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Replacing a cloud based computation tool on DrBoxOnline.com with faster running neural network

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Intro: Project Goal Summary

- **Replace FEA with DNN in Dr. Box Calculator Pro**: We aim to replace the current Finite Element Analysis (FEA) method with Deep Neural Networks (DNN) in the Dr. Box Calculator Pro to improve efficiency.

- **Provide instant predictions of buckling strength**: Our goal is to deliver immediate and accurate predictions of buckling strength for various types of corrugated paper boxes.

- **Reduce computational costs and time**: By implementing DNN, we strive to significantly cut down on the time and resources required for analysis.

- **Enhance efficiency and effectiveness in packaging and logistics**: Ultimately, our project aims to boost overall operational efficiency and effectiveness within the packaging and logistics industries.

Intro: Problem Definition

- **Current reliance on FEA is time-consuming and resource-intensive**: The existing method of using Finite Element Analysis (FEA) requires extensive computational resources and a considerable amount of time to perform.

- **Corrugated boxes are prone to buckling, causing damage and losses**: Despite their widespread use due to their lightweight and recyclable nature, corrugated boxes often buckle during storage and shipment, leading to product damage, lost revenue, and increased customer complaints.

- **Need for faster, more reliable prediction methods**: To mitigate these issues, there is a crucial need for a faster and more reliable method for predicting the buckling strength of these boxes.

Intro: Review of Specs and Requirements

- **High predictive accuracy (≥ 90%)**: The system must achieve a predictive accuracy of at least 90% to ensure reliable results.

- **Fast analysis (≤ 5 minutes per simulation)**: Each simulation should be completed within 5 minutes to facilitate quick decision-making.

- **Ability to handle diverse box types and conditions**: The system should be versatile enough to accommodate various box designs and environmental conditions.

- **System reliability above 99.9%**: The solution should maintain a high level of reliability, with an uptime of more than 99.9%, to ensure consistent performance.

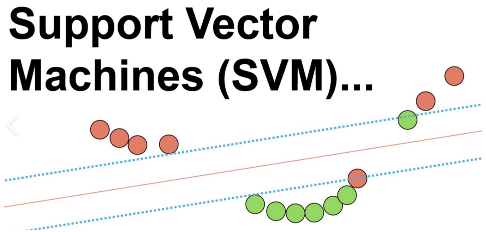
Concept Gen: Accuracy

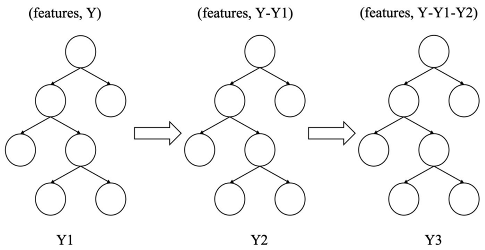
Sub-function requirements:

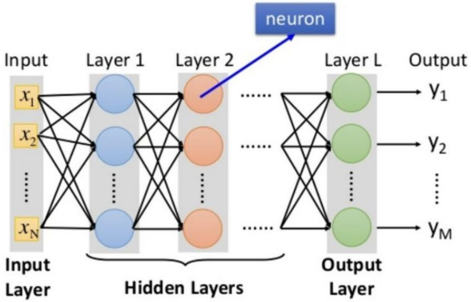
- Efficient handling of limited numerical data, high prediction accuracy, and ability to manage complex relationships between features and ultra high dimension outputs.

Generated concepts:

- Decision Boosting Trees: Capable of capturing complex, non-linear relationships between features and targets.
- Support Vector Machines (SVM): Effective in high-dimensional spaces and can handle a large number of features.
- Deep Neural Networks (DNN): Capable of learning intricate patterns and relationships in the data through multiple layers of neurons.







Concept Gen: Speed

Sub-function requirements:

- Replace complex and heavy physical calculation formulas with machine learning models.
- Achieve rapid prediction of hundreds of physical deformation features in 3D space using limited input coordinates and features.

Generated Ideas:

- Use simple linear regression models, simple but fast.
- Use deep and wide neural networks, load on GPU to accelerate the training process, hardware and big dataset demanding.
- Parallel calculating……

Formula No.	Description	Formula	Constraint
1	Tensile Strength	$\sigma_{\max} = \frac{N}{A_{\text{cross-section}}}$	$\leq [\sigma]$
2	Shear Strength	$\tau_{\max} = \frac{Q}{A_{\text{shear}}}$	$\leq [\tau]$
3	Compressive Strength	$\sigma_{\max} = \frac{P}{A_{\text{compression}}}$	$\leq [\sigma_{\text{compression}}]$
4	Torsional Strength	$\tau_{\max} = \left(\frac{M_T P}{I_P}\right)_{\max}$	$\leq [\tau]$
5	Bending Strength	$\sigma_{\max} = \left(\frac{M_N}{W_N} + \frac{M_{ny}}{W_{ny}}\right)_{\max}$	$\leq [\sigma]$
6	Combined Tensile (Compressive) and Bending	$\sigma_{\max} = \frac{N}{A} + \frac{M_{nz}}{W_n}$	$\leq [\sigma]$
		$\sigma^{+}_{\max} = \frac{N}{A} + \frac{M_{nz}}{I_z} y^{+}_{\max}$	$\leq [\sigma]^{+}$
		$\sigma^{-}_{\max} = \frac{M_{nz}}{I_z} y^{-}_{\max} - \frac{N}{A}$	$\leq [\sigma]^{-}$
7	Axial Compressive and Shear Stresses	$\sigma_\alpha = \sigma_{\text{horizontal}} \cos^2 \alpha$	
	on Inclined Plane	$\tau_\alpha = \frac{\sigma_{\text{horizontal}}}{2} \sin 2\alpha$	
8	Combined Axial and Torsional Stresses	$\sigma_{\text{eq3}} = \sqrt{\sigma^2 + 4\tau^2} = \sqrt{\left(\frac{M_n^2 + M_T^2}{W_n}\right)}$	$\leq [\sigma]$
	(Third Strength Theory)		
8	Combined Axial and Torsional Stresses	$\sigma_{\text{eq4}} = \sqrt{\sigma^2 + 3\tau^2} = \sqrt{\left(\frac{M_n^2 + 0.75 M_T^2}{W_n}\right)}$	$\leq [\sigma]$
	(Fourth Strength Theory)		
9	Combined Axial (Compressive) and Torsional	$\sigma_{\text{eq3}} = \frac{1}{W_n} \left(M_n + ND\left(1 + \alpha^2\right)^2\right) + M_T^2$	$\leq [\sigma]$
	Stresses (Third Strength Theory)		
9	Combined Axial (Compressive) and Torsional	$\sigma_{\text{eq4}} = \frac{1}{W_n} \left(M_n + ND\left(1 + \alpha^2\right)^2\right) + 0.75 M_T^2$	$\leq [\sigma]$

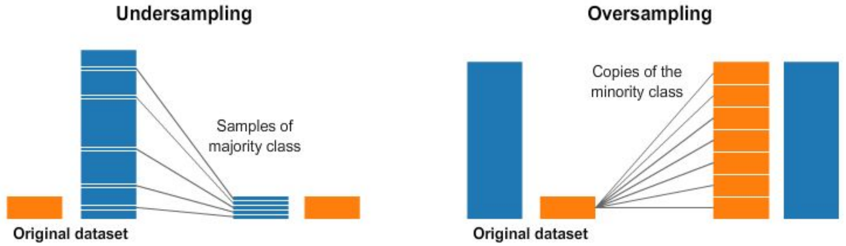
Concept Gen: Customization

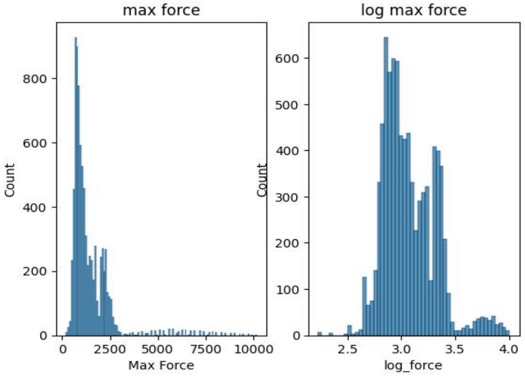
Sub-function requirements:

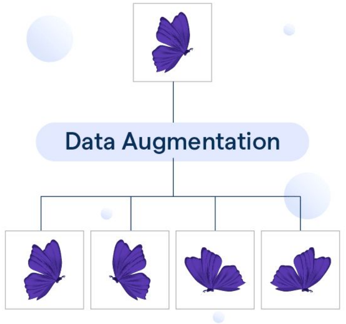
- Stable prediction deviation for various types of box with various width, length and height
- Stable prediction deviation ratio at different max-force points
- Model’s ability to capture symmetry of the environment condition

Generated Ideas:

- Using oversampling to solve imbalance training data distribution
- Finding a bijective mapping to map the data points t a uniformly or normally distributed space
- Augmenting data with spatial symmetry, enabling the model to learn symmetry conditions while enlarging the training dataset







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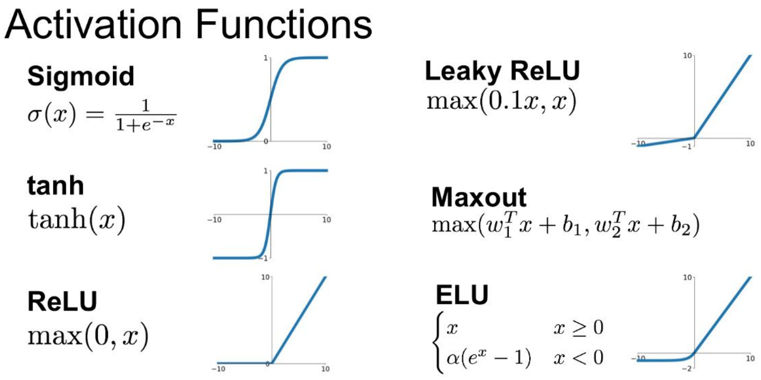
Concept Gen: Reliability

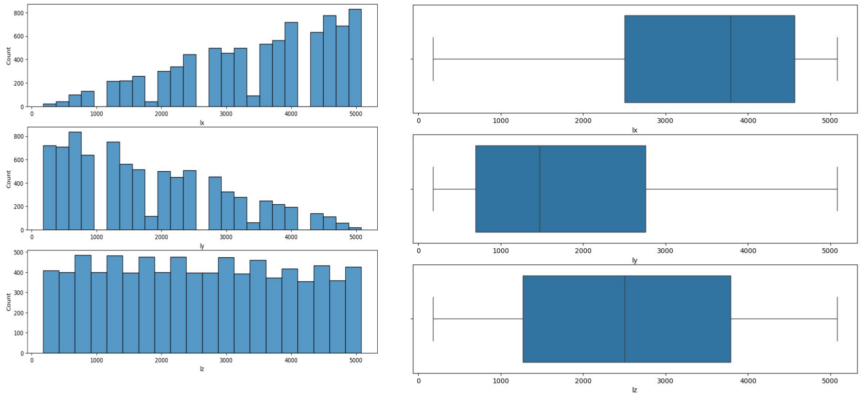
Sub-function requirements:

- Stable converging performance during model training for multiple times
- Acceptable variance of MSE loss on multiple validation sets
- Reliability above 99.9% when dealing with extremely large or small inputs

Generated Ideas:

- Use less complex model and more smooth activation functions to prevent extreme values during gradient descent
- Anomaly detection of input based on the data distribution before inference, along with exception handle module to warn the user





Concept Selection: Model Introduction

Model A: DNN with GPU acceleration,

Augment data with spatial symmetry,

Anomaly detection and exception handling.

Model B: SVM,

Use oversampling,

Employ simpler models and smoother activation functions

Model C: Decision Boosting Trees,

Parallel computing,

Find bijective mapping,

Use simpler models and smoother activation functions.

Concept Selection: Selection Matrix

Design criterion	Weight Factor	Unit	Model A			Model B			Model C		
			Value	Score	Rating	Value	Score	Rating	Value	Score	Rating
high prediction accuracy	0.36	%	95	9	3.24	90	7	2.52	92	8	2.88
Feature Learning	0.07	Score	Good	8	0.56	Good	8	0.56	Good	7	0.49
Scalability	0.05	Score	Excellent	8	0.4	Good	6	0.3	Good	6	0.3
System Optimization	0.06	Score	Excellent	9	0.54	Good	6	0.36	Good	5	0.3
Server Reliability	0.12	%	99.9	9	1.08	99	9	1.08	90	6	0.72
User Interface Design	0.02	Score	Fair	6	0.12	Fair	6	0.12	Fair	6	0.12
Cost	0.12	¥	20	9	1.08	40	7	0.84	30	5	0.6
Speed	0.2	s	260	8	1.6	200	9	1.8	400	6	1.2
			8.62			7.58			6.61		

We chose model A: DNN with GPU acceleration,

Augment data with spatial symmetry,

Anomaly detection and exception handling.

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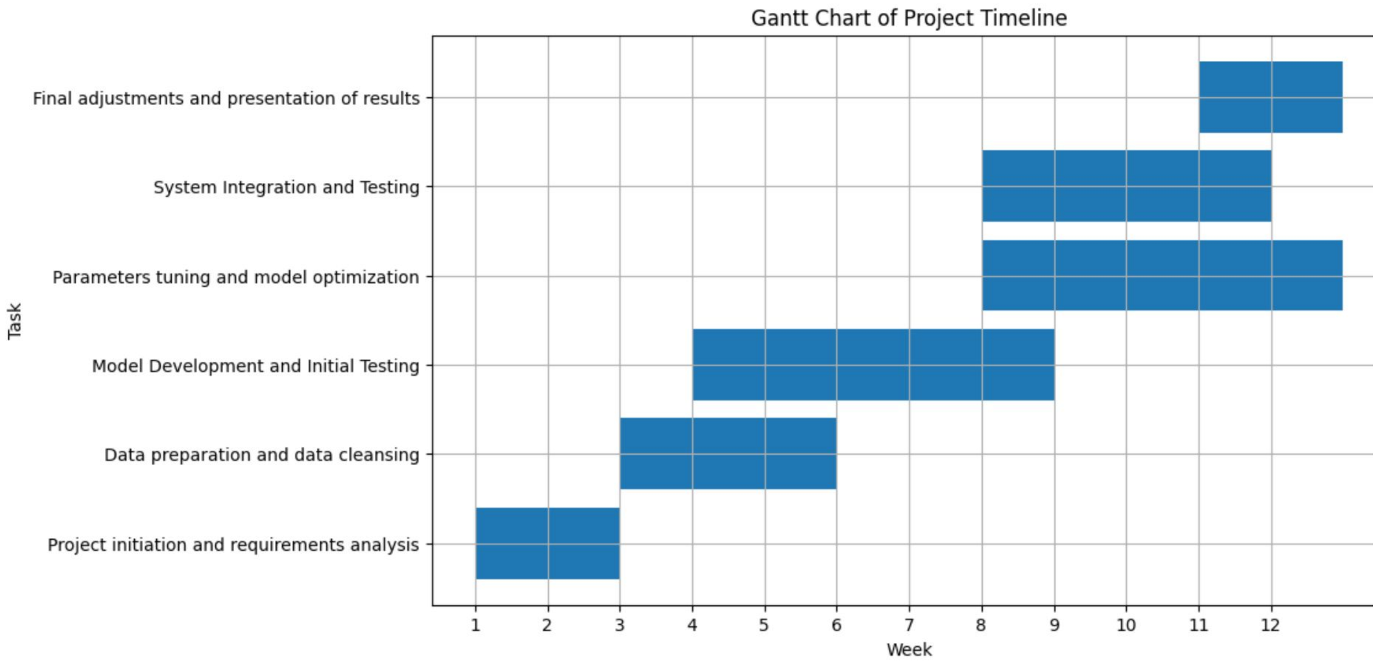
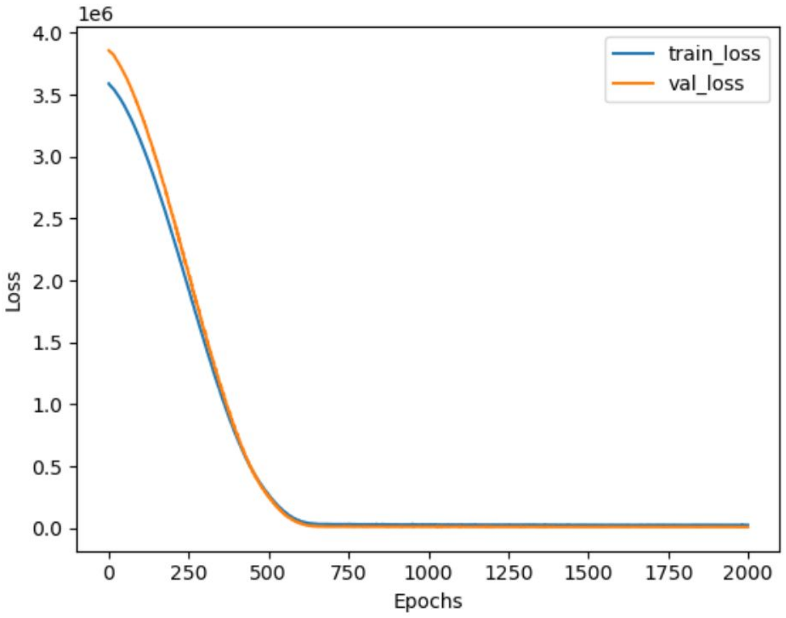
Project Plan and Progress





Use the x,y,z values to predict the maximum force (average value 2500)

MSE Loss: 7800

Next Steps

Acquire More Data for Training:

Objective: To improve the model's performance and ensure it generalizes well to new data.

Optimize Model Parameters:

Objective: To further reduce the loss and enhance the model's predictive accuracy.

Prevent Overfitting:

Objective: To ensure the model performs well on unseen data.

Expand Predictive Capabilities with More Dimensions:

Objective: To predict additional properties of the boxes, such as the maximum force they can withstand at specific points and the direction of the force.

Q&A

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THANK YOU！