Machine Learning in HEP

(A gentle introduction)

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Pre-school for ML4HEP V4

Online host: TIFR Mumbai

Statement of the Problem

Artifitial Neural Networks (ANN)

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Problems Types

Regression

Classification

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Need to approximate/estimate the said function.

Approximating/Estimating the function

Case 1:

Case 2:

Approximating/Estimating the function

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Need a parametrized approximant.

Universal Approximation Theorem

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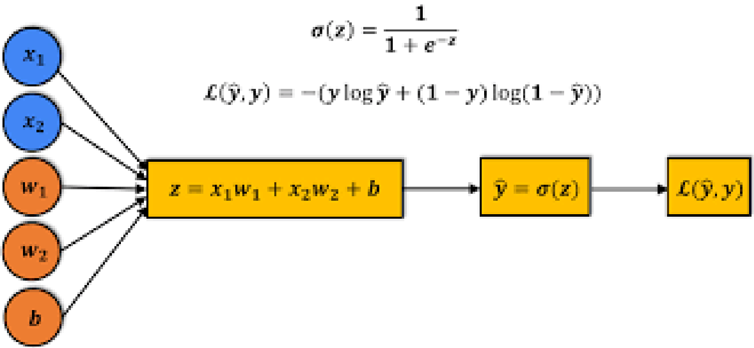
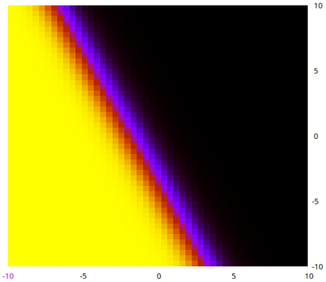
The approximant is alternating sequance of *linear maps* (hyperplane) and *non-linear maps* (envelope).

Artifitial Neural Networks (ANN)

Logistic Regression



Logistic Regression



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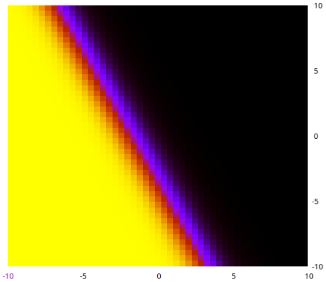

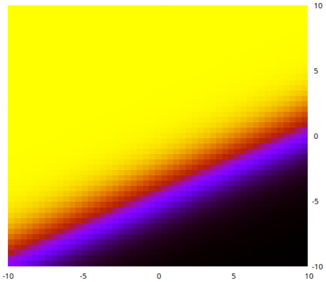

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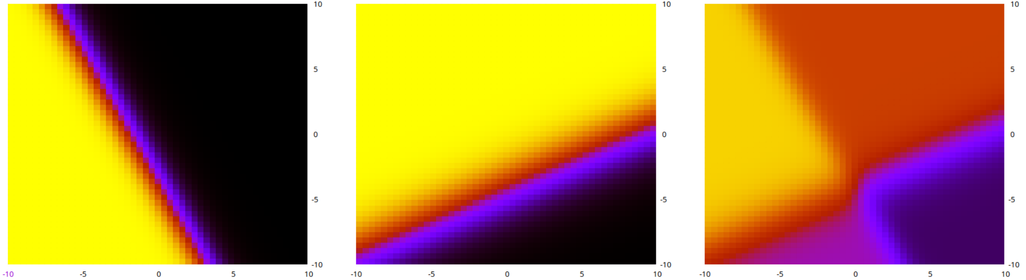

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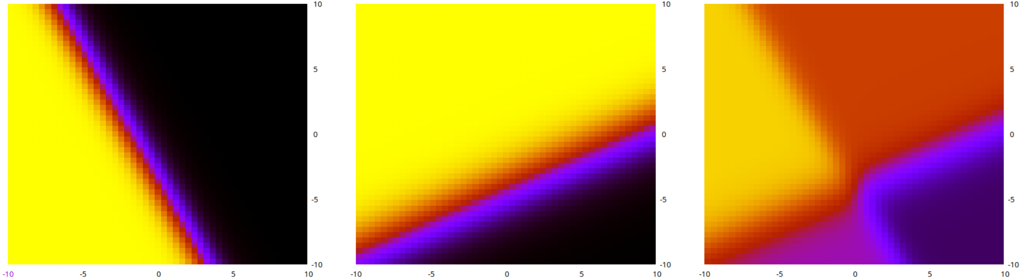
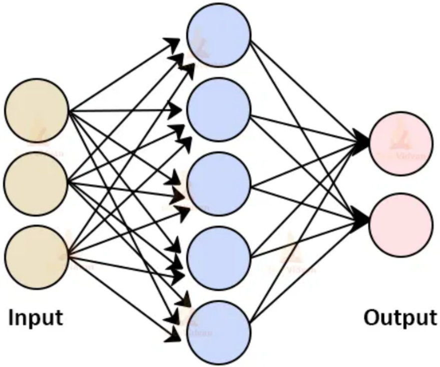


Combining several Logistic maps, we make an ANN.

Artifitial Neural Networks



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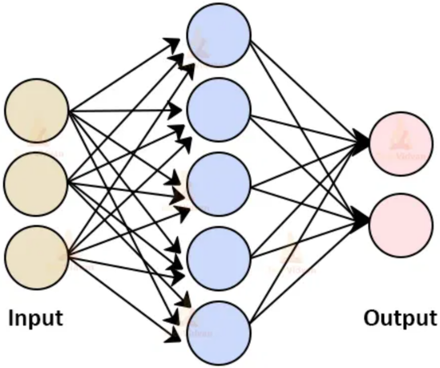
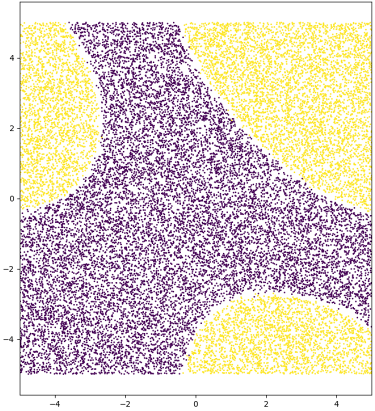
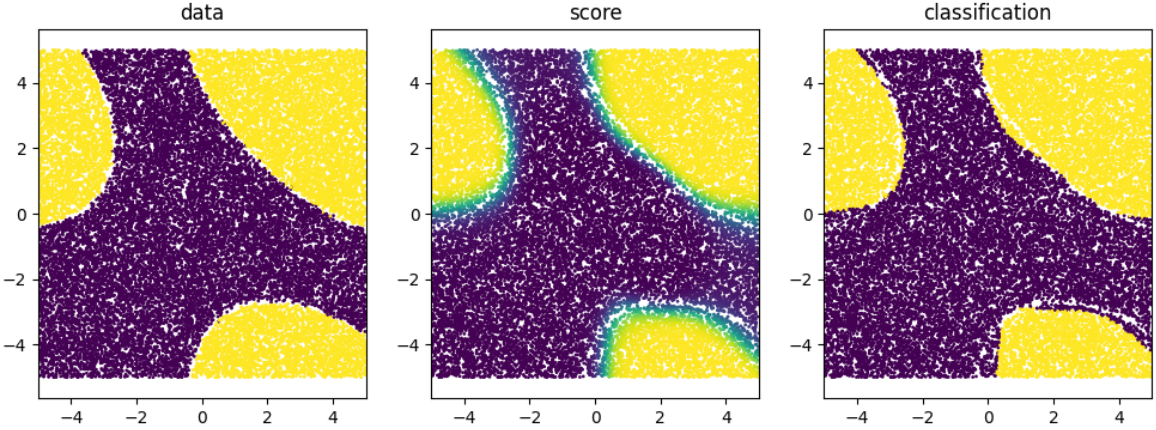
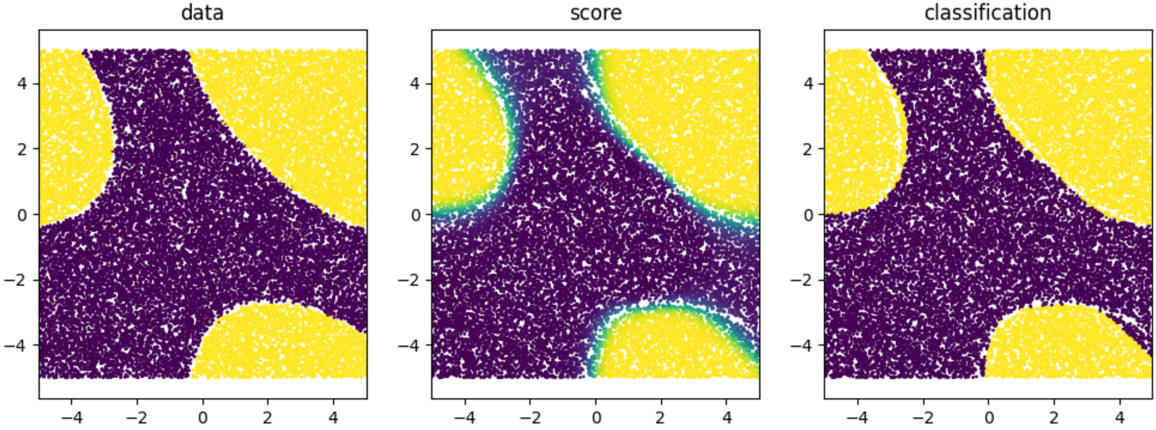




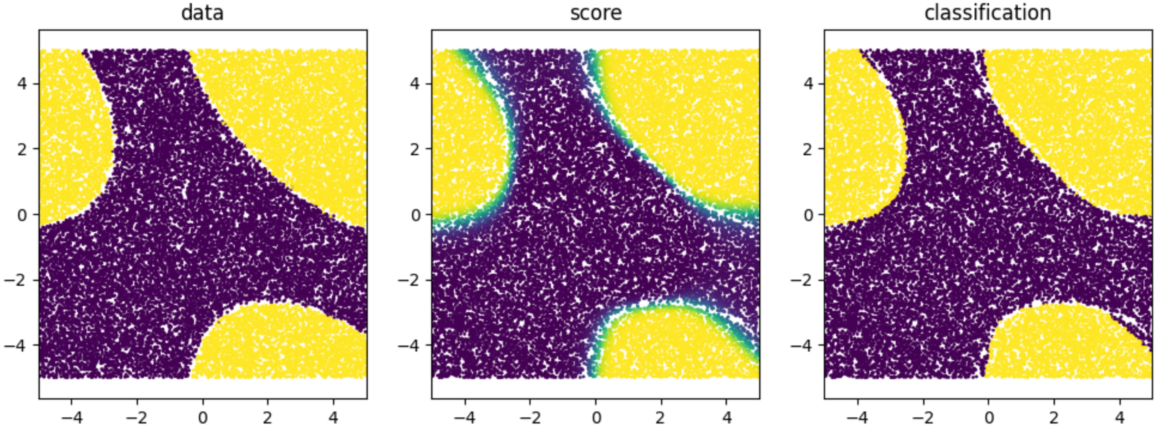
ANN: $N_{\text{hidden}} = 4$, $N_{\text{epoch}} = 10$, Accuracy $= \mathbf{97.4}\%$



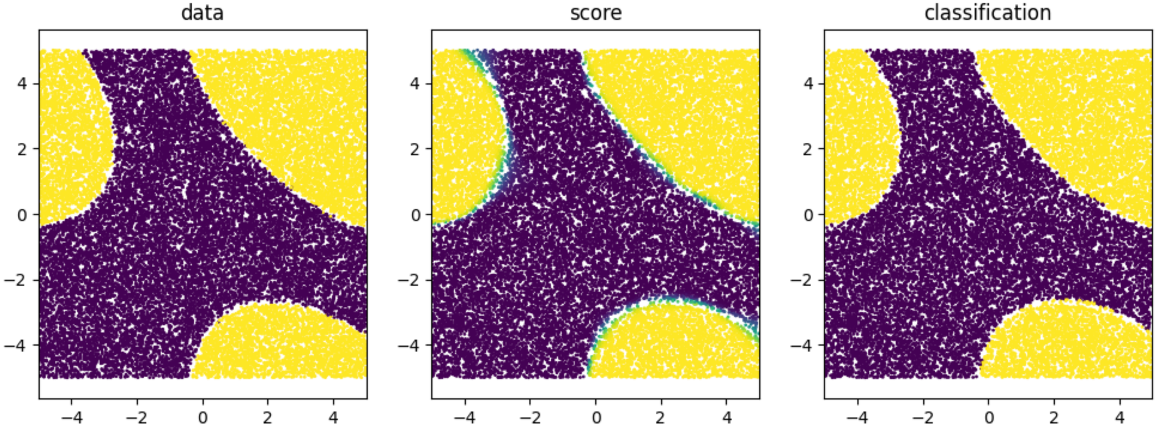
ANN: $N_{\text{hidden}} = 4$, $N_{\text{epoch}} = 20$, Accuracy $= \mathbf{97.9}\%$



ANN: $N_{\text{hidden}} = 4$, $N_{\text{epoch}} = 30$, Accuracy = $\mathbf{98.1}\%$



ANN: $N_{\text{hidden}} = 10$, $N_{\text{epoch}} = 10$, Accuracy = $\mathbf{99.7}\%$



Feature Engineering

Features: $(\mathbf{x}, \mathbf{y})$

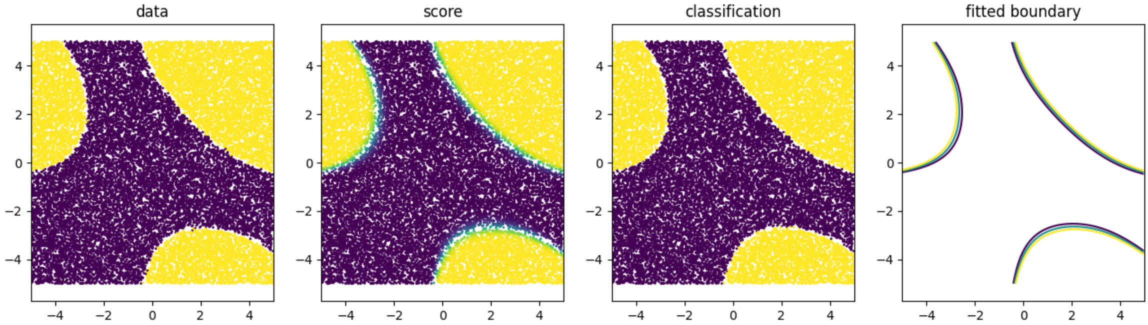
Decision boundary approximation with 4 neurons $\Rightarrow \sim 98.0\%$ accuracy
About 15 parameters to fit. Improves slowly with N_{epoch}

Decision boundary approximation with 10 neurons $\Rightarrow \sim 99.7\%$ accuracy
About 40 parameters to fit. May get stuck in local minima. Less **interpretable**.

Features: $(\mathbf{x}, \mathbf{y}, \mathbf{x}^2, \mathbf{y}^2, \mathbf{xy}, \mathbf{x}^2\mathbf{y}, \mathbf{xy}^2)$

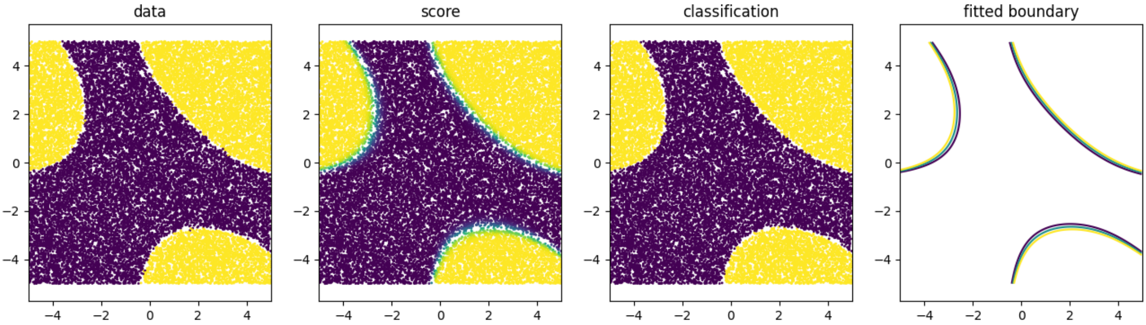
Decision boundary approximation with one neuron $\Rightarrow \sim 99.8\%$ accuracy
Less number of parameters to fit. Symmetries can help further. More **interpretable**.

ANN: $N_{\text{input}} = 7$, $N_{\text{epoch}} = 10$, Accuracy = $\mathbf{99.86}\%$, (non-linear)



x	y	x^2	y^2	xy	x^2y	xy^2
-0.031	0.055	**0.705**	**0.710**	0.051	**0.751**	**0.748**

ANN: $N_{\text{input}} = 4$, $N_{\text{epoch}} = 10$, Accuracy = **99.87**%, (non-linear + sym)



$x + y$	$x^2 + y^2$	xy	$x^2y + xy^2$
0.0069	**0.711**	-0.025	**0.776**