measure O : $\sim$ 1 sec.
2. Estimation of F: $\sim$ 10 min.
3. Collective Schedule

Computation time on the simulator

1. Computation of C: $\sim$ 10min.
2. F and O given by C
3. Individual Schedule, can run in parallel

Simulations performed with Astra[1]

[1] Pöplau, Van Rienen, and Floettmann, "3D space charge calculations for bunches in the tracking code Astra".

Objective: Automatic Accelerator Tuning

With the aid of simulation data and real data :

Inverse Problem

Find an estimate of B_{Linac} with real data (A_i, O_i) and simulation data $\left(A_j, B_j, O_j\right)$

Control Problem

Find $A^* = \underset{A \in \mathcal{A}}{\arg\min} \, F_{Linac}\left(A, \widehat{B}_{Linac}\right)$

Methods

The exploration-optimization accelerator tuning

1. Learn $\widehat{F} \simeq F_{\text{simulator}}$
2. Learn $\widetilde{F} \simeq F_{Linac}\left(A, B_{Linac}\right)$
3. Estimate $\widehat{B}_{Linac} = \underset{B \in \mathcal{B}}{\arg\min}\, d\left(\widehat{F}\left(., B\right) - \widetilde{F}\right)$
4. Adjust A such that $A = \underset{A \in \mathcal{A}}{\arg\min}\, \widehat{F}\left(A, \widehat{B}_{Linac}\right)$

Originality of the method

- Incorporate simulation data and real data
- Tackle the control problem on the real machine

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First Model

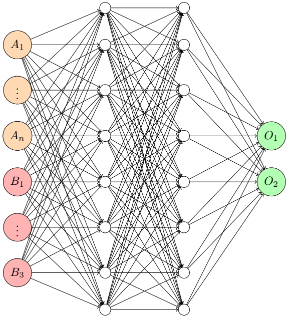

Figure: MLP as a surrogate model of a Linac

Multi Layer Perceptron

- 10k simulations sampling $\mathcal{A}$ and $\mathcal{B}$
- Minimization of the L2 loss

LinacNet

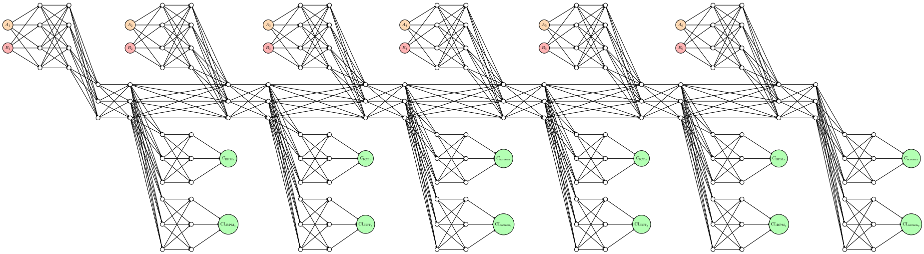

Figure: LinacNet with 6 modules corresponding to 6 detectors on the Linac

LinacNet

- Split input and output according to their position in the Linac
- Neural Network Architecture reflecting a Linac architecture
- Each Module models one Diagnostic

ThomNet

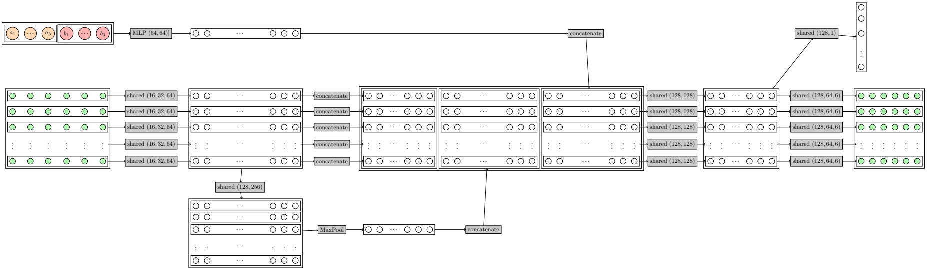

Figure: One module of ThomNet

ThomNet

- Track the full distribution of particles
- Inspired by Qi et al., “PointNet: Deep Learning on Point Sets for 3D Classification and Segmentation”

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Conclusion

Results

- Adequate architecture speed up the training and gives better results
- Precision of the same orders than the diagnostics installed on ThomX

Challenges

- Training of a of modular model
- Large GPU memory requirements if not careful
- Performance for the optimization task to be tested

Questions?