

Machine Learning for the precision determination of Parton Distribution Functions

Jesús Urtasun Elizari

Supervised by Dr. Stefano Forte and Dr. Stefano Carrazza

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How to adult...



SHOP FOR A NEW TIE.



MAKE MACARONI



DO CARDIO.



DON'T LET THE EXISTENTIAL
DREAD SET IN.



DON'T LET IT SET IN.



VACUUM THE RUG.

How to be a mature physicist...



Measure Higgs couplings.



Search for WIMPs.



Improve PDFs
determination



DON'T LET THE EXISTENTIAL
DREAD SET IN.



DON'T LET IT SET IN.



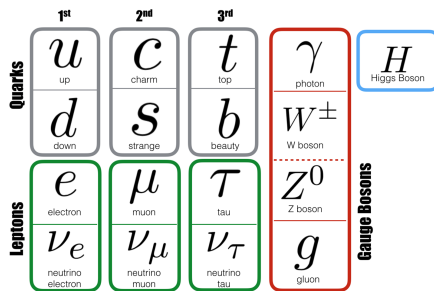
Look for strings

- ① Quantum Chromodynamics in a nutshell
 - The Standard Model
 - The strong interactions
 - Parton Distribution Functions
- ② The N3PDF project
 - Machine Learning for PDFs determination
 - Operator implementation in TensorFlow
 - Results & Conclusions

Quantum Chromodynamics in a nutshell

Quantum Chromodynamics

The Standard Model



Quantum Field Theory describing physics at the TeV scale

- 1 Fermions composing matter
- 2 Bosons mediating interactions
- 3 Scalar Higgs generating mass

Quantum Chromodynamics

Explore the strong interactions

How to explore proton's inner structure?

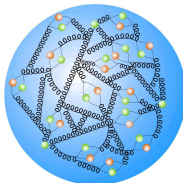
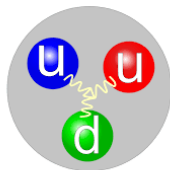


- Point-like projectile on the object \rightarrow DIS
- Smash the two objects \rightarrow LHC physics

"A way to analyze high energy collisions is to consider any hadron as a composition of point-like constituents \rightarrow **partons**" R.Feynman, 1969

Quantum Chromodynamics

Parton Distribution Functions

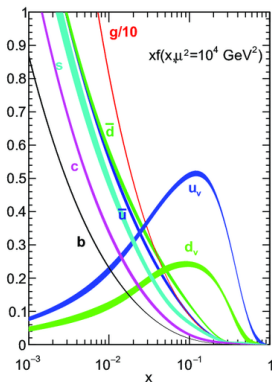


- Hadrons made of partonic objects \longrightarrow non perturbative physics
- Interactions take place only at partonic level

Parton Distribution Functions: probability distribution of finding a particular parton (u, d, ..., g) carrying a fraction x of the proton's momentum

Quantum Chromodynamics

What PDFs look like



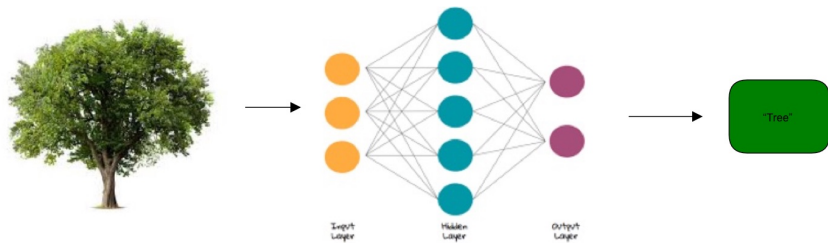
- Each parton has a different PDF $\rightarrow u(x), d(x), \dots, g(x)$
- PDFs are not predicted, and can not be measured
- PDFs are **extracted** from data

The N3PDF project

Machine Learning for the precision determination of PDFs

The N3PDF project

Machine Learning

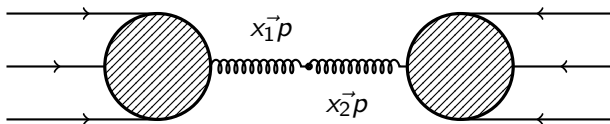


- 1 ML algorithms solve *complex* tasks like classification and regression
- 2 Neural Networks \rightarrow Non linear functions of an input x , given by $y(x) = \sigma\{\mathbf{w} \cdot x + b\}$
- 3 Rely on comparison with data \rightarrow *Learning*, need for training \mathbf{w}, b

The N3PDF project

What we actually measure

Any theory must predict a number \longrightarrow Observable σ



Factorize the problem \longrightarrow Convolute the PDFs with the partonic $\hat{\sigma}_{ij}$

$$\sigma = \int_0^1 dx_1 dx_2 f_{\alpha}(x_1, \mu_F) * f_{\beta}(x_2, \mu_F) * \hat{\sigma}_{\alpha\beta}(\alpha_s(\mu_R), \mu_F)$$

- Use a Neural networks to generate the PDFs
- Generate a vector of observables y_N

$$y_N = \sum_{i,j,\alpha,\beta} f_{\alpha}(x_i) f_{\beta}(x_j) \hat{\sigma}_{Nij\alpha\beta}$$

The N3PDF project

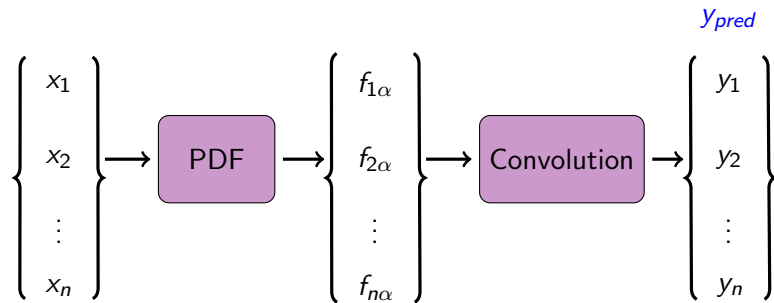
General structure of n3fit



- Use TensorFlow and Keras to determine the PDFs
- See paper by S.Carraza - J.Cruz-Martinez
"Towards a new generation of parton densities
with deep learning models",
<https://arxiv.org/abs/1907.05075>

The N3PDF project

General structure of n3fit

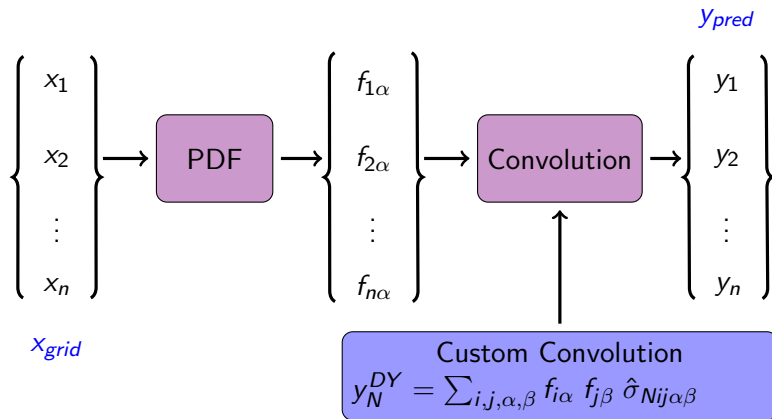


x_{grid}

- 1 Build a NN to compute y_{pred} observables from a grid x_i
- 2 Compute loss function by comparing with data
- 3 Update values of PDF \rightarrow Fit

The N3PDF project

Operator implementation



- 1 TF relies in symbolic computation \rightarrow High memory usage
- 2 Implement c++ operator replacing the convolution

Results

Checking computation

DIS:

	TensorFlow	Custom	Ratio
Convolution	1.9207904	1.9207904	1.0000000
	2.4611666	2.4611664	0.9999999
	1.3516952	1.3516952	1.0000000
Gradient	1.8794115	1.8794115	1.0000000
	1.505316	1.505316	1.0000000
	2.866085	2.866085	1.0000000

Results

Checking computation

Hadronic:

	TensorFlow	Custom	Ratio
Convolution	8.142365	8.142366	1.0000001
	8.947762	8.947762	1.0000000
	7.4513326	7.4513316	0.9999999
Gradient	18.525095	18.525095	1.0000000
	19.182995	19.182993	0.9999999
	19.551006	19.551004	0.9999999

Results

Memory saving

Hadronic only:

	TensorFlow	Custom Convolution	Diff
Virtual	17.7 GB	13.8 GB	3.9 GB
RES	12.1 GB	8.39 GB	3.2 GB

Global:

	TensorFlow	Custom Convolution	Diff
Virtual	23.5 GB	19.7 GB	3.8 GB
RES	18.4 GB	12.5 GB	5.9 GB

Summary & Conclusions

- ① PDFs are required to have accurate predictions in high energy physics
- ② ML provides a new way of determine the PDFs
- ③ Operator implementation leads to memory saving by taking full control on the computation

Thank you!



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